A PROCESS FOR REGIONAL ASSESSMENT OF WETLAND

SUMMARY REPORT

by

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DISCLAIMER

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Michael Dwyer, Esq. (North Dakota Water Users Association)
Dr. Robert L. Eng (Montana State University)
Dr. Lester Flake (South Dakota State University)
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Dr. Arnold van der Valk (Iowa State University)

1.0 INTRODUCTION

1.1 Purpose

The primary purpose of this report is to demonstrate a process for prioritizing risks of wetland loss. It is intended for use in regions where technical data are very limited, or where the time or resources for obtaining such data are very limited. Because of the unevenness of our technical understanding of wetland functions in many regions, there are often instances where required, routine decisions by agency staff must rely on "Best Professional Judgement" (BPJ). This report illustrates one means of formalizing BPJ in the context of risk assessment, using a process that incorporates available literature and information from a panel of regional experts. The process is demonstrated through an assessment of the risks to valued functions (e.g., wildlife production) as a result of wetland loss (through both conversion and degradation) in the Prairie Pothole Region of the United States (PPR). The fundamental question being addressed is:

> "Which valued, difficult-to-replace PPR wetland functions are subject to the greatest losses, and from what?"

The process described in this report is intended to support ecological risk assessment, in the sense that it facilitates a priori determinations of probability that wetland functional losses will occur if certain actions are taken. However, determinations of probability are stated in relative, qualitative terms rather than absolutely and quantitatively. Also, risk determinations are thematic rather than site-specific or geographic. Thus, unlike some prior wetland risk assessments sponsored by EPA (Abbruzzese et al. 1990, Parrish and Langsdon 1991), the process described in this report is not intended to directly prioritize geographic areas within the PPR. The process also makes no effort to predict future economic, policy, land use, or climatic changes. Rather, future conditions are generally assumed to be an extension of the current situation. This artificial assumption is made to simplify the analysis, to avoid increasing its subjectivity, and to more clearly assess the ongoing consequences of current policies. Moreover, the process described in this report does not address such fundamental policy issues as whether wetland restoration/creation should be used to compensate for wetland losses; which wet areas should be subject to regulation; whether individual wetlands should be ranked according to value; and whether other landscape components should be accorded equal or greater attention than wetlands in certain situations.

1.2 Geographic Scope

The PPR area that is the subject of this report is shown in Figure 1. Reasons for targeting this region are explained in the Wetland Research Program's Research Plan by Leibowitz et al. (1992). Although this case study has emphasized the depressional, closed, basin-type, prairie pothole (PPH) wetlands which dominate much of the PPR landscape, some other PPR wetland types, landscapes, and ecosystems are considered, as needed, to understand their interactions with the prairie pothole wetlands.

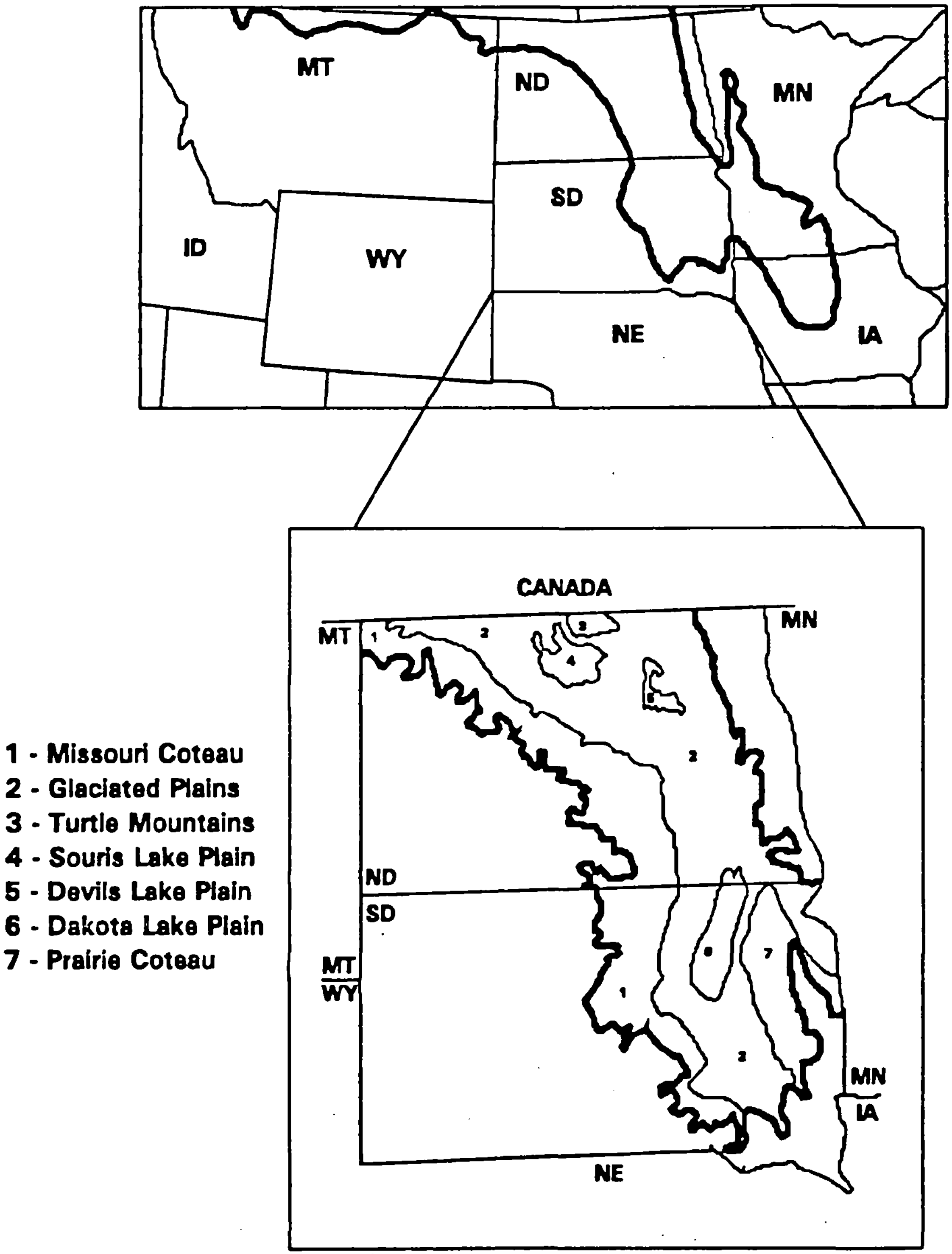

Figure 1. Boundaries of Prairie Pothole Region (PPR) Used in This Report. From Hubbard's (1988) adaptation of Kantrud and Stewart's (1977) map.

1.3 Background and Definitions

The risk assessment framework and terminology used in this report follow that proposed in the Wetland Research Program's Five-year Research Plan ("Wetlands Research: An Integrated Risk-based Research Strategy, 1992-1996" by Leibowitz et al. 1992). In that Plan, the Wetlands Research Program presented a general risk-based framework that can be applied to environmental protection in general and wetlands in particular. This approach consists of:

- **Risk assessment:** Defining, estimating, and prioritizing risks;
- **Risk management:** Developing and implementing a specific management strategy to control and manage those risks; and
- **Monitoring and evaluation:** Determining whether the management program is meeting risk reduction goals.

This report addresses just the first component (Risk Assessment). With respect to wetlands protection, the end product of a risk assessment should be a **prioritization of those wetlands of greatest value that are subject to the greatest loss of function.** A risk assessment should therefore address three separate elements: **wetland function, wetland value,** and **functional loss.** A fourth element, **replacement potential,** must also be considered, because this can offset functional loss.

Wetland function refers to processes without consideration of benefits. Wetland functions depend on two factors: **wetland capacity** and **landscape input.** The capacity of a wetland to perform a given function depends on the characteristics of the particular wetland; for example, wetland type (e.g., bog or fen), soil and vegetative properties, climatic and geomorphological conditions. However, capacity alone cannot define wetland functions, because these processes can also depend on factors originating outside of the wetland. For example, water quality improvement functions would depend on both the ability of wetlands to transform and retain pollutants <u>and</u> the landscape input of pollutants.

Wetland **value** refers to services realized by "users" who benefit from wetland functions. "Users" can be defined broadly to include fish and wildlife as well as people. Value can refer to tangible benefits, such as clean water, or intangibles, such as aesthetics. Future value could also be included in a risk assessment by taking into account future users. The current risk assessment, however, focused only on current users. Wetland values are realized directly by on-site users and can also be realized outside of the wetland by beneficiaries within the landscape; for example, downstream flood control or nutrient exports to downstream consumers.

Functional loss can result from two factors: **conversion,** which is the transformation of a wetland into a different land cover or land use (e.g., filling in a wetland for construction); and **degradation,** or the loss of function resulting from stress. This would include effects resulting from the addition of harmful agents or from the removal of beneficial factors (e.g., damage to the environmental infrastructure that maintains wetlands as a result of dam construction or stream diversion). Many of the stressors that cause wetland degradation originate outside of the wetland, e.g., nonpoint source pollution, stormwater runoff.

Replacement potential refers to the ability to replace a wetland and its valued functions through wetland restoration and creation. Replacement potential depends on the type of wetland, the function to be restored and, in the case of restoration, the type of impact that altered the original wetland (Kusler and Kentula 1990). Restoration also depends on landscape condition. It is harder to restore a wetland if the landscape processes that maintain the wetland have been disrupted. If restoration does take place in such a setting, the wetland and/or its functions sometimes may not be sustainable.

2.0 A PROCESS FOR EXPERT-BASED REGIONAL RISK ASSESSMENT

This chapter describes a process for applying the important risk assessment concepts just described (section 1.3). The objective has been to develop a process that is easy to apply, explicit in its reasoning, not unnecessarily complex, and as technically comprehensive and defensible as available information allows. The process must allow for a rational narrowing of ranking choices and priorities. This is necessary because of the obvious impossibility of ranking all possible combinations of the (conservatively) 16 functions, 14 values, 10 major functional loss factors, and 4 major basin-type wetlands that have traditionally been identified in the PPR.

2.1 Components of the Risk Assessment Approach

Within the U.S. Environmental Protection Agency, increased attention is being paid to assessing ecological risks (e.g., USEPA 1987, 1990). However, considerable difficulty is encountered in assessing ecological risks objectively when appropriate data are extremely limited. A number of approaches have been previously employed where decision-making required subjective judgements and/or where critical data were limited. For example, these include approaches for prioritizing water resources research (e.g., James and Messer 1982, Vertrees 1985, McGarigal and McComb 1989), habitat types (e.g., Crance 1985), and environmental impacts and development alternatives (e.g., Holling 1978, Bonnicksen and Becker 1983). These approaches generally involve use of expert panels and/or structured surveys, facilitated or organized by an assessment coordinator. Probably the best-known is the Delphi method (Linstone and Turoff 1975), applied widely in the social, engineering, and environmental sciences (e.g., Leitch and Leistritz 1984), and recently in an EPA-sponsored risk assessment (de Steiguer et al. 1990). The Delphi method is intended to be a simple, systematic procedure for finding agreement among technical opinions of many experts on a given subject. These opinions can be obtained through questionnaires, workshops, or individual interviews, in which all participants are asked exactly the same questions. Experts are asked to quantify their response to the technical questions, often by representing their responses on an ordinal scale, e.g., 5=strongly agree, 1=strongly disagree. Although use of an ordinal scale may conceal many nuances of individual opinions, it facilitates comparison and communication of diverse perspectives. Another key feature of the Delphi method is that individual experts are asked to respond anonymously. This avoids the tendency, common in workshops, of some experts avoiding expressing opinions for fear of criticism by colleagues, while more aggressive (but not necessarily more knowledgeable) colleagues dominate the discussions and control the group output. A third key feature of Delphi is that it is an iterative procedure. That is, after the Delphi facilitator compiles the anonymous responses of the experts to the technical questions ("first round"), he/she circulates them among the entire group of experts, and each expert is asked to respond to the same questions again ("second round"), taking into account (if they wish) the prior responses of colleagues. This tends to unify the group response.

Although at least one previous attempt (Strickland 1986) had been made to use experts and Delphi-like approaches to rate functions of wetland classes within a region, a Delphi approach had apparently never been applied to assess ecological risks to wetlands in a comprehensive manner. Moreover, no previous applications of Delphi to ecological risk assessment have used a review of the technical literature as input to participants between Delphi rounds. The relative merits and roles of the literature review and expert panel components of Delphi, as used in this application to the PPR, are described as follows.

Expert panels provide a "common sense" perspective that may not be obtainable directly by reading and summarizing technical literature. In helping the risk assessment coordinator (i.e., the author) draw conclusions from the literature, experts on a regional panel can filter out (consciously or unconsciously) published studies that have flawed designs, poor quality control, or are unrepresentative. Also, published information may be totally lacking on some topics essential to completing a comprehensive wetland risk assessment. In such instances, inferences based on the collective intuition of a body of experts are preferable to inferences made by a single risk assessor.

However, the conclusions of an expert panel can be colored by (a) the demographics of the panel membership, and (b) the protocols used to solicit, compile, and present the knowledge of panelists. In the process of evaluating a topic as broad as the regional risks of wetland loss, rarely if ever will all panelists be knowledgeable of the literature on all topics necessary to the evaluation, e.g., hydrology, toxicology, successional dynamics, data sources, resource use patterns, replacement potential, multiple types of stressors. A **literature review** can cover this broad range of topics and thus compensate for some of the limitations of depending solely on panel input. The review should focus specifically on local and regional literature because some paradigms of wetland and landscape science developed on a national scale are inappropriate when applied to a particular region.

Thus, an ideal approach would seem to be one that combines the strengths of both a literature review and an expert panel. A literature review covering the expanse of necessary topics, formatted in a report and read by all panel members, can help "level the playing field." Panelists can then exercise together the elements of common sense in making inferences (or confirming those of the literature reviewer) from the common body of literature-based information. Moreover, a literature review agreed upon by all panelists in a general sense provides a permanent published record of the technical basis for the panel's conclusions.

2.2 Risk Assessment Approach

The wetland risk assessment approach developed and applied in this project proceeded in the following sequence:

1. Identify the wetland functions that are believed to occur in the region.
2. Review regional literature, inventories, and spatial data sets.
3. Select and recruit expert panel members.
4. Prepare and distribute the first-round questionnaire.
5. Compile the panelist opinions expressed in the questionnaire, and simultaneously complete the draft literature review.

6. Circulate the second-round questionnaire.
7. Compile the panelist opinions expressed in the second-round questionnaire, interview the panelists, and develop indicators ("indicators" are defined on p. 11).
8. Revise and finalize the literature review and summarize final panel opinions.
9. Prepare the final, overall risk assessment.

The following paragraphs elaborate on these steps.

1. Identify the wetland functions that are believed to occur in the region.
This step involves initially reviewing a master list of functions commonly ascribed to wetlands. These functions can be drawn from textbooks, popular articles in the regional literature, from standardized wetland evaluation techniques, regional experts, and from conceptual models of wetland processes. Functions that clearly cannot occur in the region's wetlands are eliminated from further consideration. For example, the function "storm surge attenuation" (i.e., the reduction in energy of waves or tidal flooding), although commonly attributed to wetlands in general, occurs mainly in wetlands that bound large lakes and oceans. Thus, it could be eliminated from a list of functions potentially performed by prairie potholes. The output from this task is a preliminary list of potential functions.

2. Review regional literature, inventories, and spatial datasets.
Next, the risk assessment coordinator (in this case, the report author) assembles background information that documents the certainty and extent of the potentially occurring functions. Equally important, information on values, loss, replacement potential, and indicators (see #7) is obtained and organized by function. Values could potentially include such diverse themes as job security, flood-free real estate, and opportunities for outdoor recreation. To focus the nearly infinite possibilities, a perspective must be assumed. Wetland risk assessment, as demonstrated in this report, limits the consideration of values to those which (a) are consistent with EPA's mandates and policies for wetlands protection, (b) can be supported in part by documented wetland functions (as indicated in existing regional literature) or for which a plausible case for such a linkage could be made in at least some instances based on reasonable technical assumptions. The risk assessment coordinator, based on the literature review and common sense, organizes the information in a Function-Value Matrix (Appendix A, Table A2) showing values potentially associated with each function. Regional literature on loss factors, replacement potential, and indicators is also briefly reviewed at this point. Losses due both to conversion and degradation are considered. Because of agency mandates, consideration of replacement potential is limited to use of restored or created wetlands as replacement. Possible indicators of function, value, loss, and replacement potential (see #7) are identified at multiple scales.

3. Select and recruit expert panel members.
The outcome of a risk assessment can clearly be influenced by the particular balance of technical backgrounds, political orientations, philosophies, and personalities of panelists that are selected. Bias is inevitable. Nonetheless, risk assessments made collectively by a group are likely to be less biased than those made by an individual. The risk assessment coordinator should strive to recruit as panelists persons representing a diversity of disciplines relevant to wetland science

(e.g., ground and surface water hydrologists, sedimentologists, geochemists, soil scientists, aquatic zoologists, botanists) as well as persons familiar with economic uses of wetlands (e.g., flood damage assessors, foresters, recreation planners). Some geographic balance (within the study region) may also be desirable. Experts need not be "wetland" scientists; the primary criterion should be their depth of knowledge of particular functions, as judged by publications which the risk assessment coordinator reviewed during the previous step, and by recommendations of peers. The experts should also indicate a willingness to go beyond the limits of published analyses and cautiously exercise "best professional judgement." When recruiting experts, the risk assessment coordinator should indicate that the assignment will require about eight hours answering questionnaires, plus whatever time is necessary for examining the draft literature reviews and perhaps participating in workshops.

The exact number of panelists is not important. Although larger numbers may increase the "checks and balances" of opinion within the group and enhance the generality of the conclusions, too many panelists may hinder communication, especially if opinions are solicited in a workshop setting rather than via questionnaires. Literature on group processes (e.g., Linstone and Turoff 1975) suggests that 10-15 panelists may be optimal for conducting effective, consensus-based assessments.

4. Prepare and distribute the first-round questionnaire.

The risk assessment coordinator prepares and distributes a questionnaire that is structured to reflect knowledge gained through the preliminary literature review. As will be explained in more detail below, the questionnaire asks panelists to rate and/or rank potential and actual values, functions, and stressor-function pairs (i.e., exposure situations) associated with wetlands of the region. The questionnaire can include definitions of these risk assessment attributes and considerations for the panelists to use in formulating their responses. To facilitate comparisons among panelist opinions, responses can involve use of a standardized ordinal scale (e.g., 1=low probability or importance, 5=high probability or importance).

In rating **functions**, panelists are asked to consider the spatial and temporal extent of each function. Functions that occur in many wetlands of the region throughout most years receive a higher rating than those which occur only occasionally and then in only a few wetlands. Panelists are asked to not consider, in this assessment, the **value** of the function to society or ecosystems, or the certainty with which the function has been conclusively documented.

In addressing **values**, panelists are asked to assign separate ratings to potential and actual values. If wetlands have the capacity to deliver a service, but there are few users currently positioned to receive it, then "value" is considered to be potential rather than actual. Thus, panelists are asked to consider the general spatial and temporal distribution of current users, relative to the spatial and temporal distribution of wetlands potentially providing those services. For example, the primary users of the value "Flood Control" are people who live in floodplains. Users benefitting from the value "Runoff Purification" could be fish residing in lakes that are surrounded by nonpoint source pollution, as well as citizens who believe in the conservation of biodiversity but live in other regions. The output of this step is a prioritized list of "actual" values.

Next, functions and stressors are rated jointly. This requires a two-step process, the focal point of which is a Stressor-Function Matrix, with columns representing stressors and rows representing wetland functions (e.g., Appendix A, Table A5). Cells in the matrix represent the interaction of each stressor with each function. To limit somewhat the bewildering array of choices in such a matrix, interactions deemed nonapplicable by the risk assessment coordinator are blanked out. For example, noise (stressor) is very unlikely to have measurable effects on groundwater recharge (function), so the risk assessment coordinator blanks out the cell representing that interaction, prior to asking for input from the panel. After reviewing the matrix, panelists are asked to highlight only the ten cells they consider most important. Specifically, they are first asked to indicate which functions they expect will suffer the greatest functional losses (regardless of the social significance of the losses) during the next decade, assuming current practices and policies affecting stressors continue. As an aid to determining this, panelists are asked to take into account the following:

(a) their earlier, individual rating of functions based on spatial and temporal extent;

(b) a consideration of which wetland types are most likely to be lost, due to their spatial position on the landscape, general ownership patterns, and lack of protection from existing programs; and

(c) information on which functions occur characteristically in the most vulnerable wetland types identified in (b).

After identifying functions at highest risk, panelists are asked to identify which stressors will be most responsible for causing the projected losses of these functions directly, or for causing loss of the wetland type that supports the function indirectly. Specifically, panelists are asked to consider:

(a) which stressors cause the most irreversible losses;

(b) which wetland types recover most readily from a given stressor, based on their characteristic hydrologic, soil, and biological features;

(c) again, which functions are characteristically associated with wetland types that are most resilient or resistant to particular stressors.

Finally, panelists are asked to independently estimate the relative replacement potential of all functions (not just the priority ones). Risks of functional loss are assumed to be greatest for those wetland types that are least replaceable, other factors being equal. Panelists can be asked to use an ordinal scale to rate potential for complete replacement (via wetland restoration or creation) of each function. Functions that cannot be replaced or restored, or which require very lengthy periods and impractical investments to restore or create, are rated lowest. In all assessments, "best case" implementation is assumed; that is, panelists assume that restoration or creation is done in a landscape where conditions are ideal (but realistic) for restoration or creation, by an entity that knows and practices state-of-the-art techniques for wetland restoration or creation, and who follows up with monitoring and fine-tuning to ensure success.

5. Compile the panelist opinions expressed in the questionnaire, and simultaneously complete the draft literature review.
The panelists return the questionnaires and the risk assessment coordinator compiles them, concluding the "first round" of the process. The risk assessment coordinator at this stage relates the priority functions (which the panelists selected in the previous step's Stressor-Function Matrix) to values indexed earlier in the Function-Value matrix (e.g., Appendix A, Table A5). As a result, potential **value** impacts that could result from continued functional losses are identified. This is intended to emphasize clearly the possible relative costs of continued wetland functional loss. The literature review, now completed in draft form, is used as a common source of information for the second round of the risk assessment process. The review documents what is known about regional wetland status and trends, replacement potential, stressors, and functions.

6. Circulate the second-round questionnaire.
The risk assessment coordinator circulates to the panelists both the results of the first-round questionnaire and the completed draft of the literature review. An abbreviated version of the original questionnaire is also sent. Panelists are asked to adjust their original ratings of the risk assessment attributes based on (a) new awareness of the responses of other panel members, and (b) knowledge gained from reading the literature review that is being shared with all panelists.

7. Compile the panelist opinions expressed in the second-round questionnaire, interview the panelists, and develop indicators.
After compiling and reviewing the second-round responses to the questionnaire, the risk assessment coordinator conducts in-depth personal interviews with each panelist, either in person or by phone. Following the interviews, the risk assessment coordinator summarizes the interview comments narratively. This concludes the "second round" of the risk assessment process. The purposes of the interviews are as follows:

(a) For the panelists to explain to the risk assessment coordinator their technical comments pertaining to the literature review;

(b) For the risk assessment coordinator to gain an understanding of issues that could not be expressed adequately via the questionnaires; to do so, the risk assessment coordinator queries the panelists specifically about the logic behind opinions that differed from those expressed by most other panelists, or from the literature;

(c) For the risk assessment coordinator and the panelists to brainstorm ideas for **indicators** of wetland function at multiple scales, and possible sources of regionally comprehensive spatial data for these indicators.

As used in this report, the term "indicators" refers to wetland and landscape structural features, attributes, parameters, predictors, or variables that are highly correlated with (and ideally, also determine) the functions, values, loss factors, and replacement potentials of wetlands. Information on indicators is not needed to perform a BPJ risk assessment. However, the identification of accurate and practical indicators forms the basis for any subsequent **geographic** assessments of risk. Indicators are identified and prioritized at this point in the risk assessment process, rather than earlier, so as to (a) benefit from the results of the review of regional literature and data sets, and (b) benefit from the fact that the aforegoing risk assessment process has reduced the number of functions, values, or stressors for which indicators need to be found.

If the results of a risk assessment are to be applied to specific wetlands and landscapes, then indicators of each function, value, and stressor must be identified at multiple spatial scales (e.g., site-specific, landscape, and regional). **Site-specific indicators** are those measured at the level of an individual wetland or wetland complex, and are useful in individual regulatory or wetland management activities. They are impractical to measure on large numbers of wetlands. One example is the "proportional volume of submersed aquatic plants." **Landscape indicators** are useful in cumulative effects analyses, and often can be easily measured from available maps and aerial photographs. One example is "% vegetative cover on upland clay soils." **Regional** (or state-level) **indicators** are useful for broad-based planning efforts, and also are derived from review of available maps, compiled data, and aerial photographs, but at a coarser or less-processed scale. One example is "statewide acreage of emergent wetlands."

Indicators are identified using information from technical literature, perhaps as encoded in a conceptual model, and from information developed during brainstorming sessions with the panelists. Both "top down" and "bottom up" strategies can be used for selecting indicators at each scale. A "top down" strategy might involve first locating regional sets of environmental data (e.g., National Wetlands Inventory) and listing variables that could easily be derived from these and which intuitively seem most tightly linked with the processes and functions one is hoping to quantify. A "bottom up" strategy might involve basing the initial list of indicators solely on ecological principles, specifying the "ideal" indicator appropriate at each scale, and only then beginning to search for datasets containing variables that are the closest match. In practice, indicator selection is likely to be most realistic and effective if both strategies are applied together and iteratively.

Once candidate indicators have been identified, efforts should be made to prioritize them. Priorities can depend largely on evaluations of the cost-effectiveness of acquiring data on each indicator. Thus, potential data sources for each indicator need to be identified and evaluated in terms of effectiveness and cost. **Effectiveness** of indicators is characterized by their representativeness, completeness, and technical accuracy, i.e., the extent to which measured variables truly reflect causative or universally correlated underlying processes. Cost of acquiring indicator data is characterized partly by the availability and format of compiled datasets of known quality.

8. Revise and finalize the literature review and summarize final panel opinions.
The risk assessment coordinator revises the literature review to reflect information both from the interviews and from the adjusted (second-round) ratings submitted by panelists. The report is circulated one final time for comment to panelists and reviewers in other agencies.

9. Prepare the final, overall risk assessment.
As described in the steps above, the panel provides ratings of (a) functions, (b) potential and actual values, (c) priority exposure situations, i.e., function-stressor combinations, (d) most threatened wetland types, and (e) replacement potential. To conclude the risk assessment, it is necessary to combine all these factors into summary judgements of what is at greatest risk. Each unique combination of function, value, stressor, and replacement potential could be termed a "risk scenario." Because assessing each of the thousands of possible scenarios individually and intuitively is impractical, an approach must be designed to streamline the assessment. This project examined two basic approaches by which the risk components can be combined and the risk scenarios rated. These are described as follows:

Risk Grouping Method
This involves a sorting-type procedure for combining the risk components and then placing the resulting scenarios into broad priority groups. The number of risk groups and the sorting rules that define them are somewhat arbitrary and can be modified by the user. For example, as is discussed in Appendix A, the following groups were adopted for the PPR risk assessment:

> Group I (Highest): These included scenarios for which the **function-stressor** combination was considered by at least four panelists to be among the 10 most important; and for which the highest-rated **value** potentially associated with the function, as well as the function's **replacement potential** (via restoration) were both assigned a score of at least 4 (on a 1-5 ordinal scale, with 5 indicating that replacement is totally feasible) by a majority of panelists.
>
> Group III (Lowest): These included scenarios for which none of the function-stressor situations was considered by any panelist to be among the 10 most important.
>
> Group II (Intermediate): These included remaining scenarios, i.e., those for which the function-stressor situation was considered by only one panelist to be among the 10 most important, or which more panelists considered important, but for which none of the highest-rated **values** potentially associated with the function or its **replacement potential** (via restoration) had a modal score of greater than 3.

Numerical Scoring Method
The other approach is to use a numerical scoring protocol which literally ranks all possible scenarios by assigning a numerical score to each. Each scenario's numerical score results from some additive or multiplicative combination of scores of its risk components (function, value,

loss, replacement potential). Of course, the numerical scores resulting from this approach could easily be converted to groups similar to those described above by defining the groups numerically (e.g., quartiles of the scores). As just noted, this approach prioritizes scenarios by combining the four risk components that define them into a single score. However, the means by which component scores are weighted and combined is subject to many biases (for a discussion of these important statistical issues, see Skutch and Flowerdew 1976, Hopkins 1977, O'Banion 1980, and Smith and Theberge 1987). As shown in Appendix A (Table A7), the ultimate output is a list of finitely prioritized scenarios.

2.3 Assumptions and Limitations

Any approach to prioritizing risks also requires some generalization of the various functions, values, and loss factors. For example, for purposes of rating functions, some might advocate combining "Maintenance of runoff volume" with the function "Maintenance of runoff timing," while others might advocate splitting the latter into "..spring runoff timing" and "..autumn runoff timing." The degree of aggregation of functions can affect their ratings. It can particularly affect statements about which stressors affect "the most functions." There appears to be no completely objective means of resolving what is an appropriate degree of functional aggregation. The degree that was used in the application to the PPR was simply that chosen by the risk assessment coordinator with review by the panelists.

Another concern is that the risk assessment approach proposed in this report requires that an entire region be treated as a single entity for purposes of rating the risk components. Yet, many of a region's wetland functions do not operate as a geographically interdependent, homogeneous, or synchronous whole at the regional scale. Clearly, considerable variability in function (and the other risk assessment components) exists within most regions. Thus, attempts to rate risk factors on an "overall" regional basis will usually result in considerable simplification of actual relationships. For example, the following partial list illustrates regional variability that was encountered in the application of the approach to the PPR:

> **Functions:** Groundwater recharge is probably a prominent function of wetlands in the western PPR, but is almost nonexistent as a function of most wetlands currently existing in the eastern PPR. Also, pristine wetlands may have a greater capacity for some functions, but because of widespread degradation, ratings intended to reflect "overall" conditions may understate the true potential of some wetlands to perform some functions.
>
> **Values:** Wetlands in eastern and western parts of the PPR are roughly equally productive, yet the forage values of this production are greater in the western PPR where there are greater livestock densities and more frequent droughts.
>
> **Losses:** Temporary and seasonal wetlands may be at greatest risk of loss in the western PPR, whereas in the eastern PPR semipermanent wetlands are likelier to be threatened, simply because few temporary and seasonal wetlands remain.

Stressors: Excessive enrichment may be a greater threat to some wetland functions in the eastern PPR than excessive grazing, which occurs mostly in western portions.

Replacement Potential: Replacement of wetlands and particular functions may be quite feasible in some areas of the PPR, yet impractical in other areas due to land ownership constraints.

Indicators: As is now apparent, "geographic position" is itself a frequent indicator. The ways that it indicates specific functions are described more fully in Appendix B (the "GEO" column of Table B3).

Nonetheless, the approach proposed herein generalizes variability to the **regional** level (a) because EPA's jurisdictional responsibilities are primarily at such a level, and (b) so that results are communicated in a simple manner. The results of the risk assessment could be fine-tuned within more limited geographic areas or wetland types by future efforts and/or other interested persons, perhaps using a conceptually similar process.

3.0 SUMMARY OF APPLICATION RESULTS

Results of applying the risk assessment process are detailed in Appendix A, but a summary is provided as follows:

- By wetland type, functions associated with **temporary and seasonal wetlands** were judged by the panel to be at greatest risk in the PPR.

- The panel felt the severest risks to **functions** involve the potential for (in priority order):

  loss of rare species habitat and waterbird production (functions) as a result of artificial drainage (stressor);

  loss of groundwater recharge, invertebrate production, and runoff volume and timing functions as a result of artificial drainage, and
  loss of waterbird production as a result of tillage removal of vegetation near wetlands;

  loss of sediment retention, nitrate removal, winter wildlife cover, and migratory waterbird habitat functions as a result of artificial drainage, and
  loss of waterbird production and rare species habitat as a result of sedimentation and tillage within wetlands.

- If **values** are considered as well, scenarios above dealing with hydrologic functions (groundwater recharge, runoff volume and timing) would be assigned a lower priority by the panelists than scenarios listed above that involve habitat and water quality functions.

- With regard to **replacement potential**, the panel considered all functions of prairie pothole wetlands to be highly restorable, with the exception of detoxification functions and habitat for rare/restricted species and communities.

- The risk grouping approach does not address effects of multiple simultaneous stressors that could affect certain wetland functions disproportionately. The numerical approach addressed this issue to some degree, but introduced other biases. The numerical approach indicated that functions subject to the largest number of qualitatively different (but often interacting) stressors are waterbird production, habitat for rare species, and invertebrate production.

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A PROCESS FOR REGIONAL ASSESSMENT OF WETLAND RISK

APPENDIX A: Results of Application of the Risk Assessment Process

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1.0 SYNOPSIS OF THE PROCESS

The purpose of this appendix is to illustrate the results of applying one process for formalizing best professional judgement (BPJ) in the context of risk assessment, using available literature and a panel of prairie pothole (PPH) regional experts. The programmatic basis and underlying risk assessment framework for this effort are described in the main report. To summarize, the process involved the following steps:

Preliminary Steps:

1. Exclude from further consideration any wetland functions that clearly do not occur in the region and identify the wetland functions believed to occur.

2. Review regional literature, inventories, and spatial datasets.

3. Select and recruit panelists.

4. Prepare and distribute the first-round questionnaire.

Risk Assessment:

5. Compile the panelist opinions expressed in the questionnaire, and simultaneously complete the draft literature review.

6. Circulate the second-round questionnaire.

7. Compile the panelist opinions expressed in the second-round questionnaire, interview the panelists, and develop indicators.

8. Revise and finalize the literature review and summarize final panel opinions.

9. Prepare the final, overall risk assessment.

The manner in which each of these tasks were executed is described in the following sections.

2.0 PRELIMINARY STEPS

2.1 Identify the Wetland Functions Believed to Occur in the Region

In the beginning step of this application of the risk assessment process to the PPR, the risk assessment coordinator identified and narrowed the range of wetland functions as follows:

Not Generally Present in PPH Wetlands:
- Storm surge attenuation
- Habitat for tidal and floodplain fisheries
- Detritus export
- Base flow maintenance
- Streambank stabilization
- Wintering waterfowl habitat

Potentially Present in PPH Wetlands:
- Maintenance of Runoff Volume, Maintenance of Upland Moisture
- Maintenance of Runoff Timing
- Groundwater Recharge
- Sediment Retention
- Phosphorus Retention
- Nitrogen Removal
- Detoxification
- Carbon Transformation, Climate-related Gas Exchange
- Production of Algae
- Vascular Plant Production
- Invertebrate Production
- Fish Production
- Habitat for Rare/Restricted Species or Communities
- Waterbird Production
- Habitat for Migrating Waterbirds
- Winter Wildlife Cover
- Amphibian Production
- Furbearer Production

The initial list of functions present in PPH wetlands was drawn primarily from a general understanding of wetland functions and knowledge of aggregate characteristics of PPH wetlands.

2.2 Review Regional Literature, Inventories, and Spatial Datasets

The risk assessment coordinator began the literature review effort with an examination of several previous reviews (particularly Weller 1981, Hubbard 1988, Kantrud et al. 1989, Richardson and Arndt 1989, van der Valk 1989, and Pederson et al. 1989). Computerized bibliographic databases were then searched. These searches used more than just "wetland" keywords, so that inferences about function could be made from other disciplines (e.g., soil science). Papers and reports were obtained, read, and information included as appropriate. In reviewing the literature, the risk assessment coordinator emphasized information that documented (a) differences between wetland or landscape types, with regard to their functions, values, loss factors, and replacement potential, and (b) geographic variability (within-region spatial patterns) in the wetland or landscape types and their functions, values, loss factors, and replacement potentials.

2.3 Select and Recruit Panelists

As specified by the approach, the risk assessment coordinator selected ten experts in the region and invited them to participate in the risk assessment panel. Budgetary constraints were a factor in limiting the panel size. Partly to help ensure the independence of judgements, none of the panelists were directly employed by government; most were from academia. Major disciplines represented include wildlife ecology (4 panelists); economics, aquatic ecology, hydrology, soils (2 panelists each); and plant ecology, geochemistry, and law (1 panelist each). The panelists were as follows:

Michael Dwyer, Esq. (North Dakota Water Users Association)
Dr. Robert L. Eng (Montana State University)
Dr. Lester Flake (South Dakota State University)
Dr. Daniel Hubbard (South Dakota State University)
Dr. John Kadlec (Utah State University)
Dr. Gregory Koeln (Ducks Unlimited)
Dr. Jay A. Leitch (North Dakota State University)
Dr. James L. Richardson (North Dakota State University)
Dr. Steven J. Taff (University of Minnesota)
Dr. Arnold van der Valk (Iowa State University)

2.4 Prepare and Distribute the First-Round Questionnaire

A questionnaire was drafted, reviewed internally, and sent to all panelists. In the questionnaire, the panelists were asked to rate or rank items within each of the risk assessment components (functions, values, functional losses, replacement potentials) and their indicators. Panelists were also asked to rate their personal knowledge of each function. A less structured initial solicitation (e.g., Miller and Cuff 1986), although it might have led to greater objectivity of the process, would have required an additional Delphi round. This was not feasible due to time and budget constraints. Thus, the opportunity for input from panelists was limited to two rounds. That is, panelists were given the chance to answer the questionnaire and rank the risk attributes twice -- once before and once after seeing the responses of their colleagues and information compiled in the literature review.

3.0 RISK ASSESSMENT RESULTS

3.1 Prioritization of Functions

3.1.1 Round One

In the initial questionnaire, panelists were asked:

> "Rate [from a list of functions provided] the extent (not importance) to which you believe each function occurs in PPH wetlands." (5= extensive; 1= not extensive)

Due to space limitations, the questionnaire did not include a definition of the individual functions, or a precise quantification of "extent," so different panelists may have interpreted these terms differently.

Most of the panelists entered a response for all of the functions. Table A1 shows the results. Functions for which the fewest panelists considered themselves knowledgeable were Phosphorus Transformation and Detoxification (each 4 panelists). Functions for which the greatest number of panelists considered themselves knowledgeable were Maintenance of Runoff Volume, Groundwater Recharge, Vascular Plant Production, and Furbearer Production (each 10 panelists). The panelists also were asked to suggest additional functions that should be included. The response was as follows:

Recommended	Herein Incorporated Under:
Water for Livestock and Wildlife	Maintenance of Runoff Timing
Forage for Livestock	Vascular Plant Production
Wildlife Corridors	Indicator of wildlife functions
Habitat Patches	Indicator of wildlife functions
Migrant Bird Resting, Feeding	Included in second round; discussed under Waterfowl Production
Biodiversity	Rare/restricted Species and Communities
Gene Pool for Native Vegetation	Rare/restricted Species and Communities
Food Webs	Rare/restricted Species and Communities
Songbird Habitat	Rare/restricted Species and Communities
Algal Production	Included in second round
Visual Amenities	Not addressed
Disamenities (mosquitoes, cultivation barriers)	Not addressed

3.1.2 Summary of Information from the Literature Review

In summary, the literature seemed to indicate the extent of functions in PPH wetlands is approximately as follows:

Table A1. Panelist Rating of PPH Wetland Functions, First vs. Second Round

Function	Mode (on 1-5 scale) Round One	 Round Two
Invertebrate Production	5 (5 votes)	5 (8 votes)
Sediment Retention	4 (6 votes)	4 (6 votes)
Vascular Plant Production	4 (4 votes)	4 (6 votes)
Maintenance of Runoff Volume	3 (4 votes)	3 (5 votes)
Waterbird Production	4 (6 votes)	4 (7 votes)
Maintenance of Runoff Timing	3 (4 votes)	4 (5 votes)
Nitrogen Removal	4 (3 votes)	4 (7 votes)
Winter Wildlife Cover	4 (4 votes)	3 (6 votes)
Carbon Transformation	5 (2 votes)	not rated
Phosphorus Retention	2 (3 votes)	4 (4 votes)
Amphibian Production	4 (4 votes)	3 (6 votes)
Furbearer Production	3 (7 votes)	3 (6 votes)
Groundwater Recharge	4 (4 votes)	3 (6 votes)
Detoxification	4 (3 votes)	4 (5 votes)
Maintenance of Upland Moisture	4 (4 votes)	not rated
Fish Production	2 (5 votes)	2 and 3 (4 votes each)
Habitat for Rare/Restricted Species or Communities	not rated	4 (4 votes)
Habitat for Migrating Waterbirds	not rated	4 (4 votes)
Production of Algae	not rated	3 (6 votes)

These changes, which may have contributed to panelist changes in ratings between the two rounds, were as follows:

First Round Questionnaire Term	Second Round Questionnaire Term
1. Maintenance of Runoff Volume	Maintenance of Runoff Volume
2. Maintenance of Runoff Timing	Maintenance of Runoff Timing
3. Carbon Transformation	Vascular Plant Production
4. Nitrogen Removal	Nitrate Removal
5. Phosphorus Transformation	Phosphorus Retention
6. Maintenance of Upland Moisture	Covered by #1
(not originally listed)	Algal Production
(not originally listed)	Habitat for Migrating Waterbirds

Functions Partly Attributable to Wetlands and Nearly Ubiquitous in Time and Space in the PPR:

- Sediment Retention
- Phosphorus Retention
- Invertebrate Production

Functions Partly Attributable to Wetlands and Extensive in Time and Space in the PPR:

- Maintenance of Runoff Timing
- Nitrogen Removal
- Detoxification
- Vascular Plant Production
- Amphibian Production
- Waterbird Production

Functions Partly Attributable to Wetlands and Occurring in Many Situations in the PPR:

- Groundwater Recharge
- Maintenance of Upland Moisture
- Fish Production
- Winter Wildlife Cover
- Furbearer Production

Functions Occurring in Limited Situations in the PPR:

- Maintenance of Runoff Volume

3.1.3 Round Two

For the second round, each panelist was sent the numerical ratings he had personally assigned to each function during the first round, with the following instructions:

> "Compare your original responses with (a) the rating collectively assigned by other panel members, and (b) the literature review rating. Note that some terms have been changed slightly, and others added or consolidated. After comparing the responses, please **rate all the items again** in the space provided in the righthand column... if reading the report has given you second-thoughts about the rating you assigned [to a function] earlier, please adjust it."

Results are shown in Table A1. As a result of being given a second chance to rate the functions, there was a general tendency for panelists whose first round responses were "outliers" to rally, in round two, around the response that received the most votes in round one. Still, few overall ratings of functions changed between rounds. Exceptions were increases in ratings for Maintenance of Runoff Timing and for Phosphorus Retention, and decreases in overall ratings for Winter Wildlife Cover, Amphibian Production, and Groundwater Recharge. The round two questionnaire had been modified slightly from that used in round one, so as to clarify some ambiguities and oversights mentioned by panelists responding to the round one questionnaire.

3.2 Prioritization of Values

3.2.1 Round One

Before values could be prioritized, it was necessary to identify the general types of values that potentially could be associated with the functions. Consideration of potential values was limited to values which (a) are consistent with EPA's mandates and policies for wetlands protection, (b) are supported by documented wetland functions (as indicated in existing regional literature) or for which a plausible case for such a linkage could be made in at least some instances based on reasonable technical assumptions. The result of this initial step was a matrix (Table A2) showing values potentially associated with each function. In this manner, the universe of regional values was narrowed to those most likely to be related to wetlands.

To begin prioritizing these values, in the questionnaire the panelists were first asked:

> "Rate [from the list of values provided] the importance you believe people in the PPR attach to this value, as indicated by legislation, news coverage, etc. Do NOT account for whether people or science associates the value with wetlands, per se. (5= almost universally considered of very great value; 1= not valued, even locally)."

Due to space limitations, the questionnaire did not include a definition of the individual values, so different panelists may have interpreted value terms differently. For most values, all of the panelists responded. Table A3 shows the questionnaire results.

Potential values for which the fewest panelists considered themselves knowledgeable of public perceptions were Global Climate Maintenance and Baitfish Income (each 2 panelists). Values for which the most considered themselves knowledgeable of public perceptions were Recreational Opportunities and Forage Income (each 7 panelists), and Flood Control and Livestock Water Supply (each 6 panelists). When asked to suggest additional functions that should be included, some panelists suggested adding Hunting and Open Space as values. These are included under the broad category of "Recreational Opportunities."

Table A2. Functions of PPH Wetlands and the Principal Values They Potentially Affect

VALUES:

	Flood Control	Crop Mois.	Soil Salin.	Domes. Water	Lives. Water	Runoff Purif.	Groundw. Purif.	Ecol. Supp.	Biodi-versity	Fur $$$	Bait $$$	Forage $$$	Recre-ation
RV	X	X	X	X	X	X		X		X	X		X
RT	X	X	X		X	X		X	X	X	X		X
GR	X	X	X	X	X		X						
SR	X					X		X	X				X
PR						X		X	X		X	X	X
NR				X		X	X	X	X		X	X	X
DX				X		X	X	X	X				X
VP						X	X	X	X	X		X	X
IP								X	X		X		X
FP								X			X		X
WP								X	X				X
WW								X	X	X			X
MP								X	X	X			
BD								X	X				X

Functions

RV = Maintenance of Runoff Volume
RT = Maintenance of Runoff Timing
GR = Groundwater Recharge
SR = Sediment Retention
PR = Phosphorus Retention
NR = Nitrogen Removal
DX = Detoxification
VP = Vascular Plant Production
IP = Invertebrate Production
FP = Fish Production
WP = Waterfowl Production
MP = Furbearing Mammal Production
WW = Wintering Wildlife Cover/Shelter
BD = Biodiversity

Table A3. Panelist Rating of PPR Potential Values, First vs. Second Round

Potential Value	Round One	Round Two
Recreational Opportunities	4 (6 votes)	4 (6 votes)
Forage Income (grazing, hay)	5 (5 votes)	5 (7 votes)
Livestock Water Supply	4 (4 votes)	4 (4 votes)
Flood Control	3 (4 votes)	3 (5 votes)
Cropland Moisture Maintenance	4 (6 votes)	2 (4 votes)
Domestic Water Supply	3 (4 votes)	2 (3 votes)
Fur Income	4 (3 votes)	2 (4 votes)
Ecological Support	4 (4 votes)	not rated
Soil Salinity Avoidance	5 (2 votes)	2 (6 votes)
Baitfish Income	2 (3 votes)	2 (5 votes)
Runoff Purification	4 (4 votes)	not rated
Biodiversity	3 (7 votes)	not rated here
Groundwater Purification	4 (4 votes)	not rated

The next step in the risk assessment approach involves determining which of the potential functions (just rated) are likely to be actual values. To determine this, in the questionnaire the panelists were first asked to envision each value's users and then use this to determine the actual value. The question was worded as follows:

> "Rate the actual degree to which people or resources which could potentially benefit are located where they DO benefit from the value, regardless of whether they care about it and regardless of whether it occurs (5= conditions are extensively ideal for potential users of the function to be ACTUAL users, e.g., floodplain dwellers actually experience frequent floods; 1 = potential users are not likely to be actual users).

Table A4 shows the ratings.

Actual values for which the fewest panelists considered themselves knowledgeable were Global Climate Maintenance (1 panelist) and Soil Salinity Avoidance (2 panelists). Values for which the most panelists considered themselves knowledgeable were Recreational Opportunities (8 panelists) and Forage Income (7 panelists).

3.2.2 Summary of Information from the Literature Review

As a result mainly of reviewing the literature, the risk assessment coordinator concluded the following about actual values:

Values for Which Users and Useful Wetland Functions Interact Generally Throughout the PPR:

- Domestic Water Supply
- Ecological Support
- Biodiversity
- Global Climate Maintenance

Values for Which Users and Useful Wetland Functions Interact in Many Places in the PPR:

- Domestic Water Supply
- Recreational Opportunities
- Flood Control
- Livestock Water Supply
- Forage Income (grazing, hay)
- Soil Salinity Avoidance
- Cropland Moisture Maintenance

Values for Which Users and Useful Wetland Functions Interact Somewhat in the PPR:

- Fur Income, Baitfish Income

Table A4. Panelist Rating of PPR Actual Values, First vs. Second Round

Actual Value	Mode (1-5 scale) Round One	Round Two
Recreational Opportunities	4 (6 votes)	5 (6 votes)
Flood Control	5 (5 votes)	4 (6 votes)
Livestock Water Supply	4 (4 votes)	3,4 (4 votes each)
Forage Income (grazing, hay)	3 (4 votes)	4 (7 votes)
Runoff Purification	4 (6 votes)	not rated
Ecological Support	3 (4 votes)	not rated
Soil Salinity Avoidance	4 (3 votes)	4 (6 votes)
Baitfish Income	4 (4 votes)	2 (4 votes)
Cropland Moisture Maintenance	5 (2 votes)	3 (6 votes)
Biodiversity	2 (3 votes)	not rated here
Fur Income	4 (4 votes)	2 (5 votes)
Groundwater Purification	3 (7 votes)	not rated
Domestic Water Supply	4 (4 votes)	4,5 (4 votes each)
Global Climate Maintenance	4 (3 votes)	not rated

3.2.3 Round Two

For the second round, each panelist was sent the numerical ratings for actual and potential value which he had personally assigned during the first round. Panelists were again instructed to adjust their ratings, if they believed appropriate, based on observations of their colleagues' first-round scores and their reading of the literature review report.

Results are shown in Table A4. As was the case for wetland functions, there was some tendency for panelists whose first round responses were "outliers" to rally, in round two, around the response that received the most votes in round one. As a whole, panelists tended in the second round to more often lower their ratings for values than raise them. Specifically, ratings were lowered for Cropland Moisture Maintenance (potential and actual values), Domestic Water Supply (potential), Fur Income (potential and actual), Baitfish Income (actual), Soil Salinity Avoidance (potential), Flood Control (actual). Ratings were raised between rounds for Recreational Opportunities and Forage Income (actual values). The round two questionnaire had been modified slightly from that used in round one, so as to clarify some ambiguities and oversights mentioned by panelists responding to the round one questionnaire. These changes, which may have contributed to panelist changes in ratings of values between the two rounds, were as follows:

First Round Questionnaire Term	Second Round Questionnaire Term
Soil Salinity Maintenance	Soil Salinity Avoidance
Groundwater Purification	Domestic Water Supply
Runoff Purification	Domestic Water Supply

3.3 Prioritization of Functional Loss Factors

3.3.1 Round One

The next step in the risk assessment approach involved prioritizing functional loss factors. Because a rating of the loss factors alone could lead to ambiguous interpretations, panelists were asked to rate the loss factors only as they interacted with each wetland function. To provide a framework for this rating process, the risk assessment coordinator drafted the Stressor-Function Matrix (Table A5), described in the summary report, and circulated it to the panelists. The panelists were asked to highlight just the ten function-stressor combinations (i.e., matrix cells) they believed best represented situations where functions will suffer the greatest functional losses (regardless of the social significance of the losses) during the next decade, assuming current practices and policies continue. To formulate the matrix, 11 primary loss factors (stressors) were paired with the functions listed in Table A2.

Table A5. The Stressor-Function Matrix

The "x's" refer to interactions not identified by any panelist as important, but which potentially occur. The numbers refer to the number of panelists identifying the interaction as "one of the 10 most important" during the second round. Blank cells indicate interactions are unlikely.

	Filling or Leveling	Artificial Drainage	Excessive Groundwater Pumping	Dugouts/Impoundments	Excessive Grazing/Mowing	Tillage in Wetlands	Tillage Near Wetlands	Sedimentation	Excessive Nutrient Inputs (fertilizer, livestock, etc.)	Pesticide Use	Excessive Human Visitation
Maintenance of Runoff Volume (crop soil maintenance)	1	5	X	X		1		2			
Maintenance of Runoff Timing (flood storage, evaporation)	2	5	X	X				X			
Groundwater Recharge	X	5	X	X				X			
Sediment Retention	1	4				1		X			
Phosphorus Retention	X	1		X		X		X	X		
Nitrate Removal	1	4		X	X	X		X	X	X	
Detoxification	1	1		X		X		X	X	X	
Algal Production	X	X	X	X	X	X		X	X	X	
Vascular Plant Production	1	2	X	X	1	2		2	X	X	
Invertebrate Production	2	5	X	X	X	1		2	X	X	
Amphibian Production	X	X	X	X		X		X	X	X	
Fish Production	X	X	X	X		X		X	X	X	X
Furbearer Production	X	1	X	X		X			X	X	
Waterbird Production	2	7	X	X	1	4	5	4	X	2	X
Habitat for Migrating Waterbirds	1	4	X	X	X	1	X	X	X	X	X
Winter Wildlife Cover	1	4	X	X	1	2			X	X	X

During the first round, the scenarios considered by the panelists to represent the greatest risk were (in priority order):

- the loss of waterfowl production as a result of artificial drainage;
- the loss of wetland capacity to maintain runoff volume as a result of artificial drainage;
- the loss of invertebrate production and nitrate removal capacity as a result of artificial drainage;
- the following (all equally ranked):

  the loss of furbearer production, winter wild life cover, groundwater recharge, and capacity to maintain runoff timing -- as a result of artificial drainage;

  the loss of vascular plant production and winter wildlife as a result of tillage;

  the loss of nitrate removal capacity as a result of prolonged fertilizer use;

  the loss of waterbird and invertebrate production as a result of excessive sedimentation.

By stressor, the most votes (33) were assigned to Artificial Drainage, followed by Tillage (10), and Sedimentation (9). By function, interactions related to Waterbird Production had the most votes (15), followed by Invertebrate Production (7), Maintenance of Runoff Volume (6), and Nitrogen Removal and Winter Wildlife Cover (5 each).

3.3.2 Summary of Information from the Literature Review

The risk assessment coordinator was unable, from the literature review alone, to assign relative priorities to various stressor-function interactions (matrix cells). It was apparent in reviewing the literature that very few of the 192 possible interactions had been investigated by regional researchers. Thus, information on each interaction was summarized in narrative format, without attempting to assign priorities.

3.3.3 Round Two

For the second round, each panelist was sent a slightly modified copy of the Stressor-Function Matrix, including notations showing which cells he had earlier identified as being among the ten most important. Panelists were instructed to adjust (if they believed appropriate) their selection of the "ten most important" interactions, based on observations of their colleagues' first-round selections and their reading of the narratives in the literature review report. As a result of being given a second chance to rate the cells of the Stressor-Function Matrix (Table A5), the panelists in round two considered the following scenarios (in priority order) to represent the greatest risk:

- loss of rare species habitat* and waterbird production as a result of artificial drainage;
  * not considered, or not considered a priority, in round one results

- loss of groundwater recharge, invertebrate production, and runoff volume and timing functions as a result of artificial drainage, and loss of waterbird production as a result of tillage removal of vegetation near wetlands;

- loss of sediment retention, nitrate removal, winter wildlife cover, and migratory waterbird habitat functions as a result of artificial drainage, and loss of waterbird production and rare species habitat* as a result of sedimentation and tillage within wetlands;

- loss of waterbird* and invertebrate production*, and capacity to maintain runoff timing*, as a result of intentional filling of wetlands, and

- loss of vascular plant production as a result of artificial drainage*, and

- loss of vascular plant production and winter wildlife cover as a result of tillage within wetlands, and

- loss of vascular plant* and invertebrate production as a result of sedimentation, and

- loss of waterbird production as a result of pesticide use*.

* Not considered, or not considered a priority, in round one results.

The priorities indicated by the round two survey were generally similar to those of round one, with the ecological effects of artificial drainage again receiving the most votes. However, seven scenarios, marked with (*) above, were added, and two of the scenarios assigned intermediate ranks during round one received no votes at all during round two. These were:

- the loss of nitrate removal capacity as a result of prolonged sedimentation;

- the loss of furbearer production as a result of artificial drainage;

The round two matrix had been modified slightly from that used in round one, so as to clarify some ambiguities and oversights mentioned by panelists responding in round one. These changes may have contributed to panelist changes in ratings between the two rounds. In addition to the changes of functional terms described in section 3.3, the following terms (all pertaining to stressors) were changed between rounds:

First Round Questionnaire Term	Second Round Questionnaire Term
(not originally included)	Filling or Leveling
Tillage in/near wetland	Tillage within Tillage near wetland
Fertilizer Use	Excessive Nutrient Inputs
Feedlots/Septic Systems	Excessive Nutrient Inputs
Dugout Construction	Dugouts/Impoundments
Grazing/Mowing	Excessive Grazing/Mowing
Excessive Harvesting	Excessive Human Visitation
Salinization	Addressed by Artificial Drainage

3.4 Prioritization of Replacement Potentials

3.4.1 Round One

The risk assessment approach also requires that the potential for replacing each wetland function be identified. To do this, the panelists were initially instructed to do the following:

> "Rate the potential for replacing losses of each function by use of created/restored wetlands (e.g., Most efforts to replace function in created/restored wetlands will be fully (=5) or never (=1) successful)."For the sake of brevity, the questionnaire did not define "fully successful" and similar terms, so different panelists may have interpreted terms differently. Most of the panelists were able to estimate replacement potential for all of the functions. Greatest uncertainty surrounded the ability to replace the Detoxification function of wetlands. Table A6 shows the results.

3.4.2 Summary of Information from the Literature Review

In summary, the limited literature seemed to indicate that PPH functions could be grouped as follows with regard to their replacement potential:

Generally Replaceable by Wetland Restoration and/or Creation:
- Sediment Retention
- Phosphorus Retention
- Vascular Plant Production
- Invertebrate Production
- Fish Production
- Waterbird Production
- Winter Wildlife Cover
- Furbearer Production

Replaceable with Somewhat More Difficulty:
- Maintenance of Runoff Timing
- Maintenance of Runoff Volume
- Groundwater Recharge
- Nitrogen Removal
- Detoxification
- Amphibian Production

The literature review emphasized that the prospects for success in restoration and creation projects depend not only on the function, but on the basin hydrologic type, engineering approach, design specifications, the landscape setting, baseline biological communities, and other factors discussed in Appendix B, section 5.

3.4.3 Round Two

In the first-round questionnaire the panelists had been asked to enter a single functional rating for replacement wetlands, regardless of whether they were restored or created. In the second-round survey, panelists were asked to assign separate functional ratings to restored wetlands and created wetlands. Also, the slightly modified terms for functions, described in section 3.1.3 above, were used.

Panelists were again instructed to adjust their ratings, if they believed appropriate, based on observations of their colleagues' first-round scores and their reading of the literature review report. Results are shown in Table A6, and suggest that the greatest attention be focused on difficulties in replacing rare species and communities, and on difficulties in replacing the detoxification function of wetlands.

3.5 Overall Risk Assessment

After completing both rounds of the risk assessment process, the risk assessment coordinator was able to integrate the information into a final risk assessment, using protocols described in section 2.2 (#9) of the Summary Report. The Risk Grouping approach consisted of reviewing rankings in the matrix (as described in section 3.3) with regard to values that panelists had indicated were a priority in the PPR (as described in section 3.2). Priority function-stressor combinations were assigned lower priority when associated with lower-priority values. However, lower priority function-stressor combinations were not assigned higher priority when associated with higher-priority values, because in the overall risk assessment framework, functions were considered to take precedence over values in the rating of scenarios. Similarly, replacement potential was factored in to this final rating of scenarios only after function-stressor combinations had been ranked. Based on the evaluation, scenarios listed in Table A7 were considered to represent the greatest risk.

The Numerical Scoring approach for ranking the risk scenarios was also examined (Table A8). That approach used the same information (as summarized in Table A9) on function, value, loss,

Table A6. Panelist Rating of Replacement Potential of PPH Wetland Functions, First vs. Second Round

Function	Restoration		Creation
	Round One	Round Two	
Invertebrate Production	4 (6 votes)	5 (9 votes)	5 (6 votes)
Sediment Retention	5 (5 votes)	5 (7 votes)	5 (7 votes)
Vascular Plant Production	4 (4 votes)	5 (7 votes)	3 (5 votes)
Maintenance of Runoff Volume	3 (4 votes)	5 (7 votes)	5 (5 votes)
Waterbird Production	4 (6 votes)	5 (7 votes)	4 (5 votes)
Maintenance of Runoff Timing	3 (4 votes)	5 (6 votes)	5 (6 votes)
Nitrogen Removal	4 (3 votes)	5 (5 votes)	3,4,5 (3 votes each)
Winter Wildlife Cover	4 (4 votes)	5 (6 votes)	4, 5 (4 votes each)
Phosphorus Retention	2 (3 votes)	5 (7 votes)	3 (4 votes)
Furbearer Production	3 (7 votes)	5 (5 votes)	4 (4 votes)
Groundwater Recharge	4 (4 votes)	5 (5 votes)	3 (6 votes)
Detoxification	4 (3 votes)	4 (5 votes)	3 (4 votes)
Maintenance of Upland Moisture	4 (4 votes)	5 (4 votes)	2, 5 (3 votes each)
Fish Production	4 (3 votes)	5 (5 votes)	4, 5 (3 votes each)
Habitat for Rare/Restricted Species or Communities	not rated	2 (4 votes)	1,2,3 (3 votes each)
Habitat for Migrating Waterbirds	not rated	5 (6 votes)	5 (4 votes)
Production of Algae	not rated	5 (5 votes)	4 (4 votes)

Table A7. Grouping of the PPR Risk Assessment Scenarios.

Group I (highest):

- loss of capacity of habitat to support rare species and communities, as a result of artificial drainage;

Group II:

- loss of waterbird production as a result of artificial drainage;
- loss of invertebrate production as a result of artificial drainage,
  and
  loss of waterbird production as a result of tillage removal of vegetation near wetlands;
- loss of sediment retention, nitrate removal, winter wildlife cover, and migratory waterbird habitat functions as a result of drainage,
  and
  loss of waterbird production and rare species habitat as a result of sedimentation and tillage within wetlands.

Group III:

- loss of groundwater recharge, and runoff volume and timing functions, as a result of artificial drainage.

Group IV:

- loss of capacity to maintain runoff timing, as a result of intentional filling of wetlands.

Table A8. Numerical Ranking of the PPR Risk Assessment Scenarios.

Higher scores indicate greater risk. See p. A-17 for discussion of approach used to determine the scores.

Score	Scenario
16.50	The loss of **habitat for rare/restricted species** and communities as a result of (in risk order): (1) artificial drainage, (2) sedimentation, and tillage within wetlands, (3) pesticides and intentional filling of wetlands, (4) excessive grazing/mowing.
13.50	The loss of **waterbird production** as a result of (in risk order): (1) artificial drainage, (2) vegetation removal (by tillage) in adjoining uplands, (3) sedimentation, and tillage within wetlands, (3) pesticides and intentional filling of wetlands, (4) excessive grazing/mowing.
12.70	The loss of **invertebrate production** essential to waterbirds, as a result of (in risk order): (1) artificial drainage, (2) sedimentation, and intentional filling of wetlands, (3) tillage within wetlands.
11.74	The loss of wetland capacity to **detoxify contaminants**, as a result of artificial drainage and intentional filling.
11.46	The loss of **vascular plant production** as a result of (in priority order): (1) sedimentation, artificial drainage, and tillage within wetlands, (2) intentional filling and excessive grazing/mowing.
11.22	The loss of wetland capacity to **retain sediments** as a result of (in priority order): (1) artificial drainage, (2) intentional filling and tillage within wetlands. and The loss of **habitat for migrating waterbirds** as a result of (in priority order): (1) artificial drainage, (2) intentional filling and tillage within wetlands.
10.46	The loss of **winter cover for wildlife** as a result of (in priority order): (1) artificial drainage, (2) tillage within wetlands, (3) excessive grazing/mowing and intentional filling of wetlands.
10.34	The loss of wetland capacity to **maintain runoff timing** as a result of (in priority order): (1) artificial drainage, (2) intentional filling of wetlands.
9.85	The loss of wetland capacity to **remove nitrate** as a result of (in priority order): (1) artificial drainage, (2) intentional filling of wetlands.
9.50	The reduction in **production of algae** vital to ecosystem support, as a result of artificial drainage.
9.37	The loss of wetland capacity to **retain phosphorus** as a result of artificial drainage.
8.85	The loss of wetland capacity to **recharge groundwater** as a result of artificial drainage.
8.58	The loss of wetland capacity to **maintain runoff volume** as a result of (in priority order): (1) artificial drainage, (2) sedimentation, (3) intentional filling and tillage within wetlands.
7.12	The loss of **furbearer production** as a result of artificial drainage.
6.50	The loss of **fish production** as a result of artificial drainage and sedimentation.

Table A9. Summary of Numerical Ratings of Risk Components, by Function

This risk rating pertains to the PPR overall. It is recognized that some ratings within particular subareas of the PPR differ.

	Function	Value[1]	Loss[2]	Replacement Potential[3]	Basin Type[4]	Loss Factors[5]
Invertebrate Production	5	4.5	3.20	5,5	T,S	D, S/F, TW
Sediment Retention	4	4.5	2.72	5, 5	T,S	D, F/TW
Vascular Plant Production	4	4.5	2.96	5, 3	T,S	D/S/TW
Maintenance of Runoff Volume	3	2.5	3.08	5, 5	T,S	D,S,F/TW
Waterbird Production	4	4.5	5.00	5, 4	T,S	D, TU, S/TW, P/F
Maintenance of Runoff Timing	4	3.5	2.84	5, 5	T,S	D, F
Nitrogen Removal	4	3.25	2.60	5, 4	T,S	D, F
Winter Wildlife Cover	3	4.5	2.96	5, 4.5	T,S	D, TW, G/F
Phosphorus Retention	4	3.25	2.12	5, 3	T,S	D
Furbearer Production	3	2.	2.12	5, 4	S,SP	D
Groundwater Recharge	3	3.25	2.60	5, 3	T,S	D
Detoxification	4	4.5	2.24	4, 3	T,S	D
Fish Production	2.5	2.	2.00	5, 4.5	SP,P	D
Habitat for Rare/Restricted Species or Communities	4	4.5	6.00[6]	2, 2.5	SP	D, S/TW, P/F
Habitat for Migrating Waterbirds	4	4.5	2.72	5, 5	T,S	D, F/TW
Production of Algae	3	4.5	2.00	5, 4	S,SP	D

[1] **The mean of the potential + actual values, for the value (from Table A2) assumed most closely related to the function.**

[2] **To assign a rating for loss, the number of votes assigned by panelists to each function (i.e., the sum of votes for all stressors affecting each function, see Table A5) was tallied. The minimum number of votes (0) was assigned a rating of 2 and the maximum number of votes (25, for waterfowl production) was assigned a rating of 5. The number of votes a function received (1-24 votes) was normalized to this range.**

[3] **A rating (1-5) of the likely success of wetland restoration and wetland creation, respectively, under ideal conditions and with sufficient passage of time. Based on number of panelist votes.**

[4] **These are the types of wetland likely to experience the greatest loss of the named function. This is not necessarily the wetland type optimal for the function. Abbreviations: Temporary, Seasonal, SemiPermanent, Permanent.**

[5] **These are the stressors (in rank order) voted most likely to cause loss of the named function, based on expected future extent and irreversibility. Abbreviations: Drainage, Filling, Excessive Grazing/Mowing, Impoundments, Pesticide Use, Sedimentation, Tillage in Wetland, Tillage in Upland. For any function, unlisted stressors may also cause impacts.**

[6] **Not rated by panelists but assumed to be approximately the same as for the waterfowl production function.**

and replacement potential used by the grouping approach. However, the manner in which results from the Numerical Scoring approach are formatted (Table A8) appears to place greater emphasis on functions and less on stressors, as compared to the grouping approach (Table A7) shown above. The numerical approach involved the following steps:

1. Each **function** was represented by whatever round two score (range of 1-5) received the most votes from panelists. In the event of a tie (i.e., two scores receiving equal votes), the mean of the scores was used.

2. To numerically represent each **value**, the potential and actual value scores were averaged. To do this, the score (1-5) having the most votes for potential value was added to the score (1-5) having the most votes for actual value, and then divided by 2.

3. Each function was then associated with a single value by assigning it, based on the literature review, to the value with which it seemed to be most tightly linked, as follows:

Function	Value
Invertebrate Production	Recreational Opportunities (via Waterfowl Production)
Sediment Retention	Recreational Opportunities (via Waterfowl Production)
Vascular Plant Production	Forage Income (grazing, hay)
Maintenance of Runoff Volume	Soil Salinity Avoidance
Waterbird Production	Recreational Opportunities
Maintenance of Runoff Timing	Flood Control
Nitrogen Removal	Domestic Water Supply
Winter Wildlife Cover	Recreational Opportunities
Phosphorus Retention	Domestic Water Supply
Furbearer Production	Fur Income
Groundwater Recharge	Domestic Water Supply
Detoxification	Domestic Water Supply
Fish Production	Baitfish Income
Habitat for Rare/Restricted	Species or Communities Recreational Opportunities
Habitat for Migrating Waterbirds	Recreational Opportunities
Production of Algae	Recreational Opportunities (via Waterfowl Production)

4. To numerically represent **functional loss**, the number of votes attributable to all stressors was tallied for each function.* Then, the minimum number of votes received by any function (0) was assigned a rating of 2** and the maximum number of votes (15 in the first round, 25 in the second round) was assigned a 5. The number of votes (1-24) a function received was normalized to this range.

* It is recognized that, because impact severity is not accounted for explicitly in this calculation, a bias is introduced: functions impacted severely by a few distinguishable stressors receive a lower rating for loss than those impacted lightly by many

distinguishable stressors.

** The minimum was set at 2 rather than 1 because all listed stressor-function interactions were based on prior evidence that at least some adverse impacts occur.

5. To numerically represent **replacement potential**, the score having the most votes for wetland **restoration** was used. This was based on an assumption that in the PPR, wetland restoration would be initiated more routinely than creation. However, the scores were inverted by subtracting each from 5, so as to correctly imply that less replaceable functions are at greater risk. In the first round, the score is for replacement potential generally, as the panelists during that round were not asked to distinguish between restoration and creation.

6. The final risk score of each scenario (Table A8) was simply the sum of the scores for function, value, loss, and replacement potential, calculated as described above.

7. Within each scenario, Table A8 also summarizes the functional loss factors in priority order based on the number of votes received from panelists during the second round.

An alternative to both the numerical and grouping approaches would involve conducting an iterative sorting process in a workshop rather than by a two-round questionnaire. This might save time, would allow for immediate clarification of uncertain terms, and could allow for dynamic exchanges of opinions among panelists. A workshop was precluded in the present application partly for logistical reasons, and partly because the spontaneity of a workshop format sometimes does not allow complex subjects to be adequately weighed and considered.

4.0 LIMITATIONS

Before applying the results described in this appendix, users should be cognizant of several limitations:

1. The results are intended to be used as **only one of several** possible inputs into making decisions about relative ecological risk. That is, they should not be considered the only basis for establishing priorities. The nature of other inputs to the risk assessment process will depend on more specific purposes. For example, if a specific objective is to determine priorities for future **research**, the extent of current knowledge about a particular stressor or function might be used as a criterion, in addition to those considered herein. Or if a specific objective is to determine priorities for **regulatory action**, the extent of litigative precedent in regulating particular stressor might be used as an additional criterion.

2. Appropriate definitions of "value" are elusive, and inclusion of value as a component of risk assessment is problematic. This is particularly true where the role of ecosystems or functions in supporting things of value to people is unanalyzed, indirect, or subtle, and as a result may be unrecognized and unvalued by the public generally. Yet, risks are difficult to assess without assuming values, either implicitly or explicitly.

3. The results of using Delphi and similar structured group processes are, of course, strongly influenced by the makeup of the panel. Although care was taken to select persons generally recognized as knowledgeable of key aspects of PPR wetlands, it is possible that different priorities might have emerged had a different set of experts been chosen.

4. As described in section 2.3 of the Summary Report, the results also depend somewhat on the manner in which terms and geographic areas are aggregated. Results are unlikely to be equally applicable to all species or subareas within the study region.

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A PROCESS FOR REGIONAL ASSESSMENT OF WETLAND RISK

APPENDIX B: Technical Documentation

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1.0 INTRODUCTION

This appendix focuses on the basin-type wetlands of the Prairie Pothole Region (PPR), specifically, those wetlands which lack surface-water outlets during most years, are smaller than about 20 acres, and intermittently become dry. This appendix contains both information collected from an extensive literature review, and inferences made from that information. Information in the appendix was compiled to establish a common information source for all members of a panel charged with qualitatively assessing risks of loss of prairie pothole (PPH) wetlands. The process used in that risk assessment is described in the Summary report, and its application is documented in Appendix A. As explained in the Summary report, the risk assessment of which this literature review was a part has treated the entire PPR as a single entity. Yet clearly, considerable variability exists within the region. Thus, attempts to describe "overall" regional conditions have resulted in considerable simplification of actual relationships.

2.0 INVENTORY AND STATUS OF PPH WETLANDS

The U.S. portion of the PPR, which is the focus of this report, comprises 36% of the total PPR. Although the PPR contains only about 5% of the wetlands in the conterminous U.S., the density of wetlands in the PPR is greater than in most regions of the United States. Accurate, current figures on wetland acreage for the entire region or individual states are not available. The best potential source -- the National Wetlands Inventory of the U.S. Fish and Wildlife Service (USFWS) -- is not yet complete (see sections 4.3 and 6.0). A secondary source -- the county soil surveys of the Soil Conservation Service (SCS) -- also does not contain complete regional coverage that would allow quantification of acreage of hydric soils. Estimates of statewide wetland acreage, and percent of land as wetland, have been made by the USFWS (1990a) as follows:

	Total Land Acreage in PPR	Statewide Total Wetland Acreage	Wetland Acreage in PPR
IA:	7,680,000	421,900 (1.2%)	35,000*
MN:	13,440,000	8,700,000 (16.2%)	1,635,000*
MT:	5,760,000	1,882,176 (2.0%)*	no data
ND:	24,960,000	2,490,000 (5.5%)	1,500,000*
SD:	17,280,000	1,780,000 (3.6%)	1,546,000

* Data on wetland acreage located specifically in the PPR is from Iowa Dept. Natural Resources (1990), Minnesota Pollution Control Agency (1990), and North Dakota Dept. Health and Consolidated Laboratories (1990b). PPR boundaries used by the states may differ from those used by this report, shown in Figure 1 of the summary report, thus affecting acreage estimates. The figure for total wetland acreage in Montana is from Montana Dept. Health and Environmental Sciences (1990).

Most of these figures do not include cropped wetlands (those that were tilled at the time of the survey). In the PPR, the proportion of wetlands has seldom been compiled on a watershed basis. Data compiled by U.S. Army Corps of Engineers St. Paul District (1989) for watersheds of the Red River of the North (Minnesota and North Dakota) show that "storage" exceeded 10% of watershed area in 9 of 44 watersheds, the largest figures being 51% and 35% of watershed area. Other portions of the PPR would be expected to have a generally higher incidence of storage and wetlands. "Storage" in the U.S. Army Corps of Engineers (1989) study was defined as the area of lakes, ponds, and swamps colored blue on standard U.S. Geological Survey (USGS) topographic maps; the author reports much inconsistency in this among adjoining maps, and wetland acreage is surely underestimated. A sample of 17 North Dakota PPH basins had watershed:basin ratios ranging from 2.5 to 15.3 (Borthwick 1988).

Wetland depressions (hereinafter called "basins," see Cowardin 1982) of the PPR have most often been classified according to the system of Stewart and Kantrud (1971). This classification will be used in this report, and includes the following classes:

Permanent: The center of the wetland basin contains surface water during all years.

Semipermanent: The center of the wetland basin contains surface water during most years.

Seasonal: The center of the wetland basin contains surface water through mid-summer during most years of normal precipitation.

Temporary: The center of the wetland basin contains surface water for less than about two weeks during most years of normal precipitation, although in some years, heavy summer precipitation can reflood these wetlands briefly.

"Saturated" wetlands (e.g., bogs, fens) also occur to a very limited extent in the region, but along with streams and rivers. Although they may be of considerable importance in the PPR for support of biodiversity, they are mostly non-depressional and are not emphasized in this report.

Wetland basins vary greatly in their salinity and in their annual change. During an average year, perhaps 26% of the temporary, 51% of the seasonal, and 72% of the semipermanent basins contain surface water (Cowardin et al. 1988). Over an idealized wet-dry cycle, the vegetation in semipermanent wetlands goes through four stages: dry marsh, regenerating marsh, degenerating marsh, and lake marsh, with associated consequences for functions and values (Weller 1981).

Although comprehensive data on the percentages of the basic basin types are lacking, some reasonable estimates have been made from statistical samples (e.g., Cowardin et al. 1988). For the PPR overall, temporary and seasonal basins are believed to be most **numerous**, whereas seasonal and semipermanent basins probably comprise the largest **acreage** (Stewart and Kantrud 1973). The generalized distribution of various types can be inferred from state-level geologic maps and topographic relief maps. **Semipermanent** basins tend to occur in areas of dead-ice and terminal (stagnation) moraines, and in areas of moderately to steeply rolling relief with few streams (Krapu and Duebbert 1989). Geographically, such areas occur largely in eastern South Dakota (in the Missouri-Prairie Coteau subregion) and along the western edge of the region in the Dakotas (Kantrud et al. 1989)(see Figure 1 in the summary report). Semipermanent basins also prevail in Iowa, because the greater intensity of agricultural activity there has resulted in tile-drainage of nearly all temporary and seasonal wetlands (pers. comm., A. van der Valk, Iowa St. Univ., Ames). **Temporary and seasonal** basins tend to occur in areas with ground moraines and lake plains, or are areas of gentle relief with scattered, poorly-developed channels (Krapu and Duebbert 1989). Geographically, such areas increase as a proportion of all basins in a westward direction. The annual variability in extent of surface water tends to increase in a southerly direction within the central and western parts of the PPR.

Sample-based estimates of wetland size distribution, by type, are available, but comprehensive data are lacking. In North Dakota, 92% of the basins in the PPR are reported to be < 10 acres (Stewart and Kantrud 1973), and in South Dakota portions of the PPR, "most" of 2342 sampled wetlands were < 1 acre in size (Cowardin et al. 1981). Semipermanent basins are typically the larger wetland basins. Large basins also occur in situations of collapsed glacial outwash (Bluemle 1977). Some of the widest, shallowest wetland basins occur in the lake plains subregions of north-central North Dakota and northeastern South Dakota. PPH basins within the PPR commonly occur at densities exceeding 20 per square mile and may exceed 100 per square mile in some undrained areas (Smith et al. 1964). Similar types of data are summarized by Hubbard and Linder (1986) and Hubbard (1988).

3.0 FUNCTIONS AND VALUES

The following pages of the report discuss each potential* wetland function, along with its potentially* associated values, and potential* indicators of both the function and its values. This reflects the major components of wetland risk assessment, as discussed in section 1.3 of the Summary Report. Each function's discussion of indicators begins with a discussion of indicators appropriate at landscape and regional scales, and then addresses indicators that are best assessed and interpreted site-specifically.

3.1 Maintenance of Runoff Volume

DESCRIPTION: The volume of surface water runoff (i.e., landscape input) is diminished when water evaporates or is transferred to long-term or permanent storage in aquifers. Some PPH wetlands reduce runoff partly by efficiently evaporating (and transpiring) water, or in some cases transferring it to underground storage. The detention function of wetlands is discussed separately, in section 3.2.

DOCUMENTATION OF FUNCTION OCCURRENCE: The role of PPH wetlands in regulating the volume of runoff, as opposed to its timing, is uncertain.

On one hand, some evidence suggests PPH wetlands dissipate water and thus reduce the volume of runoff. Relatively high rates of water loss from evapotranspiration and groundwater recharge have been documented during the mid-growing season, especially in basins smaller than about 5 acres (e.g., Allred et al. 1971, Millar 1971, Shjeflo 1968). Although evapotranspiration and deep recharge are slow processes, measurable in days, weeks, or even years (vs. runoff from storm events, which is measurable in hours), these processes can prime a landscape's soil absorptive capacity before storm events, so that runoff volume is reduced or prolonged following a storm. The long hydraulic detention times in PPH basins can result in large total losses of runoff to infiltration, recharge, and evapotranspiration, even though the rates of these processes are usually small relative to rates occurring in uplands.

On the other hand, other evidence suggests PPH wetlands conserve water and thus maintain the volume of runoff. Vegetation of PPH wetlands appears to reduce evaporation of open water at either end of the growing season, probably through reduction in wind velocity and shading (Eisenlohr 1966, Shjeflo 1968). If wetlands do, indeed, conserve a measurable amount of runoff in this manner, they might help maintain local water table levels. This might benefit crop production and wildlife production, because during the nongrowing season period, subsurface storage of water becomes a crucial determinant of crop yields the following growing season

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* The term "potential" is not used to infer something that is generally undocumented or which could be created but doesn't currently exist. Rather, it is used to mean that only some wetlands possess the function or value, and more individualized examination is needed to confirm it in specific instances.

(Schroeder and Bauer 1984). "Conserved soil moisture" also is reported to be a better annual index of waterfowl numbers than are indices based on the extent of ponded water (Boyd 1981). Artificial drainage of wetlands can eliminate the ability of subsurface soil moisture to move upward in winter to replenish moisture in frozen soil above it (e.g., Malo 1975). In certain types of flat landscapes not characterized by recharge basins, this moisture might contribute measurably to sustaining crops and wildlife habitat the following growing season (Hubbard and Linder 1986). However, this increase in antecedent springtime soil moisture also could theoretically aggravate regional flooding. Regardless of whether PPH wetlands are dissipators or conservers of runoff volume, it still remains uncertain whether they dissipate or conserve enough volume of runoff (at least during the growing season) to cumulatively exert a detectable and socially important effect some distance downslope.

ASSOCIATED POTENTIAL VALUES: Changing the volume of runoff can potentially have implications for several values. If wetlands predominantly dissipate runoff, via evapotranspiration or deep recharge (i.e., recharge that is not readily released to surface waters downslope), then landowners with property in low areas surrounding each basin, as well as in downstream areas, could theoretically benefit from lower water levels during severe runoff events. On the other hand, this reduction in runoff could potentially be detrimental to a goal of maintaining adequate water supplies for livestock and crops during summer months. If, as discussed above, PPH wetlands have the opposite effect (i.e., they conserve water on the landscape), then the resultant increase in runoff volume could aggravate flood losses but could also help sustain crops, livestock, and wildlife.

DOCUMENTATION OF VALUE: Losses of property as a result of flooding are of great concern in the PPR. There are over 200,000 households located within the 6209 square miles of 100-year floodplains in the PPR (FEMA data files). The largest concentration of floodable residences is in North Dakota, and flooding there damages up to $100 million per year worth of crops, roads, and property (ND Dept. Health and Consolidated Laboratories 1990b). In the Devils Lake area, Leitch and Scott (1984) assumed that for each acre of wetland restored, annual flood damages to transportation facilities would be reduced by $3.17, and flooding of crops would be reduced on 1.11 acres. Also, they estimated the benefits of making an acre of agricultural land flood-free would be $14.83. Including recreation values, total income generated by an undrained wetland for its flood control functions was estimated to be about $29/acre.

It is apparent that many PPR citizens (e.g., 79% in a survey by Grosz and Leitch 1990) value wetlands for their ability to reduce downstream flood losses. No studies have established a causal link between loss of runoff volume as a result of wetland evapotranspiration or recharge, and actual decreases in economic losses due to flooding.

TEMPORAL EFFECTS: Hydrologic inputs to PPR wetlands vary greatly among years. Throughout most of the PPR, landscape inputs (i.e., runoff volume) are greatest during early spring. Comparing two years (or locations) with equal amounts of total annual precipitation, the volume of spring runoff is likely to be much greater for the year (or location) in which, during the preceding autumn, a major rainstorm was followed by freezing, which then was followed by a snow cover that persisted through the winter. Conversely, less spring moisture is available during years (or locations) where winters are mild and lack continuous insulating snow cover. Springtime weather conditions also affect runoff. At years or locations where frozen soils persist late into the spring, wetland capacity for detaining runoff inputs and permitting their infiltration may be reduced (a point which, at least for clay hydric soils, is debatable; pers. comm., J.L. Richardson, North Dakota St. Univ., Fargo). Any of the temporal effects just described can overwhelm the effects of spatial characteristics described in the following sections.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape inputs to wetlands can be represented by indicators of **runoff** (such as watershed size, springtime rainfall, snow depth, and total annual precipitation) and indicators of **groundwater discharge** (such as subregion within the PPR and geology). Runoff inputs may be represented more accurately if the actual **water yield** to wetlands is used to represent landscape input. Water yield is precipitation, minus the evapotranspirative and other losses that occur in uplands before runoff from precipitation can reach wetlands. Evapotranspirative losses in uplands are measurably influenced in some situations (e.g., Deibert et al. 1986, Sophocleous and McAllister 1987) but not all (e.g., Khakural 1988) by **crop type and tillage practices**, as well as by **grazing regimes** (e.g., Hofmann et al. 1983).

Runoff inputs to wetlands are also affected by geomorphic characteristics of the watershed area upslope of the wetlands. Runoff entering wetlands is likely to be greater, and storm hydrographs sharper, where upslope watersheds are **elongate** in shape, relatively **steep**, comprised of clayey or similar **less-permeable soils**, and are **channelized or artificially drained**. Conversely, as a watershed becomes more rounded in shape and dominated by generally flat permeable soils that are not artificially drained, runoff inputs to downslope wetlands diminish, having the same effect as a decrease in watershed area. However, if wetlands are mainly of a type whose water budget is dominated by groundwater (e.g., semipermanent basins), then conversion of upland grasslands to tillage can cause water tables to drop and wetlands to dry up (pers. comm., J.L. Richardson, North Dakota St. Univ., Fargo).

In the PPR, available data suggest that the **potential** hydrologic input to wetlands (i.e., precipitation surplus plus groundwater) is greatest in the southern and eastern part of the region. The **actual** input, as noted above, depends on factors such as crop type, soil type, slope, soil permeability, watershed shape, and extent of upstream channelization/drainage. Within the PPR, soil permeability (as predicted by soil type) probably shows few geographic patterns, as the ratio of till to outwash is about the same in Iowa as in North Dakota (pers. comm., J.L. Richardson, North Dakota St. Univ., Fargo). Also, the **form of precipitation** (snow vs. rain) measurably affects the degree to which it is stored or evaporated by the landscape. Citing evidence from a study in northern Ontario, Winter and Woo (1990) state that wetlands delay streamflow response to rainfall but not to snowmelt; it is not apparent that this is the case in the PPR (pers. comm., J.L. Richardson, North Dakota St. Univ., Fargo). In the northwestern part of the PPR, over 25% of the annual precipitation occurs as snow, whereas less than 12% occurs as snow in southeastern South Dakota (Winter and Woo 1990).

<u>Capacity</u> for losing water via evaporation in wetlands depends partly on landscape factors. As is apparent in the conceptual model (see Appendix C), the effects of **wind velocity** and **air temperature**--which measurably influence evapotranspiration--can be indicated by landscape/regional characteristics such as **latitude, longitude, elevation**, and general **topographic relief**. Regional geologic patterns can also determine characteristics that operate within wetlands and are conducive to evaporative loss of runoff, as described in (B) below. The relative extent of runoff lost to recharge can also be estimated from geologic and topographic patterns; in watersheds having a large **proportion of wetland basins located near regional drainage divides**, these basins are often groundwater recharge areas (Sloan 1972). Similarly, the **contagion characteristics** of the wetland spatial distribution (e.g., distribution of acreage in wetlands is dispersed vs. clumped) are likely to affect potential for evaporative loss. As expressed by Hubbard (1988):

> "<u>Complexes</u> should provide for better groundwater recharge and better water retention than similar acreages of wetlands in a large, single basin...small [temporary, seasonal] wetlands will regenerate their storage capacity and be ready to store the next runoff event much more quickly than large wetlands."

In addition, climatic patterns influence and indicate relative losses from evapotranspiration. Subregions within the PPR having a larger portion of their hydrologic **inputs occurring during summertime** (vs. spring) may lose considerable water via transpiration, assuming water tables do not drop below the root zone for extended periods. Wetlands located in subregions with a relatively greater portion of runoff occurring in summertime probably are more capable of reducing runoff volume. However, the differences among PPH wetlands in their capacity to reduce runoff volume may be attributable more to differences in recharge capacity than to differences in evapotranspiration (Sloan 1972). Indicators of recharge are discussed in section 3.3 (page B-15).

B. Site-level (Within-wetland) Indicators of Function

Wetlands of all types may reduce runoff volume, but the magnitude of this function is partly indicated by **wetland water regime** (i.e., as used in this report, meaning the basin hydroperiod or permanence type -- temporary, seasonal, semipermanent, or permanent). Water regime in turn can be indicated generally by plant species, soil profile, landscape geology, relief, and geographic position. Drier basins, such as temporary and seasonal types, are often densely vegetated. Until the water table drops below the root zone in early summer, the vegetation in these wetlands can efficiently reduce runoff volume by evapotranspirating water and directing some runoff into underlying groundwater storage (i.e., recharge). However, wetland basins that are relatively deep (e.g., semipermanent) tend to lose a smaller portion of their water to evaporation, because a smaller portion of the water volume is directly exposed to wind and sunlight. Moreover, the peripheral vegetation of semipermanent basins, although it transpires water throughout the growing season, shields much of the water surface from wind and sun and thus reduces losses due to evaporation (Eisenlohr 1966, Shjeflo 1968).

Another site-specific indicator of wetland capacity for reducing runoff volume is **basin size and shape**. Wetland basins that are small, with convoluted and/or gently sloping shorelines, are likely to have a larger proportion of their area as shallows, i.e., smaller depth-to-volume ratio (Millar 1971). Such conditions lead to warmer water temperatures and a larger percent cover of vegetation, which in turn can lead to greater rates of water loss via summertime evapotranspiration (Crow and Ree 1964), at least in temporary and seasonal basins. Small, convoluted basins may be optimal for loss of surface water via recharge.

A third site-specific indicator is **the ratio of emergent or woody vegetation to open water**. Because during the growing season an equal or greater volume of runoff can be lost via vegetative transpiration than by unvegetated open water, densely vegetated wetlands, if temporary or seasonal, may have a greater capacity for reducing runoff volume. However, during months when vegetation is dormant, evaporative water losses may be less where conditions allow a continuous ground cover or dense litter layer to protect wet sediments from exposure to wind and sun (e.g., Rickerl and Smolik 1990).

Fourth, the **vegetation type** probably influences evapotranspirative losses. Wetland basins dominated by submersed, shallow-rooted, or fine-leaved plants (as indicated partly by the successional status of the basin) generally experience less evapotranspirative loss of water than those dominated by broad-leaved, deep-rooted species.

Finally, water **chemistry** both influences and indicates potential for reduction in runoff volume. Loss of water can be less in permanently saline basins than in freshwater basins, due to reduced evaporation (e.g., Whiting 1984), and reduced transpiration due to impedance of osmotic tension in plants. Moreover, saline wetlands typically represent groundwater discharge situations, whereas loss of runoff volume is enhanced in situations of groundwater recharge. In the PPR, saline basins mostly occur in topographically low positions on glacial outwash in western and northern areas.

Each of the above five site-specific indicators can be manifested on a regional level as well. That is, because these indicators correlate roughly with regional geologic and climate patterns, in a general sense they may show spatial trends within a region.

POSSIBLE INDICATORS OF VALUES:

A. Regional and Landscape-level Indicators of Value

Economic value of the runoff volume reduction function can be indicated partly by **number of floodplain properties**, the **market value** of these properties, and their **position and proximity** relative to those wetland complexes that cumulatively have the greatest capacity for reducing runoff volume. Also, the **season of flooding** may partly determine the value of runoff control. Spring floods can delay planting, summer floods tending to damage maturing crops as well as dwellings, and autumn floods can delay harvest. Ecological values of maintaining runoff volume also depend on the season of flooding and the position and proximity of wetlands to areas of greatest intrinsic ecological importance.

B. Site-level (Within-wetland) Indicators of Value

Local economic values of this function for water supply are indicated partly by the **density of livestock**, the **extent of cropped wetlands**, and the **drought vulnerability** of the most widely grown crops. The value of wet areas to livestock and crops increases in proportion to the severity of drought occurring during a particular year.

3.2 Maintenance of Runoff Timing

DESCRIPTION: Surface water runoff (i.e., landscape input) is delayed in its down gradient journey when water is detained (i.e., increased functional capacity) in wetland basins. PPH wetlands facilitate detention of runoff because they mostly lack well-defined surface water outlets, and interbasin subsurface flows are very slow (e.g., 0.05 meters/day, Tipton et al. 1972). When runoff is detained in a regionally dispersed manner by PPH basins, pulses of water that eventually enter downstream areas in most cases are staggered (desynchronized). This broadens the storm hydrograph and reduces streamflow peaks.

DOCUMENTATION OF FUNCTION OCCURRENCE: Prairie pothole wetlands can reduce peak flows occurring in channels downslope, because they have considerable capacity for detaining runoff (e.g., Hubbard and Linder 1986, Ludden et al. 1983). Detention of precipitation occurs largely because most PPH basins lack surface water outlets, and also because robust vegetation that occurs in some wetlands is capable of effectively intercepting and storing drifting snow (Sloan 1972), allowing water to infiltrate in depressions rather than moving downslope during melt periods.

Several empirical landscape studies and landscape simulation studies in the PPR have attempted to demonstrate diminuation of downstream peak flows as a result of the presence of many wetlands, or aggravation of peak flows due to artificial drainage of wetlands (Brun et al. 1981, Moore and Larson 1979, U.S. Army Corps of Engineers St. Paul District 1989). These studies have not differentiated whether any peak flow diminuation is due to volume reductions, as just discussed in section 3.1, or to runoff timing alterations (i.e., desynchronization) associated with wetlands, as discussed below. Artificial drainage of wetlands was implicated by Sidle (1983) in the increase of economically damaging floods of the James River in North Dakota. In flat landscapes of Florida, watersheds where most of the wetlands have been drained or channelized have detention times of only 2.2 days, vs. 4.5 days for undrained, unchannelized watersheds (Bedient et al. 1976). However, as discussed in section 4.2, wetland drainage does not inevitably cause increased flood stages downstream. In some cases, alteration of main-channel wetlands may do more than artificial drainage of isolated wetlands to aggravate flooding (Moore and Larson 1979, Ogawa and Male 1983), and in some instances artificial drainage could theoretically ameliorate peak flows by decreasing antecedent moisture conditions prior to storm events (Hill 1976).

Nonetheless, PPH basins have considerable potential for storing runoff. In the large wetland complexes of Salyer National Wildlife Refuge of North Dakota, undrained, mostly unconnected wetlands were reported to be storing 58% of the inflow, plus all local runoff (Malcolm 1979). In the Devils Lake Basin of North Dakota, wetland basins store between 41% of the runoff from severe (100-year) storm events, and up to 72% of the runoff from smaller events (Ludden et al. 1983). In the Pembina River Basin of North Dakota, each undrained wetland can store up to one acre-foot of runoff (Kloet 1971), a figure also supported by the data of Hubbard and Linder (1986) from 213 wetlands in northeastern South Dakota. Moreover, that study noted that most wetlands were not filled to capacity at the time of measurement.

ASSOCIATED POTENTIAL VALUES: At a landscape level, detaining runoff in wetland basins has implications for several values. By flattening the storm hydrograph, some wetlands help reduce flooding in downslope areas. This can potentially reduce economic damage to property, as quantified in section 3.1. The effects on ecological resources of releasing runoff more gradually can be either adverse (e.g., reduced frequency of scouring flows needed to maintain habitat of some species) or positive (e.g., increased annual minimum flows, improved purification of runoff due to lengthened processing time).

On a site-specific level, by detaining water later into the growing season, wetlands can provide water for livestock, soil moisture for surrounding croplands, and habitat for aquatic wildlife, particularly in areas of glacial till (Hubbard 1988). However, this renders some temporary wetlands unsuitable for cultivation.

DOCUMENTATION OF VALUE: On a landscape level, damages to property as a result of flooding are of great concern in the PPR. On a local level, water supplies for livestock and crops are also a great concern, particularly in the western part of the region. Maintaining soil moisture in that area is a major public concern. It is apparent that many PPR citizens (e.g., 79% in survey by Grosz and Leitch 1990) think that wetlands are important for their ability to reduce downstream flood losses. Although some regional studies have supported a link between wetlands and peak flow reduction, no studies have established causal links between shortened detention times, increased flow synchronization, increased peak flows, and actual economic losses due to flooding.

TEMPORAL EFFECTS: Hydrologic inputs to PPR wetlands vary greatly among years. Throughout most of the PPR, landscape inputs (i.e., runoff volume) are greatest during early spring. Comparing two years (or locations) with equal amounts of total annual precipitation, the volume of spring runoff is likely to be much greater for the year (or location) in which, during the preceding autumn, a major rainstorm was followed by freezing, which then was followed by a snow cover that persisted through the winter. Conversely, less spring moisture is available during years (or locations) where winters are mild and lack continuous insulating snow cover. Springtime weather conditions also affect runoff. At years or locations where frozen soils persist late into the spring, wetland capacity for detaining runoff inputs and permitting their infiltration may be reduced (a point which, at least for clay hydric soils, is debatable; pers. comm., J.L. Richardson, North Dakota St. Univ., Fargo). Any of the temporal effects just described can overwhelm the effects of spatial characteristics described in the following sections.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Landscape inputs to wetlands can be represented by indicators of **precipitation** and **water yield** or their surrogates (e.g., watershed shape, soil type, slope, and channelization extent) as described on page B-7. Also, differences in **rainfall or snowmelt intensity** exist within the PPR; subregions with shorter, more intense rainfall or snowmelt may yield proportionally more runoff to wetlands.

Capacity for detaining runoff in wetlands can be indicated by within-wetland factors, but the important consequences of detention -- i.e., whether detention will result in synchronization or desynchronization of downstream flows -- depend on between-wetland landscape factors, specifically, the spatial arrangement of wetlands relative to receiving channels, and the diversity of their sizes (storage volumes). Science has not advanced to the point where it is possible to specify all combinations of wetland spatial position, size, and type that are optimal for desynchronizing flows.

B. Site-level (Within-wetland) Indicators of Function

Review of the conceptual model suggests several site-specific indicators that determine or correlate with hydrologic detention. Perhaps the most important indicator of the ability of a wetland to detain flow is the **frequency and magnitude of connection to other basins.** This is indicated partly by the height of the rim separating basins in a complex, as well as the subsurface flow patterns and the extent of artificial drainage connections. Basins that remain hydrologically isolated, regardless of the size of the runoff event, are essentially "noncontributing areas." These basins can have the largest influence on runoff timing because all runoff that reaches them is retained. The **ratio of basin size to watershed (catchment) size** is also important. Provided their water budgets are not dominated by groundwater discharge, basins that are large relative to the watershed (catchment) area are likely to be effective in detaining runoff. A third indicator of the magnitude of runoff detention in wetland basins is **wetland water regime.** Water regime can be indicated generally by plant species, soil profile, landscape geology, relief, and geographic position. Drier wetland basins, such as temporary and seasonal types, probably have a larger proportion of their basin available for storage and infiltration of spring runoff. Infiltration occurs because (a) the topographic position of most temporary and seasonal basins enhances their ability to recharge groundwater, (b) thawing of sediments occurs earlier in the season than in semipermanent and permanent basins, thus making interpore space available in wetland soils for water storage, and (c) when frozen, the clayey soils that typify many of these basins contain macropores which facilitate loss of runoff to ground water recharge. In contrast, semipermanent and permanent basins are often dominated by the more sustained inflows from groundwater discharge, leaving little space available for subsurface storage of runoff. **Wetland soil type** may also partially indicate wetland capacity to desynchronize inputs. Hydric soils which during years of snow cover do not freeze deeply, or which thaw earlier in the spring (e.g., blackish mineral soils), allow runoff to infiltrate during the weeks when most runoff occurs. Finally, wetland capacity for detaining runoff is suggested by **wetland size and shape**. As noted earlier, smaller wetlands and wetland basins with convoluted shorelines are likely to have more gently sloping shorelines and a larger proportion of their area as shallows. Such zones are more likely than deepwater to support recharge and infiltration, which in turn makes space available for storing runoff.

POSSIBLE INDICATORS OF VALUES:

A. Regional and Landscape-level Indicators of Value:

Economic value of the hydrologic detention function can be indicated partly by the **season of flooding** (summer floods tending to damage crops as well as dwellings), **number of floodplain properties**, the **market value** of these properties, and their **position and proximity** relative to wetlands that cumulatively have the greatest capacity for reducing runoff volume. Ecological values of maintaining runoff timing also depend on the season of flooding and the position and proximity of wetlands to areas of greatest intrinsic ecological importance.

B. Site-level (Within-wetland) Indicators of Value:

The values of this function are expressed primarily at the landscape scale. See the discussion above.

3.3 Groundwater Recharge

DESCRIPTION: Surface water runoff (i.e., landscape input), when delayed in storage areas during its downgradient journey, can move downward into underlying aquifers, recharging the groundwater.

DOCUMENTATION OF FUNCTION OCCURRENCE: Recharge has been documented in several PPH basins, particularly those with temporary or seasonal water regimes in the western portion of the PPR (Sloan 1972, Eisenlohr et al. 1972). Infiltration rates of up to 0.5 foot per day have been reported (Sloan 1972). In a Minnesota part of the PPR, wetlands recharge aquifers probably by applying a relatively constant hydraulic head that forces water into underlying unweathered till, Wall et al. (1989). It is not apparent that the presence of wetland vegetation or soils enhances recharge; rather, such wetland basins just happen to occur in topographic situations that are intrinsically supportive of recharge.

ASSOCIATED POTENTIAL VALUES: Primarily at a landscape level, recharge from wetlands can play a role in sustaining groundwater used domestically and for pastured livestock. Because loss of recharge functions can result in greater well-drilling and pumping costs, and possibly greater agricultural expenses, loss of wetlands might aggravate such expenses, if indeed the role of wetlands is large relative to that of other landscape components that contribute to groundwater (e.g., Hubbard and Linder 1986). Recharge from wetlands also sustains groundwater that discharges to other wetlands (e.g., semipermanent and permanent basins), thus potentially supporting their ecological, water purification, and economic values (Lissey 1971; Richardson and Arndt 1989). Seasonally fluctuating water levels in wetlands, as controlled largely by natural rates of recharge, are important to maintaining wetland productivity. On the other hand, loss of recharge wetlands can cause remaining wetlands and ditches to become groundwater discharge areas which increase the salinity of soils, rendering them unsuitable for cultivation (Arndt and Richardson 1986, Hendry and Buckland 1990).

DOCUMENTATION OF VALUE: Groundwater is a major source of consumed water in the PPR, contributing from 39% (in North Dakota) to 83% (in Iowa) of the water used in 1980. Use specifically for domestic human consumption varies from 34% (in Iowa and Montana) to 52% statewide in Minnesota. Use for livestock and irrigation varies from 30% in Iowa and Minnesota to 86% in Montana (Moody et al. 1986). The U.S. Geological Survey considers future groundwater development in North Dakota to be limited partly by "insufficient aquifer recharge" (Paulson 1983). Where PPH basins recharge groundwater, it helps ensure adequate water supplies for livestock and crops. This is a particularly great concern in the western part of the region.

However, the role of wetlands specifically, as opposed to other landscape elements, in supporting these values is debated. The geographic extent to which recharge via PPH wetlands enters groundwater tapped by wells, as opposed to recharging zones higher or lower than those used domestically, is unknown. Although some PPH basins are known to recharge groundwater, there appear to be no data that link recharge rates specifically from wetlands to actual use rates and economic values of the users. However, if indeed recharge in the western and flatter parts of the PPR occurs only rarely in uplands (Freeze and Banner 1970, Lissey 1971, Malo 1975), the value of wetlands in that subregion can be assumed directly.

TEMPORAL EFFECTS: Hydrologic inputs to PPR wetlands vary greatly among years. Throughout most of the PPR, landscape inputs (i.e., runoff volume) are greatest during early spring. Comparing two years (or locations) with equal amounts of total annual precipitation, the volume of runoff available for springtime recharge of groundwater is likely to be much greater for the year (or location) in which, during the preceding autumn, a major rainstorm was followed by freezing, which then was followed by a snow cover that persisted through the winter. Conversely, less spring moisture is available during years (or locations) where winters are mild and lack continuous insulating snow cover. Springtime weather conditions also affect water available for recharge. At years or locations where frozen soils persist late into the spring, wetland capacity for detaining runoff and permitting its infiltration as recharge may be reduced (a point which, at least for clay hydric soils, is debatable; pers. comm., J.L. Richardson, North Dakota St. Univ., Fargo). Any of the temporal effects just described can overwhelm the effects of spatial characteristics described in the following sections.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape <u>inputs</u> to wetlands that support groundwater recharge can be represented by indicators of **precipitation** and **water yield**, including watershed shape, slope, crop type, soil type, and artificial drainage, as described on page B-7.

<u>Capacity</u> for recharging groundwater is indicated primarily by regional and landscape factors. In particular, **climate**, as represented by regional position within the PPR, is a primary indicator of recharge. Undrained basins in the western and northern parts of the PPR (including the Lake Agassiz plain) contain predominantly recharge wetlands, whereas basins in Iowa, southern Minnesota, and parts of eastern South Dakota mostly contain discharge or flow-through wetlands (pers. comm., J.L. Richardson, North Dakota St. Univ., Fargo).

Topographic position is another landscape indicator of recharge. At least in the eastern portion of the PPR, wetland complexes located near major regional divides often recharge groundwater (Swanson et al. 1988). Thus, when local terrain is homogeneously flat or slopes sharply away from a wetland (i.e., great local relief and large regional slope, cf. Winter 1977), the water table often slopes away as well, resulting in a hydraulic gradient favorable for movement of water into the groundwater system. In contrast, wetlands located at the bottom of a relatively steep slope are often areas of groundwater discharge, because the water table crops out at the surface near the deflection point of the slope.

Also, the **contagion characteristics** of the wetland spatial distribution (e.g., distribution of acreage in wetlands is dispersed vs. clumped) are likely to affect potential for recharge. Wetland acreage occurring as complexes rather than as single large wetlands should provide for better groundwater recharge (Hubbard 1988) because such landscape are more likely to indicate diversified potentiometric gradients, which are more conducive to recharge.

B. Site-level (Within-wetland) Indicators of Function

Wetland water regime is a prominent indicator of groundwater recharge. Water regime can be indicated generally by plant species, soil profile, landscape geology, relief, and geographic position. Drier wetland basins, such as temporary and some seasonal basins, have been documented as being recharge areas in much of the northwestern PPR (Lissey 1971, Loken 1991), particularly where they occur as part of a wetland complex. In contrast, the larger semipermanent and permanent basins are often dominated by groundwater discharge or are flow-through systems. However, in the western PPR (Richardson et al. 1991) or in landscapes with water tables recently lowered by extensive artificial drainage, semipermanent basins probably assume increased importance for recharging groundwater. Another site-specific indicator (but not determinant) of the ability of a wetland to recharge groundwater is the **ratio of wetland size to watershed size.** Large basins that have very small watersheds, or whose watersheds contain many other basins, are likely to be groundwater discharge areas. Conversely, small basins (at least in the western PPR) tend to be groundwater recharge areas (Loken 1991).

Water and soil chemistry can indicate, but not determine, the direction of groundwater exchange where the magnitude of exchange is great. Basins that have higher specific conductivity, pH, alkalinity, hardness, magnesium, sulfates, and total dissolved solids; and lower concentrations of calcium and total bicarbonates, are likely to be dominated by groundwater discharge, not recharge (Sloan 1972, Arndt and Richardson 1986). In the PPR, such basins occur mostly in western and northern areas. In soil profiles, recharge is suggested by presence of only small quantities of gypsum ($CaSO_4 . 2H_2O$) and absence of calcite (CaCO3). Recharge basin soils are generally nonsaline, noncalcareous, with deep sola (depth of soil development). Also, they usually have well-developed eluvial (highly leached) and argillic (clay enriched) horizons (Miller et al. 1985, Hubbard 1988). They would generally be classified as Argiaquols.

The texture of soil and subsurface materials is often a major determinant of groundwater exchange, although not of recharge or discharge specifically. In theory, groundwater should move most rapidly through coarse sands or gravels and successively slower through fibric peats, deep sapric peats, and clays. In some cases, this ranking is easily overridden by topographic factors and the presence of rooted wetland plants. Macropores created by plants enhance infiltration into underlying aquifers through shallow clay layers or compacted bottom sediments (Eisenlohr 1966). On the other hand, the surface layer of organic matter formed by these plants progressively accumulates (unless removed by waves, currents, wind, animals, fire, sulfate reduction, or decomposition). In doing so, it might progressively isolate or seal a wetland from groundwater systems.

The above site-specific indicators can be manifested on a regional level as well, because they are partly a reflection of regional geologic patterns.

POSSIBLE INDICATORS OF VALUES: Economic values of this function are partly indicated by the **density of livestock** or **humans dependent on wells**, the **depth of wells** relative to wetland inputs to the groundwater, and the **drought vulnerability** of the subregion. Ecological values of recharging groundwater also depend on the local drought vulnerability and the proximity of recharging wetlands to areas of greatest intrinsic ecological importance.

3.4 Sediment Retention

DESCRIPTION: Sediment retention is the process by which sediment borne by overland runoff (e.g., sheet flow) and incoming surface waters is deposited (sedimentation) and retained (stabilization). PPH wetlands retain sediments by (a) trapping them in basins closed to surface outflow, (b) anchoring sediments with plant roots, and (c) intercepting and reducing erosional energies (e.g., wind, waves). To be stabilized over long periods of time, sediment entering wetlands must either be deposited in deep permanent waters, or be stabilized by encrusting precipitates or roots of wetland vegetation. High winds typical of the region can remove a small portion of the sediment from large (especially saline) basins during drought periods.

DOCUMENTATION OF FUNCTION OCCURRENCE: PPH wetlands retain virtually all sediment which enters them because they lack surface water outlets. Sediment retention, perhaps because it seems so obviously present in PPH basins, has seldom been documented in the PPR. One study of a series of South Dakota potholes reported accretion rates of between 430 and 800 g/m^2/year (Martin and Hartman 1987a). An open lake system in South Dakota removed 43, 33, and 100% of the suspended solids from tributary input during three successive years (SDRCWP 1990), and two open wetland complexes in North Dakota removed 13 and 28% of the tributary suspended sediment, vs. a 2000% increase in sediment exported from a ditch-drained wetland complex (Malcolm 1979). Sedimentation rates might also be inferred from data collected by Callender 1969, Frickel 1972, Churchill et al. 1975, and Okland 1978.

ASSOCIATED POTENTIAL VALUES: Excess sediment deposition impairs fish production, biodiversity, and flood storage and conveyance. For example, little of the sediment entering the James River in South Dakota is transported downriver (Benson 1988). At a landscape level, wetlands are among the most effective landscape features for mitigating sedimentation problems. They do so by intercepting and retaining eroded sediment before it reaches larger, more permanent waterbodies. Thus, protection and enhancement of this function in wetlands could help maintain and restore public uses of downslope lakes and rivers, such as fish production, biodiversity, and flood conveyance. However, on a site-specific level, retaining sediments in PPH wetlands can adversely impact the ecological and hydrologic values of the wetlands themselves. Thus, the potential landscape-level values of some wetlands to effectively treat nonpoint nutrient runoff must be balanced against the likelihood that site-specific (and eventually, landscape) ecological values may compromised.

DOCUMENTATION OF VALUE: All of the states of the PPR, in their annual 305b water quality report, declare sedimentation the most important threat to public uses of surface waters. In South Dakota, 26% of the assessed river miles statewide have water quality that is so degraded it does not support any of their designated uses, and 44% show partial support; about 12% are not fishable due to water quality problems. Some 20% of the lakes do not meet their designated uses (SD Dept. Water and Natural Resources 1990). In North Dakota, 25% of the assessed river miles, and 36% of the lake acres, have water quality that is so degraded it does not fully support all of their designated uses (ND Dept. Health and Consolidated Laboratories 1990b).

Also, public opinion surveys indicate that many PPR citizens (e.g., 90% in survey by Grosz and Leitch 1990) think that wetlands are important for their ability to purify water. Despite reductions of erosion in some counties as a result of implementing the federal Conservation

Reserve Program (CRP), sedimentation problems may be increasing, as a trend of converting grasslands (range, hay, pasture) to row crops continues (Kantrud et al. 1989). Although PPH basins are known to retain sediment, no attempts have been made to link quantitative estimates of sedimentation rates specifically from wetlands to actual use rates and economic values of the users of downslope water that is benefitted.

TEMPORAL EFFECTS: Throughout most of the PPR, runoff inputs to wetland basins are greatest during early spring. Often, this early spring runoff bears the largest portion of sediment entering wetlands. Much of the sediment originates from lands tilled the previous autumn. Comparing two years (or locations) with equal amounts of total annual precipitation, the transport of sediment is likely to be much greater for the year (or location) in which, during the preceding autumn, a major rainstorm was followed by freezing, which then was followed by a snow cover that persisted through the winter and was followed by a warm early spring. Under such conditions, the large spring thaw is likely to mobilize considerable sediment. Conversely, springtime sediment runoff may be less during years (or locations) where winters are mild and lack continuous insulating snow cover. In other instances, springtime conditions affect sediment inputs to a greater degree than conditions during the preceding autumn or winter. Although PPH basins retain nearly all sediment that reaches them, their cumulative removal efficiency may be greatest during years when the runoff occurs later in the season, or during years when summer (vs. early spring) storms contribute a larger portion of the annual sediment input to wetlands. That is because as the season progresses, wetland soils thaw and vegetation develops more fully, thus increasing trapping efficiency. Any of the temporal effects just described can overwhelm the effects of spatial characteristics described in the following sections.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape <u>inputs</u> of sediment to wetlands can be represented by indicators of the amount, intensity (Young and Wiersma 1973), and timing of **precipitation** and **water yield**, as described on page B-7. Other factors indicate potential sediment inputs to wetlands resulting both from erosion of upland areas, and from the lack of interception of runoff-borne sediment before it reaches wetlands. These include proximity to wetlands of **land covers**, **soil types**, and **slope conditions** that are considered highly erodible or poorly interceptive (i.e., weak buffers). In watersheds with erosion-resistant soils, wetlands surrounded by wide **buffer strips** of dense vegetation usually receive the least inputs of sediment, unless tile- (vs. ditch-) drainage is prevalent. Also, the **type of grazing regime** (Hofmann et al. 1983) and **crop management practices** (e.g., conservation tillage, contour plowing) determine both the magnitude of sediment runoff (Young and Wiersma 1973) and lack of interception before reaching wetlands. The Soil Conservation Service office in each county of the PPR has integrated erosion factors to identify and list soil mapping units considered to be **Highly Erodible Land (HEL)**. Where these HEL units are based on vulnerability to non-wind related erosion (as predicted mainly by slope), these data can be used to assess relative sedimentation risks of various wetland complexes and other water bodies. **Artificial drainage** of individual wetlands normally causes initially large exports of sediment to downslope areas. In localized situations, drainage might occasionally reduce long-term sediment export to downslope areas, in two ways. First, at least in watersheds where drainage is accomplished by use of tile rather than ditches, artificial drainage can cause a large portion of the precipitation to infiltrate rather than move downslope as overland runoff and carry soil with it. Second, wetland drainage could theoretically reduce landscape-level sediment inputs if drainage results in farm operators planting crops in drained lands rather than in highly erodible uplands, which under the CRP are frequently returned to a permanent cover such as hay (Danielson and Leitch 1986).

Capacity for retaining sediment is related, on a landscape scale, to the spatial arrangement of wetland complexes relative to inputting land uses. Science has not advanced to the point where it is possible to specify all combinations of wetland spatial position, size, and type that are optimal for retaining sediment at a landscape scale. Nonetheless, the **contagion characteristics** of the wetland spatial distribution (e.g., proportion of subregional wetland acreage that is dispersed vs. clumped) are likely to affect both the potential extent of sediment input to wetlands and wetland capacity to retain it. Wetland acreage occurring as scattered complexes rather than as single large wetlands should be more likely to be located near and downslope from sediment sources, partly because complexes tend to occur in hummocky terrain. Although in hummocky terrain the predominant land cover (rangeland) is usually less supportive of erosion than is cropland, where soil tillage does occur, erosion may be great. Moreover, the larger shoreline-to-area (or smaller depth-to-volume) ratio associated with a more dispersed wetland acreage implies that a larger portion of sediment-bearing runoff will enter wetlands via shoreline zones of dense vegetation. Although such vegetation has minimal effect on long-term sedimentation of a basin, it may reduce the amount of sediment in suspension and thus benefit some other wetland functions (e.g., Dieter 1990).

B. Site-level (Within-wetland) Indicators of Function

Most of the site-specific indicators described for the function, Maintenance of Runoff Timing (section 3.2), are suitable as indicators of sediment retention, because retention is closely linked to hydraulic retention or settling time. Again, the **frequency and magnitude of connection to other basins** and the **ratio of wetland size to watershed size** are important indicators of sediment retention capacity. Also, **wetland water regime** influences sediment retention. Water regime can be indicated generally by plant species, soil profile, landscape geology, relief, and geographic position. The drier wetland basins, such as temporary and seasonal types, probably have a larger proportion of their basin available for storage and infiltration of spring runoff, with concommitant deposition of suspended sediment. However, large temporary and seasonal basins that are saline, burned, or otherwise sparsely vegetated may become minor sources rather than sinks for sediments during windy or overflow conditions, whereas sediments deposited in semipermanent and permanent basins are usually protected from wind erosion by overlying waters.

Where concern focuses on turbidity **within the open water portions** of an individual wetland or lake basin, other indicators are appropriate. Turbidity may be caused by either inorganic (e.g., clay) or organic (e.g., plankton) in the open water area. Turbidity problems are likely to be aggravated if the basin is **tilled or re-ditched** during seasonal dryout periods or drought years; has **steep banks of erodible soil**; is **excessively enriched**; contains **animals that disturb shallow bottom** sediments (e.g., carp, livestock, humans in boats); has recently lost protective shoreline vegetation as a result of overgrazing, burning, or salination; or is **shallow and exposed to strong winds** (Carper and Bachmann 1984). On the other hand, indicators of diminished problems with open water turbidity include **dense vegetative cover** (both submerged aquatics and emergents) close to the path of incoming sediment during the season of greatest sediment runoff (e.g., Dieter 1990); high densities of **filter-feeding zooplankton**; and **high salinity** or specific conductance (approximately greater than 500 μS/cm, Akhurst and Breen 1988). Specific conductance is generally greater in basins in glacial outwash areas than in glacial till (Swanson et al. 1988). Conductance fluctuates greatly from year to year within PPH wetland basins; in-basin sediment deposition rates might be expected to fluctuate accordingly.

POSSIBLE INDICATORS OF VALUES: The values of retaining sediment in wetlands can be indicated by the ecological, commercial, and recreational **importance of the receiving waters relative to those of the retaining wetlands** (Ribaudo 1986), and the **vulnerability** as of receiving waters as judged by factors described above under the discussion of indicators of inputs. All of the PPR states, in their 305b water quality reports, have listed water bodies impacted by nonpoint sediment runoff.

3.5 Phosphorus Retention

DESCRIPTION: Phosphorus **retention** is the process by which phosphorus borne by overland runoff (e.g., sheet flow), incoming surface waters, and perhaps groundwater and precipitation, is held for long periods within the sediments, water column, or biota of a wetland basin. While phosphorus is being retained within a basin, it can be converted from one form to another, e.g., from organic to inorganic form, or from oxidized to reduced form.

DOCUMENTATION OF FUNCTION OCCURRENCE: On a landscape level, PPH wetlands would seem to retain virtually all phosphorus which enters them. This is because most phosphorus is retained by adsorption to surface sediments within wetland basins, or by seasonal incorporation into plant material. In the PPR generally, phosphorus is unlikely to migrate downward into groundwater systems, partly because of adsorptive calcareous soils and alkaline pH values (Hubbard 1988). However, in the eastern PPR, groundwater originating from recharge sites mainly in upland cultivated areas with non-sulfatic soils may contain elevated concentrations of phosphorus (e.g., SDRCWP 1990, Wall et al. 1989). Isolated PPH wetlands become sources rather than sinks for phosphorus only when (a) biological materials from within a basin are dispersed outside the basin by mobile vertebrates, emerging insects, or severe runoff events that connect basins, or (b) phosphorus-bearing sediments and plants are blown from large saline basins during seasonal dryout or drought years.

On a site-specific level (i.e., within wetland basins) phosphorus may be repeatedly reduced and oxidized as influenced by seasonal and annual wetland water levels. The highly productive and diverse biological communities may also cycle the phosphorus rapidly between particulate and dissolved form; between sediments, biota, and water column; and between open water and marsh zones. During severe winters when basins freeze completely to their bottoms, phosphorus in the water column may be forced into the sediments (pers. comm., J. Kadlec, Utah State Univ., Logan). Phosphorus retention has been studied in few PPH basins. An open lake system in South Dakota removed 70, 80, and 100% of the tributary phosphorus input during three successive years (SDRCWP 1990). Two open wetland complexes in North Dakota removed 52 and 85% of the tributary phosphorus, vs. a 200-to-600% increase from two drained wetland complexes (Malcolm 1979).

ASSOCIATED POTENTIAL VALUES: Excess phosphorus causes blooms of algae which potentially impair drinking water quality, biodiversity, and opportunities for swimming and fishing. Fishing is popular throughout the region, yet fish populations in many rivers and lakes are subject to die-offs as a result of oxygen depletions caused by excessive algal growth, which in turn had been stimulated by abnormal enrichment by phosphorus-laden runoff. If wetlands play a measurable role in retaining phosphorus, and if phosphorus is a primary factor limiting the algae which diminish ecological and recreational values of waters used or valued by the public, then wetland loss could further diminish these values and increase the cost to taxpayers of waste treatment plant construction.

On a landscape level, much of the phosphorus in runoff is associated with suspended sediment. Because wetlands (as discussed above) are among the most effective landscape features for mitigating sedimentation problems, they may also intercept much of the associated phosphorus before it reaches larger, more permanent waterbodies. Thus, protection and enhancement of this function in wetlands could help maintain and restore important public uses of downslope lakes and rivers. However, on a site-specific level, retaining phosphorus in wetlands will have both positive and adverse effects on the ecological values of the wetlands themselves. In particular, the competition between algae and vascular wetland plants for phosphorus has complex implications for all trophic levels, and ultimately, overall wetland production and biodiversity. Also, some experienced observers have speculated that apparent declines in emergent plant species richness (and simultaneous increases in dominant stands of cattail) in some PPH wetlands might be the result of increased inputs of nutrients, including phosphorus (see section 4.9). Thus, the potential landscape-level values of some wetlands to effectively treat nonpoint nutrient runoff must be balanced against the likelihood that site-specific (and eventually, landscape) ecological values may compromised. For protecting most surface waters from these problems, the state of North Dakota specifies a criterion of 0.100 mg/l phosphate (Minnesota's is a similar 0.090 mg/l), but recommends a more stringent target value of <0.025 mg/l for lake improvement projects. Minnesota considers waters having <0.040 mg/l phosphorus to be fully supporting of all designated uses.

DOCUMENTATION OF VALUE: Virtually all of the lakes in the PPR are considered hypereutrophic or eutrophic, according to annual 305b water quality reports. While this condition to some degree preceded human settlement, sediment cores indicate it has been aggravated by increasing agricultural and urban runoff (e.g., Allan et al. 1980). In South

Dakota, 26% of the assessed river miles statewide have water quality that is so degraded it does not support any of their designated uses, and 44% show partial support; about 12% are not fishable due to water quality problems. Some 20% of the lakes do not meet their designated uses (SD Dept. Water and Natural Resources 1990). In North Dakota, 25% of the assessed river miles, and 36% of the lake acres, have water quality that is so degraded it does not fully support all of their designated uses (ND Dept. Health and Consolidated Laboratories 1990b).

Public opinion surveys indicate that many PPR citizens (e.g., 90% in survey by Grosz and Leitch 1990) think that wetlands are important for their ability to purify water. Although PPH basins are known to retain phosphorus, no attempts have been made to link quantitative estimates of phosphorus retention rates specifically from wetlands to ecological resources or to actual economic values associated with downslope use.

TEMPORAL EFFECTS: Throughout most of the PPR, runoff inputs to wetland basins are greatest during early spring. Often, this early spring runoff bears the largest portion of phosphorus-bearing sediment that enters wetlands. Much of the sediment phosphorus originates from lands tilled the previous autumn. Comparing two years (or locations) with equal amounts of total annual precipitation, the transport of phosphorus in sediment is likely to be much greater for the year (or location) in which, during the preceding autumn, a major rainstorm was followed by freezing, which then was followed by a snow cover that persisted through the winter and was followed by a warm early spring. Under such conditions, the large spring thaw is likely to mobilize considerable sediment-borne phosphorus. Conversely, springtime sediment runoff may be less during years (or locations) where winters are mild and lack continuous insulating snow cover. In other instances, springtime conditions affect phosphorus inputs to a greater degree than conditions during the preceding autumn or winter. Wetlands may retain a larger portion of the phosphorus borne by spring runoff during years when the runoff occurs later in the season, or during years when summer (vs. early spring) storms contribute a larger portion of the annual phosphorus input to wetlands. That is because as the season progresses, wetland soils thaw and vegetation develops more fully, thus increasing trapping efficiency. Any of the temporal effects just described can overwhelm the effects of spatial characteristics described in the following sections.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape inputs of phosphorus depend partly on characteristic **methods, rates, frequencies, and seasonal timings of fertilizer application**. As shown in the detailed map by Omernik (1976), instream concentrations of phosphorus are greatest in Iowa, and decline in a generally westerly direction within the PPR. At least in Montana, phosphorus is the predominant plant nutrient applied as fertilizer (Bauder et al. 1991). Phosphorus inputs to wetlands from fertilizer can be inferred directly from **fertilizer type** and indirectly by **soil and crop type** (i.e., assuming particular fertilizers are associated with particular soils and crops). Fertilizer input to wetlands also depends on (a) **type of cultivation** and associated specific practices (e.g., conservation tillage, contour plowing, irrigation), (b) soil erodibility, as indicated by **soil type and slope**; (c) **proximity** of treated soils to wetlands, (d) transport mechanisms, as indicated by **precipitation** and **water yield volume** (White 1983) or their surrogates (e.g., **rainfall/snowmelt intensity, watershed shape, soil type**, and **slope**), and (e) width and type of **buffer strips** (vegetated, unfertilized sediment-filtering zones) surrounding wetlands. Use of upstream **artificial drainage** as an indicator of increased phosphorus input may depend on whether drainage is accomplished by ditches or subsurface tiles. Ditches draining PPR wetlands have been reported to have elevated levels of phosphorus (e.g., Malcolm 1979). In contrast, reports of water quality from watersheds drained by subsurface tile suggest lower phosphorus concentrations, at least after several years have passed following installation. This is probably because tile drains increase infiltration and thus reduce transport in overland flow. Landscape inputs of phosphorus may be indicated as well as by indicators of **soil erosion**, as described on page ?. Additional phosphorus enters wetlands from dry deposition (e.g., windborne sediments); groundwater (e.g., SDRCWP 1990); pesticide and road salt runoff; upslope wetlands (especially those with organic substrates) whose water levels have recently been drawn down following a period of stagnated, anoxic conditions in the sediment; and animals (e.g., livestock, waterfowl, sewage).

Capacity for retaining phosphorus is related, on a landscape scale, to the spatial arrangement of wetland complexes relative to contributing land uses. Science has not advanced to the point where it is possible to specify all combinations of wetland spatial position, size, and type that are optimal for retaining phosphorus at a landscape scale, but it may be reasonable to assume that this would be roughly comparable to the pattern that would be optimal for retaining sediments. Again, the **contagion characteristics** of the wetland spatial distribution (e.g., proportion of subregional wetland acreage that is dispersed vs. clumped) are likely to affect both the potential extent of phosphorus **input** to wetlands and wetland **capacity** to retain it. Wetland acreage occurring as scattered complexes rather than as single large wetlands should, by chance alone, be more likely to be located near and downslope from phosphorus sources, providing more opportunities for **input**. At the same time, the larger shoreline-to-area (or smaller depth-to-volume) ratio associated with a more dispersed wetland acreage implies that a larger portion of phosphorus-bearing runoff will enter wetlands via aerobic shoreline zones of dense vegetation and weathered sediments, which have a high **capacity** for taking up and transforming phosphorus.

The **basin water regime** probably influences phosphorus retention. Water regime can be indicated generally by plant species, soil profile, landscape geology, relief, and geographic position. The drier wetland basins, such as temporary and seasonal types, probably have a larger proportion of their basin available for storage and infiltration of spring runoff, with concomitant deposition of suspended sediment and retention of phosphorus. These wetland types are also likely to have more weathered surface horizons, with consequently greater potential for phosphorus adsorption. However, the seasonally fluctuating water levels in temporary and seasonal wetlands may cause a large portion of the phosphorus pool to be biologically available. However, the phosphorus retention capacity in semipermanent and permanent basins is not negligible, because the higher salinity and alkalinity that typify these basins is conducive to precipitating phosphorus from the water column.

B. Site-level (Within-wetland) Indicators of Function

Most of the site-specific indicators described for the functions, Maintenance of Runoff Timing (section 3.2), and Sediment Retention (3.4) are suitable as indicators of phosphorus retention. Again, the **ratio of wetland size to watershed size**, and the **frequency and magnitude of connection to other basins** are important indicators. Where concern focuses on phosphorus transformations **within the open water portions** of an individual wetland or lake basin, other indicators are appropriate. Phosphorus availability may increase if the basin is **tilled or re-ditched** during seasonal dryout periods or drought years, is **shallow and exposed to strong winds** (e.g., Kenney 1985), has **steep banks of erodible soil**, or contains **animals that disturb shallow bottom** sediments (e.g., carp, humans in boats). On the other hand, indicators of diminished capacity for dispersing phosphorus into open water (i.e., longer phosphorus turnover times) include alkaline soils with large calcium content; dense vegetative cover (both submerged aquatics and emergents) close to the path of incoming sediment; and high salinity. In the PPR, saline basins occur mostly in topographically low positions on glacial outwash in western and northern areas, whereas basins with calcitic water quality occur on glacial till in other areas.

POSSIBLE INDICATORS OF VALUES: The values of retaining phosphorus in wetlands can be indicated by the ecological, commercial, and recreational **importance of the receiving waters relative to those of the retaining wetland**, and their **vulnerability** as judged by factors described above under the discussion of indicators of inputs. All of the PPR states, in their 305b water quality reports, have listed water bodies impacted by nonpoint fertilizer runoff.

3.6 Nitrogen Removal

DESCRIPTION: Nitrogen removal is the process by which dissolved nitrogen (a) disappears from the immediate landscape as a result of being converted to gaseous forms, or (b) is retained for long periods within the sediments, water column, or biota of a wetland basin. While nitrogen is being retained within a basin, it can be converted from one form to another, e.g., from organic to inorganic.

DOCUMENTATION OF FUNCTION OCCURRENCE: On <u>landscape and regional levels</u>, PPH wetlands would seem to retain or remove much of the nitrogen which enters them. As with phosphorus, this is due mainly to the physically closed nature of individual pothole basins with regard to surface water flow. Unlike phosphorus, which to some degree accumulates over time in such basins, nitrogen can be removed permanently from a basin. This happens mainly as a result of denitrification, a biologically-mediated process which converts nitrate to nitrogen gases. To a perhaps lesser extent, nitrogen may be lost from PPH wetlands by a process known as ammonia volatilization (e.g., Murphy and Brownlee 1981).

In one study in South Dakota, between one-third and one-half of the total nitrogen applied as fertilizer was removed from the landscape by denitrification (SDRCWP 1990). In semipermanent basin wetlands specifically, Davis and van der Valk (1978) in Iowa reported 86% removal of the inputted nitrate and 78% of the ammonia. An open lake system in South Dakota removed 44, 46, and 100% of the tributary nitrogen input during three successive years; this was less than the proportion of phosphorus removed (SDRCWP 1990). Two open wetland complexes in North Dakota removed 13 and 58% of the tributary nitrate, vs. a >10-fold increase from a drained wetland complex (Malcolm 1979). An unvegetated wet basin in South Dakota that was loaded with municipal wastewater removed 1765 kg N/ha (White and Dornbush 1988). On a regional basis, Jones et al. (1976) in northwestern Iowa found that of 34 watersheds, those with a larger percentage of land as wetlands had less nitrate in streamflow. Nitrogen can be removed temporarily from surface waters by being buried below the root zone in rapidly accreting sediments or by adsorption of ammonium nitrogen to clays (e.g., Martin and Hartman 1987a).

Isolated PPH wetlands become sources rather than sinks for nitrate only when (a) biological materials from within a basin are dispersed outside the basin by mobile vertebrates, emerging insects, or severe runoff events that connect basins, (b) nitrogen-bearing sediments and plants are blown out of a wetland basin during seasonal dryout or drought years, or (c) denitrification rates are so low that nitrate accumulates and leaches into groundwater systems or laterally into subsurface flow, which may carry it into nearby wetlands.

On a <u>site-specific level</u> (within wetland basins), nitrogen may be repeatedly reduced and oxidized from ammonium to nitrate forms, with consequences for aquatic community structure. The potential for this to happen can be indicated by fluctuations in seasonal and annual wetland water levels, which in turn may be evidenced by soils with strong argillic horizons (Hubbard 1988).

ASSOCIATED POTENTIAL VALUES: On <u>landscape and regional levels</u>, because wetlands are among the most effective landscape features for denitrification (Groffman and Tiedje 1989) and are often located so as to intercept most runoff and groundwater, they also intercept much of the associated nitrate before it reaches larger, more permanent waterbodies. Thus, protection and enhancement of nitrogen removal functions of wetlands could help maintain and restore important public uses of downslope lakes, rivers, and aquifers. Fishing is very popular throughout the region, yet fish populations in many rivers and lakes are subject to die-offs as a result of oxygen depletions caused by excessive algal growth, which in turn had been stimulated by abnormal enrichment by nutrient-laden runoff. In surface waters of less than 3000 μmhos conductance (Barica 1978), algal blooms occur where there is excess nitrate (e.g., Moore and Haertel 1975). Perhaps of even greater public concern, nitrate in glacial outwash areas can readily infiltrate into groundwater and impair the quality of groundwater withdrawn for drinking. If wetlands play a measurable role in removing nitrate from ground or surface waters used or valued by the public, then wetland loss could increase the cost to taxpayers of measures to remediate contaminated groundwater or treat contaminated surface waters.

On a site-specific level, retaining nitrogen could have both adverse and positive effects on the ecological values of the wetlands themselves. In particular, the competition between algae and vascular wetland plants for nitrogen, while perhaps less important than competition for phosphorus, nonetheless has complex implications for all trophic levels, and ultimately, overall wetland production and biodiversity. Selective removal of nitrate by wetlands might trigger increased growths of blue-green algae that may be less useful to typical PPH food webs (cf. Barica et al. 1980). Also, some experienced observers have speculated that apparent declines in emergent plant species richness (and simultaneous increases in dominant stands of cattail) in some PPH wetlands might be the result of increased inputs of nutrients, including nitrogen (see section 4.9). Thus, the potential landscape-level values of some wetlands to effectively treat nonpoint nutrient runoff must be balanced against the likelihood that site-specific (and eventually, landscape) ecological values may compromised.

DOCUMENTATION OF VALUE: Public opinion surveys indicate that many PPR citizens (e.g., 90% in survey by Grosz and Leitch 1990) think that wetlands are important for their ability to purify water. If wetlands are indeed effective for removing nitrate, then the currently degraded water quality in parts of the PPR where wetland losses have been greatest (e.g., Iowa) can be blamed at least partly on these past losses. In **South Dakota**, 26% of the assessed river miles statewide have water quality that is so degraded it does not support any of their designated uses, and 44% show partial support; about 12% are not fishable due to water quality problems. Some 20% of the lakes do not meet their designated uses (SD Dept. Water and Natural Resources 1990). In **North Dakota**, 25% of the assessed river miles, and 36% of the lake acres, have water quality that is so degraded it does not fully support all of their designated uses.

Groundwater contamination by nitrate has also been widely documented. Wells having severe (>10 mg/l) levels of nitrate contamination comprise 17% of those in Montana PPR counties, 6% of those in Iowa PPR counties, and 2% of those in South Dakota counties. In one area of South Dakota (Oakwood-Poinsett watershed), 37% of the domestic wells exceeded 10 mg/l (SDRCWP 1990), a level hazardous to humans. In one area of the Minnesota PPR, 10 of 15 sampled wells exceeded the level (Wall et al. 1989). Groundwater with nitrate levels great enough to potentially produce adverse ecological effects in wetlands occurred in 38% of the South Dakota PPR counties (compiled from DeMartino and Jarrett 1991).

Wetlands remaining in the most contaminated areas, as well as in areas where groundwater is particularly vulnerable to contamination due to hydrogeologic conditions, are especially valuable to society because whatever nitrate they can remove reduces the severity of the local problem and its potential threat. Similarly, wetland restoration efforts whose primary objectives are nonpoint source management and drinking water protection might target such areas. All of the PPR states have mapped areas of groundwater vulnerability and/or groundwater contamination from nitrate over at least a portion of the state.

Although PPH basins are known to remove nitrogen, no attempts have been made to link quantitative estimates of denitrification rates specifically in wetlands to economic values of maintaining fishing opportunities and groundwater quality in surrounding areas.

TEMPORAL EFFECTS: Throughout most of the PPR, landscape inputs to wetland basins of nitrate (e.g., from fertilizer and livestock) are often greatest during early spring. Although wetland plants take up and store considerable nitrate at this time, they store most of it only temporarily. In contrast, denitrification results in permanent losses of nitrogen, and denitrification rates may be equal or greater at the beginning and end of the growing season than during mid-summer (Christensen 1985, Myrold 1988, SDRCWP 1990, Zak and Grigal 1991). Thus, denitrification functions in wetlands may be of greatest value in removing nitrate during years when runoff inputs occur early or late in the growing season. However, if runoff resulting from the spring melting of snow surrounding wetlands occurs prior to ice-out in wetlands, it flows under the ice, purging basins of anoxic, ammonia-rich water which can subsequently be released into receiving waters (if seasonal connections exist) without being substantially denitrified, thus causing water quality problems (ND Dept. Health and Consolidated Laboratories 1990b). This adverse impact may be more likely to occur in landscapes dominated by semipermanent and permanent basins, because they tend to remain frozen longer into the spring.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

PPH wetlands are focal points for nitrate accumulation. Regional and landscape inputs of nitrogen depend partly on characteristic **amounts, methods, rates, frequencies, and seasonal timings of fertilizer application**. This can be inferred directly from **fertilizer type** and indirectly by **soil and crop type** (i.e., assuming particular fertilizers are associated with particular soils and crops). Fertilizer input to wetlands also depends on (a) soil leaching potential, as indicated by **soil type, crop type, and crop management practices** (e.g., summer fallowing, irrigation, conservation tillage, contour plowing); (b) transport mechanisms, as indicated by **precipitation** and **water yield** or their surrogates (e.g., **rainfall/snowmelt intensity, watershed shape, soil type, and slope**), (c) **proximity** of treated soils to wetlands and connecting subsurface flow zones, and (d) width and type of **buffer strips** (vegetated, unfertilized, filtering zones) surrounding wetlands. As shown in the detailed map by Omernik (1977), instream concentrations of nitrate are greatest in Iowa, and decline in a generally westerly direction within the PPR. Most streams east of the Missouri Coteau exceed 1 mg/l nitrate on a mean annual basis. With regard to groundwater, the incidence of both actual and potential nitrate contamination is greatest in eastern South Dakota, Iowa, and southwestern Minnesota (Nielsen and Lee 1987).

The extent of **artificial drainage** upstream may also be a useful indicator of increased transport and nitrogen input. In other regions with flat terrain drained by agricultural ditches, watersheds which had less than 7% remaining wetland cover (Chescheir et al. 1987), were appreciably less effective for removing nitrate than were watersheds with more extensive wetlands (Bedient et al. 1976). Nitrate also enters wetlands via **groundwater discharging from contaminated aquifers** (e.g., many semipermanent and permanent basins in the eastern and southern PPR); from **atmospheric deposition** (e.g., White 1983); from **nitrogen fixation** processes of the cyanobacteria that dominate many PPH basins (e.g., Barica et al. 1980, Brownlee and Murphy 1983); and from **animals** (e.g., livestock, waterfowl, sewage). In fact, livestock feedlots (and perhaps also spills from fertilizer storage tanks) may be a more frequent cause of severe (>10 mg/l nitrate) groundwater contamination than is routine fertilizer application (Kross et al. 1990, SDRCWP 1990, Meyer 1985).

Capacity for removing nitrate is partly related to regional-scale factors. Denitrification is probably hindered somewhat in the eastern PPR because soils of most wetlands there are relatively sulfur-poor; this deficit exacerbates competition among microbes for available carbon, thus reducing denitrification rates (pers. comm., J. Richardson, North Dakota St. Univ., Fargo). Except where irrigated and underlain by sandy soils, wetlands in the **western part of the PPR** would be expected to play a larger role in preventing groundwater contamination because they are both good sites for denitrification and tend to be areas of groundwater recharge.

Capacity for removing nitrate is also related to landscape-scale factors, particularly the spatial arrangement of wetland complexes relative to contributing land uses and associated contaminated aquifers. Science has not advanced to the point where it is possible to specify all combinations of wetland spatial position, size, and type that are optimal for removing nitrate at a landscape scale. Nonetheless, the **contagion characteristics** of the wetland spatial distribution (e.g., proportion of subregional wetland acreage that is dispersed vs. clumped) are likely to affect both the potential extent of nitrate input to wetlands and wetland capacity to remove it. Wetland acreage occurring as scattered complexes rather than as single large wetlands should, by chance alone, be more likely to be located near and downslope from nitrate sources. Finally, the larger shoreline-to-area (or smaller depth-to-volume) ratio associated with a more dispersed wetland acreage implies that a larger portion of nitrate-bearing runoff will enter wetlands via shoreline zones which support high rates of denitrification due to their characteristic soils, fluctuating water levels, and high density of plants.

B. Site-level (Within-wetland) Indicators of Function

Most of the site-specific indicators described for the functions, Maintenance of Runoff Timing (section 3.2), and Sediment Retention (section 3.4) are suitable as indicators of nitrate removal. Thus, the **frequency and magnitude of connection to other basins** and the **ratio of wetland size to watershed (or groundwater source) size**, are important indicators.

Volumetric **soil moisture**, as inferred from **wetland water regime** also is perhaps the most important indicator of denitrification capacity (Groffman and Tiedje 1989). Measurements of denitrification in a South Dakota wetland soil indicated that conditions of less than 22% volumetric soil moisture completely inhibit denitrification (Lemme 1988). A wetland does not have to be exposed to runoff for very long to reach these moisture levels and remove nitrate. In fact, studies of an emergent wetland by Lindau et al. (in press) showed that under loading rates typical of the PPR, denitrification begins within a day of when nitrogen enters a wetland, and reaches a peak at 7 days. Yet some citizens may not consider areas saturated for so brief a time to really be wetlands.

Other factors associated with wetland water regime can be used to infer relative capacity for denitrification. First, **water table levels fluctuate** the most in temporary and seasonal wetland basins, partly as a result of both diurnal and seasonal evapotranspiration. Such fluctuations, from saturated to drained condition, are associated with switches in sediments between anoxic (anaerobic, or reduced) and oxic (aerobic, or oxidized) conditions. Fluctuating water levels might be expected to enhance denitrification so long as (a) anaerobic conditions still occur, (b) moisture levels in the upper soil layers are not too severely depleted (i.e., pore space is 30-60% water-filled; Linn and Doran 1984, Lemme 1988), (c) carbon supplies also are not limiting, and (d) salinity conditions are not extreme. Second, **soil temperature** might be expected to be warmer in temporary and seasonal wetlands during much of the year, due to their shallow depths. Third, denitrification can be hindered in wetlands lacking **sulfatic soils** (e.g., western parts of the PPR), as sulfate reduction processes compete for available carbon. This happens to a much lesser degree in temporary and seasonal wetlands than in semipermanent wetlands (pers. comm., J. Richardson, North Dakota St. Univ., Fargo).

Thus, on the basis of seasonal hydrologic fluctuations, warmer temperature, and diminished sulfate reduction processes, **temporary and seasonal** wetlands might be more capable of removing nitrate from surface runoff than are semipermanent and permanent basins. As noted by Kantrud et al. (1989), "It would seem that temporary and seasonally flooded wetlands would be especially efficient in removal of excess nitrogen."

However, other logic suggests that **semipermanent and permanent** wetlands might be more effective than temporary and seasonal wetlands for removing nitrate. Because semipermanent and permanent wetlands are usually groundwater discharge or flow-through systems, they are less susceptible to drought, and by definition, remain saturated and thus favorable to denitrification for longer periods. Prolonged drought in temporary wetlands not only results in moisture deficits inhospitible to denitrifying microbes, but also can result in diminuation (via mineralization) of organic matter essential for sustaining denitrifiers. Organic matter content of soils in semipermanent and permanent wetlands generally seems to be greater than in temporary and seasonal wetlands (however, Loken (1991) reported less organic matter in soils of semipermanent groundwater discharge wetlands; he attributed this to the inhibiting of production by the high salinity of these basins). Also, once nitrate has contaminated groundwaters, the permanent and semipermanent wetlands -- which, often being groundwater discharge or flow-through systems, are in direct contact with the contamination for a longer portion of the year -- may be expected to play a relatively larger role in removing nitrate.

In summary, it is probable (but generally undocumented) that in areas of sulfatic soils of the eastern PPR, semipermanent wetlands have a greater capacity to remove nitrogen than do temporary/seasonal wetlands, whereas in the western PPR or in areas with sandy soils or rapid infiltration, all wetland water regimes are about equally capable of removing nitrogen (pers.

comm., J. Richardson, North Dakota St. Univ., Fargo). Overall, wetlands in the western part of the PPR would be expected to play a larger role than eastern PPR wetlands in preventing groundwater contamination, because they tend to be areas of groundwater recharge.

Soil fertility is also an indicator of denitrification potential. Nitrogen removal by wetlands is typically greatest where soils are **especially fertile** (moderately alkaline clays with adequate organic matter) and have **large water-holding capacity** (i.e., saturated for long duration). Microbial biomass in North Dakota soils can be greater in areas underlain by siltstone than in areas underlain by sandstone or shale parent material (Schimel et al. 1985). Tillage and fertilization of soils over time also might increase the suitability of remaining soil carbon as an energy source for denitrifying microbes (Groffman et al. 1991). As a result, denitrification rates may be greater in wetlands that have been exposed to nutrient runoff than in relatively pristine wetlands (pers. comm., J. Kadlec, Utah State Univ., Logan).

The **percent cover or root biomass of rooted plants** (as possibly inferred from plant species or community type) is another possible indicator of denitrification capacity. Although some rooted plants are capable of "pumping" nitrates from the sediment into aboveground tissues and eventually into the water column, wetland plants also enhance denitrification by (a) enhancing the availability of carbon (e.g., from litterfall), (b) speeding the diffusion of oxygen (via roots) into otherwise anaerobic subsurface zones, especially during mid-growing season, and (c) increasing diurnal and seasonal fluctuations in the water table, and consequently the oxidation status, as a result of evapotranspiration. Denitrification may be greatest where soil organic matter reaches a maximum just below the soil surface, but above the depth limit of the root zone (Parkin and Meisinger 1989). In this zone, impeded lateral flow increases the time available for nitrate loads to interact with prolific microbial populations present in the surrounding root masses. A minor amount of denitrification can occur within shallow aquifers, depending on the amount of oxidizable organic matter that has infiltrated (Hiscock et al. 1991); this could in turn be greatly enhanced by recharge from carbon-producing temporary wetlands (e.g., Trudell et al. 1986). Although the effects of different native wetland communities on denitrification have not been determined in the PPR, limited studies elsewhere have found greater denitrification in grassy buffer strips than in forested wetlands (Groffman et al. 1991) and more denitrification in soils cropped with oat/clover cover than in those with corn (Fraser et al. 1988).

Indicators such as basin hydrologic type and soil organic matter can be manifested on a regional level as well. That is, because these indicators correlate roughly with geologic and climate patterns within the region, in a general sense within-region spatial trends in denitrification might exist. For example, the occurrence of anaerobic conditions and fluctuating water levels might be greater in subregions where the wetland resource, due partly to geologic conditions, is comprised of proportionately more small, temporary, densely-vegetated wetlands with anoxic, under-ice conditions in winter.

POSSIBLE INDICATORS OF VALUES: The values of removing nitrate from the landscape can be indicated by the ecological, domestic, and recreational **importance of the aquifers and**

receiving waters relative to those of the wetland, and their vulnerability as judged by factors described above under the discussion of indicators of inputs.

3.7 Detoxification

DESCRIPTION: For purposes of this report, detoxification is the process by which xenobiotic contaminants, including synthetic hydrocarbons and atypical concentrations of heavy metals, are converted from forms toxic to plants or animals to forms that are relatively harmless.

DOCUMENTATION OF FUNCTION OCCURRENCE: On a landscape level, PPH wetlands would seem to retain much of the contaminant load that enters them, due largely to the physically closed nature of individual pothole basins with regard to surface water flow. However, studies of detoxification functions of PPH wetlands are lacking. Circumstantially, occurrence of natural detoxification processes might be inferred from the data of Martin and Hartman (1985). Their analyses of sediment and/or fish in five PPH basins found no evidence of toxic concentrations of PCBs or organochlorine pesticides, despite expected exposure. Isolated PPH wetlands become sources rather than sinks for contaminants only when (a) contaminants are highly soluble and infiltrate into underlying groundwater systems before they can be naturally detoxified, (b) contaminants from within a basin are dispersed outside the basin by mobile vertebrates or emerging insects, or (c) sediment-adsorbed contaminants are blown out of a wetland basin during seasonal dryout or drought years.

On a site-specific level (i.e., within wetland basins) contaminants may be transformed to less harmful substances by physicochemical processes or microbial communities. The former generally results only in deactivation of pesticides, while the latter results in actual degradation (Rao et al. 1983). Among various ecosystems, wetlands frequently have the largest year-round microbial densities (e.g., Henebry et al. 1981). In being detoxified, contaminants may be repeatedly reduced and oxidized (depending on seasonal and annual wetland water levels). Contaminants also may be cycled rapidly between sediments, biota, and water column (as well as between open water and marsh zones) by the highly productive and diverse biological communities. Detoxification mechanisms have generally not been studied in PPH basins. Although the theoretical occurrence of this function in PPH wetlands is inarguable, its mechanisms and extent are generally unknown in the PPR.

ASSOCIATED POTENTIAL VALUES: Contaminants impair potability of both groundwater and surface water, as well as having adverse ecological effects. Thus, contamination increases the cost to taxpayers of waste treatment plant construction and other remedial measures. On a landscape level, because wetlands are possibly among the most effective landscape features for retention and detoxification, and are generally located so as to intercept most runoff and contaminated groundwater, they may also intercept much of the contaminant load before it reaches larger, more permanent waterbodies. Thus, protection and enhancement of contaminant removal functions of wetlands could help maintain and restore important public uses of downslope lakes and rivers. However, on a site-specific level, retaining contaminants could impair the ecological functions and values of the wetlands themselves. Long hydraulic detention rates in PPH wetlands could lead to severe problems with direct toxicity (e.g., Grue et al. 1986) or bioaccumulation as has been documented in wetlands elsewhere. Thus, the potential landscape-level values of some wetlands to effectively treat contaminated runoff must be balanced against the likelihood that site-specific (and eventually, landscape) ecological values may compromised.

DOCUMENTATION OF VALUE: Pesticides, rather than heavy metals or chemicals related to mineral extraction or industrial processing, appear to be the primary contaminant within the PPR. Pesticides have not only entered PPH wetlands extensively, but have also contaminated groundwater in a few parts of the PPR (e.g., Kross et al. 1990, Moody et al. 1988). However, most parts of the region have yet to detect a problem (ND Dept. Health and Consolidated Laboratories 1990a). In some cases this may simply be because contamination plumes of more persistent contaminants have not yet had time to migrate downward into drinking water supplies, while in other cases such migration may never occur due to the nature of the pesticide and the detoxification capacity of the landscape (particularly its wetland component).

Certain trace metals appear to occur naturally within the PPR at levels potentially toxic to some aquatic life, and a few instances have been recorded of PPH wetlands being contaminated by metals associated with inputs specifically from drainage waters. At the Milk River Reclamation Project near Bowdoin National Wildlife Refuge, Montana, potholes were contaminated by arsenic, boron, selenium, and zinc (Willard et al. 1988). Also, sediment sampling in just five PPH basins by Martin and Hartman (1984) found that levels of arsenic, cadmium, lead, and selenium were higher than in riverine wetlands nearby, but were within normal or background ranges. Acidic deposition, which has been documented to occur at least in North Dakota (Smith 1988), could compound such problems in some types of PPH wetlands, as well as posing a direct threat to their productivity. Its extent of occurrence in the PPR is unknown. Temporary, recharge wetlands are likely to be most vulnerable. In western parts of the PPR, their water budget is dominated by direct snowmelt whose acidity has had less opportunity to be diminished by movement across or within upland soils.

Wetlands remaining in the most contaminated areas, as well as in areas where groundwater is particularly vulnerable to contamination due to hydrogeologic conditions, are especially likely to be valued by society. That is because their ability to remove any amount of contamination reduces the severity of the local problem and its potential threat to downslope areas. Similarly, wetland restoration efforts whose primary objectives are drinking water protection may target such areas. All of the PPR states have mapped areas of groundwater vulnerability over at least a portion of the state.

Although PPH basins can be assumed to detoxify some of the contaminant load, no attempts have been made to link quantitative estimates of detoxification rates specifically in wetlands to economic values of maintaining groundwater quality and ecological values in surrounding areas. Public opinion surveys indicate that many PPR citizens (e.g., 90% in survey by Grosz and Leitch 1990) think that wetlands are important for wetlands for their ability to purify water.

TEMPORAL EFFECTS: Rainfall volume (Haith 1986) or irrigation volume (Kolberg et al. 1990) and timing relative to timing of pesticide application (Isensee et al. 1990) are critically important to leaching and runoff of pesticides. Throughout most of the PPR, landscape inputs to wetland basins of pesticides are greatest during early spring and summer (Grue et al. 1988). This is often when microbial activity and associated detoxification processes are greatest (Myrold 1988). Thus, detoxification processes in wetlands may be slightly more effective during years when runoff input or pesticide spraying occurs later in the season, or during years when summer (vs. early spring) storms contribute a larger portion of the pesticide input to wetlands.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape inputs of pesticides (the major PPR contaminant) to wetlands depend on characteristic **methods, rates, frequencies, and seasonal timings of pesticide application**, as well as the pesticide's physicochemical **mobility** (e.g., transported by sediment vs. rapidly infiltrates vs. remains airborne), **persistence**, and **bioaccumulation potentials**. These can be inferred directly from **pesticide type** and indirectly by **crop type** (i.e., assuming particular pesticides are associated with particular crops). Pesticide input to wetlands and groundwater also depends (a) on **position and proximity** of wetlands relative to pesticide sources; (b) on soil leaching potential, as indicated by **soil type** (e.g., particle size and organic content), **crop type**, and **crop management practices** (e.g., irrigation, conservation tillage, contour plowing); **depth and type of subsurface geologic materials and formations** (e.g., their permeability and hydraulic conductivity, with glacial outwash areas often having more well contamination than glacial till areas; see SDRCWP 1990), (c) on width and type of **buffer strips** (vegetated, unsprayed, filtering zones) surrounding wetlands, and (d) on transport mechanisms, as indicated by timing and amount of **precipitation** and **water yield** or their surrogates (e.g., **rainfall/snowmelt intensity, watershed shape, soil type, and slope**). Transport of insecticides is also indicated by **wind direction and velocity relative the spatial positions of crop acreage and wetlands** at the time of spraying. The extent of **artificial drainage** upstream may not be a useful indicator of increased pesticide input. Some studies suggest that subsurface tile drains, at least, reduce downslope pesticide concentrations by increasing infiltration and thus reducing transport in overland flow (Southwick et al. 1990, VanScoyoc and Kladivko 1989). Within the PPR, the incidence of both actual and potential pesticide contamination of groundwater is greatest in eastern South Dakota, Iowa, and southwestern Minnesota (Nielsen and Lee 1987).

Capacity for removing contaminants is related, on a landscape scale, to the spatial arrangement of wetland complexes relative to contributing land uses and associated contaminated aquifers. Science has not advanced to the point where it is possible to specify all combinations of wetland spatial position, size, and type that are optimal for detoxifying various types of contaminants at a landscape scale. Nonetheless, the **contagion characteristics** of the wetland spatial distribution (e.g., proportion of subregional wetland acreage that is dispersed vs. clumped) are likely to affect both the potential extent of contaminant input to wetlands and wetland capacity to detoxify it. Wetland acreage occurring as scattered complexes rather than as single large wetlands should, by chance alone, be more likely to be located near and downslope from contaminant sources. Moreover, the larger shoreline-to-area (or smaller depth-to-volume) ratio associated with a more dispersed wetland acreage implies that a larger portion of contaminant-loaded runoff will enter wetlands via shoreline zones of dense vegetation, where much of the plant uptake, fluctuating sediment oxygen conditions, and microbial activity associated with detoxification processes is likely to occur.

B. Site-level (Within-wetland) Indicators of Function

Most of the site-specific indicators described for the functions, Maintenance of Runoff Timing (section 3.2), and Sediment Retention (section 3.4) are suitable as indicators of detoxification capacity. Thus, the **ratio of wetland size to watershed (or groundwater source) size**, and the **frequency and magnitude of connection to other basins** are important determinants. Wetland **soil type** is also a possible indicator of detoxification potential. Microbial density, and thus detoxification capacity, is typically greatest in wetlands with sediments that are **fertile** (or enriched by manure fertilizers) and **highly organic** (however, in the case of mercury contamination, this characteristic may be detrimental, as it can increase the bioavailability of mercury; Jackson 1986). Also, sediments with a high **cation exchange capacity** are often capable of immobilizing many contaminants. Similarly, basins whose water quality is highly **alkaline or saline** might be more capable of chemically adsorbing, degrading, and/or immobilizing many contaminants (e.g., Cairns and Dickson 1977, Wayland and Boag 1990). However, microbial degradation processes may be less effective at extreme salinities. In the PPR, saline basins occur mostly in topographically low positions on glacial outwash in western and northern areas.

The **percent cover or root biomass of fibrous-rooted plants** (as possibly inferred by plant species, community type, and management history) is another possible indicator of detoxification capacity. Some scientists have speculated that some rooted plants facilitate contamination of groundwater by creating pore spaces in soils through which contaminants are rapidly carried by infiltrating runoff. Also, some evidence suggests that wetland plants can mobilize contaminants (particularly metals) from the soil by taking them up via roots and translocating ("pumping") them into aboveground tissues. On the other hand, wetland plants enhance microbial activity associated with detoxification, due to increasing the (a) availability of carbon (e.g., from litterfall), and (b) diffusion of oxygen (via roots) into otherwise anaerobic subsurface zones. In summary, it is likely that the capacity for detoxifying pesticides may be greatest where soil organic matter reaches a maximum just below the soil surface, but above the depth limit of the root zone. In situations where lateral flow in this zone is impeded, the time available for pesticide loads to interact with prolific microbial populations present in the surrounding root masses is increased, thus maximizing the detoxification process.

Wetland water regime also is likely to influence or at least indicate detoxification capacity. Water regime can be indicated generally by plant species, soil profile, landscape geology, relief, and geographic position. PPH basins, especially the temporary and seasonal ones, experience great diurnal and seasonal **fluctuations in water level** partly as a result of evapotranspiration.

Such fluctuations, from saturated to drained condition, are associated with switches in sediments between anoxic (anaerobic, or reduced) and oxic (aerobic, or oxidized) conditions. Severe diurnal and seasonal changes occur in water column acidity (pH) as well, as a result of intense photosynthetic activity of algae. Such changes in pH and oxidation status can be expected to mobilize many contaminants (e.g., some heavy metals) and perhaps speed the degradation of others.

Thus, detoxification capacity might be greatest in the permanent and semipermanent wetlands. In temporary and seasonal wetlands, prolonged drought is more likely to cause mineralization of the organic matter essential for sustaining detoxifying microbes. Thus, soils in these basin types would seem to be generally lower in organic content, and higher in alkalinity, than soils in semipermanent and permanent basins. However, as noted earlier, Loken (1991) reported more organic matter in soils of temporary wetlands; he attributed this to the inhibiting of production in semipermanent wetlands by high salinity). Also, if contaminants have reached groundwater, the permanent and semipermanent wetlands -- which, as groundwater discharge or flow-through systems, are in direct contact with the contamination for a longer portion of the year -- might be expected to play a relatively larger role in removal processes.

POSSIBLE INDICATORS OF VALUES: The values of removing pesticides from the landscape can be indicated by the ecological, domestic, and recreational **importance of the aquifers and receiving waters relative to those of the retaining wetland**, and their **vulnerability** as judged by factors described above under the discussion of indicators of inputs. Many of the PPR states, in their 305b water quality reports or other reports, have documented the locations and extent of contamination problems in groundwater used for drinking, as has the USGS (e.g., Moody et al. 1988). The US Fish and Wildlife Service monitors contaminants at many National Wildlife Refuges and other areas. States also have listed water bodies impacted by nonpoint chemical runoff, and in some states, a subset of these water bodies has been assigned highest priority, based on a variety of social and technical factors.

3.8 Vascular Plant Production and Carbon Cycling

DESCRIPTION: Wetland plants in the PPR produce large quantities of carbon as they grow. Carbon production per unit area is particularly great among emergent vascular plants, and to a lesser extent among woody and aquatic bed species. Rates of decomposition (decay) are also relatively great in most types of PPR wetlands.

DOCUMENTATION OF FUNCTION OCCURRENCE: Although sometimes less productive than fertilizer-subsidized crops and domesticated forages, the yields of plants in PPH basins are commonly at least twice those of upland native plants, and in some cases can provide up to four times the amount of forage or hay as adjacent uplands (Fulton et al. 1986).

On a landscape level, PPH wetlands would seem to retain much of the carbon that is produced within each basin, due largely to the physically closed nature of individual pothole basins with regard to surface water flow. Isolated PPH wetlands become sources rather than sinks for carbon only when (a) carbon is decomposed into its dissolved organic forms and infiltrates into underlying groundwater systems before it can be converted to particulate matter or gas, (b) carbon (e.g., ingested plant or invertebrate material) from within a basin is dispersed outside the basin by mobile vertebrates or emerging insects, (c) particulate carbon is blown out of a wetland basin during seasonal dryout or drought years, or (d) may be gassified (e.g., to methane or carbon dioxide). On a site-specific level (i.e., within wetland basins) microbial communities, invertebrates, and physicochemical processes cause routine shifts among the physical and chemical forms of carbon. Among various ecosystems, wetlands frequently have the largest year-round microbial communities (e.g., Henebry et al. 1981), and these help cycle carbon rapidly among particulate and dissolved forms.

ASSOCIATED POTENTIAL VALUES: The sustained high primary and secondary production in PPH wetlands is largely due to the capacity of PPH basins to physically retain carbon, especially under climatic conditions that facilitate its rapid cycling. On a landscape level, because PPH wetlands are highly productive, they can energetically subsidize wildlife populations and biodiversity over a wide region. On a site-specific level, vascular plant production in wetlands not only supports within-basin fish and wildlife recreational values, but also can support economically important cultivation, livestock grazing, and harvesting of hay and baitfish (e.g., Carlson and Berry 1990). Moreover, the production of vascular plants and associated carbon contributes to many other wetland functions, such as sediment retention (section 3.4), denitrification (section 3.6), and detoxification (3.7). However, in some basins, the decomposition of carbon reserves (e.g., vascular plants) under snow-covered winter ice can deplete dissolved oxygen, kill fish and some invertebrates, and ultimately affect fish and wildlife values both within the wetland basin and, in some instances, in waters farther downslope.

DOCUMENTATION OF VALUE: The wildlife values supported by vascular plant production are documented in section 3.8. Although the extent of agricultural activities in the PPR is known on a county basis, the percentage of these activities occurring specifically in wetlands cannot easily be determined. Only a few attempts have been made to link quantitative estimates of plant production in PPH wetlands to economic values of hay, baitfish, and other harvestable resources (e.g., Ogaard 1981).

TEMPORAL EFFECTS: Vascular plant production within individual basins will be greater during years that are relatively wet and have temperatures that support an extended growing season. However, an exceptionally wet year or an extended series of wet years can drown emergent plants and cause many basins to become dominated by submerged aquatic species, which generally are less productive than emergents. Total annual shoot production can change 18-fold as a PPH wetland passes through various successional stages (van der Valk and Davis 1981). Cycling of carbon (via decomposition and re-use) might be greater during years with mild winters and adequate soil moisture.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape <u>inputs</u> of carbon to PPH basins are probably minor compared to carbon fixed within each basin by photosynthesis. Some carbon enters wetland basins from **animals** (e.g., livestock, waterfowl); **groundwater** (primarily dissolved organic matter); **atmospheric deposition**; and **runoff**, particularly where permanent or intermittently exposed wetlands located upslope have been **drained**. Vascular plant production is also sustained by landscape inputs in the form of seeds carried among wetlands by animals or wind. In the PPR, the <u>capacity</u> for supporting vascular plant production or cycling carbon has not been demonstrated to be related to processes occurring at a landscape scale.

B. Site-level (Within-wetland) Indicators of Function

The **percent cover and diversity of rooted plants** is a fairly direct indicator of production. Monotypic stands, despite their sometimes great percent cover, are often relatively stagnant with regard to annual production. In contrast, mixed-species stands interspersed with small patches of open water often are highly productive. The role of epiphytic algae in contributing to overall primary production also increases with increasing proportion of moderately deep (0.5-2 m) open water. Submerged aquatic plants, which also flourish in more open areas, especially when fish are removed from a basin (Hanson and Butler 1990), are often less productive than emergent species. **Wetland water regime** (or less direct surrogates of wetland water regime such as plant species, soil profile, landscape geology, relief, and geographic position) sometimes can indicate vascular plant production. In general, vascular plant production increases across a gradient of increasing moisture, from temporary to semipermanent wetlands (Fulton et al. 1986), at least until limited by salinity, buildup of organic matter, and associated hydrogen sulfide (van Mensvoort et al. 1985); or by excessive water depth (i.e., light penetration). In the 42 PPH wetlands examined by Loken (1991), less vegetation occurred in semipermanent (groundwater discharge) than in temporary or seasonal (groundwater recharge, or flowthrough) basins. Basins whose water levels remain relatively constant for more than a year or two may experience diminished production (Hubbard 1988b), as may wetlands exposed to years of sustained drought. Production depends not only on basin type, but the **successional status** of the plant community, e.g., number of years elapsed since severe drought (van der Valk and Davis 1991). Although most PPH basins are highly eutrophic, and thus not usually nutrient limited, wetland **soil type** may indicate somewhat the potential for vascular plant production. Elevated production capacity may be indicated by the presence of fertile soils that are **moderately organic and not highly acidic**. Nitrogen in particular limits the production of some key wetland plants in the PPR (Neill 1990).

POSSIBLE INDICATORS OF VALUES: The value of forage provided by PPH wetlands to livestock increases in proportion to the temporal and spatial severity of drought occurring during a particular year. The value of plant production also can be indicated by the ecological, commercial, and recreational importance of the wetland **basins** in which the production occurs, and their **position and proximity** relative to ecological, domestic, and recreational users. More specifically, the <u>forage</u> value of wetland plants can be indicated by the **annual moisture condition** (wetlands assuming increased importance to livestock during drought years, Ogaard 1981), and by the **plant species** (e.g., cellulose and lignin content), which in turn can be indicated by **wetland water regime** and **time of year.** Plants that typify seasonal and temporary wetlands are generally better-quality forage than those of semipermanent basins, especially during the early and mid-growing season (Hubbard 1988). Also, the **diversity** of productive plant communities may be a key to making their production valuable to waterbirds; higher waterbird production may be more likely to be sustained in wetland complexes where plant communities are not only productive, but diverse.

3.9 Invertebrate Production

DESCRIPTION: PPH wetlands sustain a wide variety of aquatic and semi-aquatic insects and crustaceans. Individual taxa can be grouped as follows (after Jeffries 1989, McLachlan 1970, 1975, 1985, Wiggins et al. 1980):

- Overwintering Residents: disperse passively; include many snails, mollusks, amphipods, worms, leeches, crayfish.

- Overwintering Spring Recruits: reproduction depends on water availability; include most midges, mayflies, some beetles.

- Overwintering Summer Recruits: reproduce independent of surface water availability, requiring only saturated sediment; include phantom midges and some dragonflies, mosquitoes.

- Non-wintering Spring Migrants: mostly require surface water for overwintering, adults leave temporary water before it disappears in spring or summer; includes most water bugs, some water beetles.

DOCUMENTATION OF FUNCTION OCCURRENCE: Wetland invertebrate communities in the PPR occur seasonally at high densities and are highly diverse. On a landscape level, invertebrate production within PPH wetlands may subsidize other ecosystem types (e.g., upland passerines feeding on emerging insects) and wetlands in other regions (e.g., via transport in guts of migratory birds). However, most invertebrate production probably is utilized or recycled in the basins in which it originates. Thus, invertebrate production is primarily a site-specific function. High densities of invertebrates (which usually indicate, but are not synonymous with, high production) have been documented in several PPH basins (e.g., Schultz 1987, LaBaugh and Swanson 1988).

ASSOCIATED POTENTIAL VALUES: The capacity of PPH basins for supporting high densities of invertebrates during particular seasons is not only of intrinsic importance, but is essential for supporting other functions, particularly waterbird habitat functions. On a landscape level, because wetlands appear to host relatively diverse and abundant invertebrate communities the PPR, they can subsidize insectivorous wildlife populations and biodiversity over a wide region. On a site-specific level, invertebrate production in wetlands primarily supports within-basin fish and wildlife recreational and biodiversity values; certain species (leeches) that proliferate in fish-free basins also can help support local baitfish markets, and some wetlands are leased for this purpose (Hubbard 1988). Moreover, as demonstrated in the conceptual model (Appendix C), invertebrates contribute to or help serve as catalysts of many other wetland functions, such as sediment retention (section 3.4), phosphorus retention (3.5), denitrification (3.6), detoxification (3.7), and carbon cycling aspects of vascular plant production (3.8).

DOCUMENTATION OF VALUE: The wildlife values supported in part by PPH invertebrate communities are documented in section 3.11. Some waterfowl seem to select habitat based on the **total biomass** of invertebrates, rather than the number (density) or mean size (dimension) of the invertebrates (Ball and Nudds 1989). Also, the **type of invertebrate** (e.g., mud-dwelling worm vs. epiphytic snail vs. swimming beetle) determines use by a particular waterfowl species (Swanson and Duebbert 1989), and this in turn may be influenced with organic inputs associated with interannual hydrologic conditions (Murkin and Kadlec 1986). Apparently no attempts have been made to link quantitative estimates of invertebrate production in PPH wetlands to economic values of the fish or wildlife resources that depend on invertebrates. Indeed, few attempts have been made to measure just invertebrate production (as opposed to density).

TEMPORAL EFFECTS: Invertebrate production within individual basins may be greater during years that are relatively wet and have temperatures that support an extended growing season. An extended series of wet years can cause many basins to become dominated by submerged aquatic species, which generally support greater densities of invertebrates than do emergents.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape <u>inputs</u> of invertebrates to PPH basins occur as a result of dispersal of adults from surrounding basins. This dispersal may be active (i.e., flying adults) or passive (e.g., attached to vertebrates, see Swanson et al. 1984). In the PPR, the <u>capacity</u> for supporting invertebrate production (not diversity) has not been demonstrated to be related to processes occurring at a landscape scale.

B. Site-level (Within-wetland) Indicators of Function

The **density of invertebrates** is a fairly direct but imperfect indicator of invertebrate production. Its use at this stage of a regional risk assessment is impractical given the current lack of representative data from all portions of the PPR. The **percent cover and diversity of submersed plants** is also a fairly direct indicator of invertebrate production (e.g., Hanson and Butler 1990). Mixed-species stands of vegetation interspersed with small patches of open water often have the greatest invertebrate densities (Kaminski and Prince 1981; Murkin et al. 1982, Weller and Frederickson 1974, Broschart and Linder 1986). The actual size of the patch openings may be unimportant (Ball and Nudds 1989). **Wetland water regime** (or less direct surrogates of wetland water regime, such as plant species, soil profile, landscape geology, relief, and geographic position) may to some degree indicate invertebrate production capacity. In general, seasonal and especially semipermanent basins tend to support the greatest invertebrate densities (Swanson and Duebbert 1989, Nelson 1989). Basins whose **water levels show naturally large annual fluctuation** may be particularly productive. In contrast, those whose levels remain relatively constant over many years (Weller 1981), or which have very productive fish populations, may eventually experience diminished invertebrate production, as may temporary wetlands that are exposed to sustained drought. Basins **not subject to drastic, artificial hydrologic alteration**, such as sudden changes in water level, may also support greater invertebrate production. Wetlands which are **subject to moderate levels of grazing (particularly by muskrat), burning, or especially mowing** generally support 2 to 3 times the biomass of invertebrates of untreated wetlands, at least during the first year following treatment (Ball and Nudds 1989). Wetlands **not subjected to artificial drainage and/or tillage** have greater densities of invertebrates than those so altered (see sections 4.2 and 4.6). Although most wetland basins are highly eutrophic, and thus not usually nutrient limited, wetland **soil type** may indicate somewhat the potential for invertebrate production. Elevated production capacity may be indicated by the presence of fertile soils that are **highly organic** yet **not highly acidic.** Specifically, the most productive basins may be those with salinities in the 1000-3000 μmhos range (Barica 1978).

POSSIBLE INDICATORS OF VALUES: The values of invertebrate production can be indicated by the ecological and recreational importance of the wetland **basins** in which the production occurs, and the **position and proximity** of wetland basins relative to important ecological and recreational users. Also, the size class distribution or functional/life cycle **diversity** of productive invertebrate communities may be a key to making their biomass valuable to waterbirds; greater waterbird production might be sustained only in wetland complexes where invertebrate communities are not only productive, but diverse. Finally, the value of invertebrates to waterfowl varies by **season and year**, with invertebrate densities perhaps having a greater effect on waterfowl production during years of normal (vs. above-normal) precipitation (Murkin and Kadlec 1986b).

3.10 Fish Production

DESCRIPTION: The more permanent PPH wetlands can support a productive fish community, comprised mainly of fathead minnows and brook sticklebacks.

DOCUMENTATION OF FUNCTION OCCURRENCE: Fish communities in the PPR can be very productive (e.g., Payer 1977). The function is mainly site-specific.

ASSOCIATED POTENTIAL VALUES: The capacity of PPH basins for supporting productive fish communities is important to some waterbirds (e.g., grebes, herons) and baitfish harvesting enterprises. Like the function, the associated values are mainly site-specific. In South Dakota, semipermanent PPH wetlands are often stocked and used seasonally as rearing ponds for northern pike and walleye (USFWS 1990a), and baitfish enterprises occur locally throughout the region. Fish production in wetlands also may contribute to or help serve as a catalyst of some other wetland functions, such as sediment retention (section 3.4), phosphorus retention (section 3.5), and carbon cycling aspects of vascular plant production (section 3.8). One recent study indicated that fish removal from certain PPH basins might improve water clarity and stimulate growth of macrophytes important to waterfowl (Hanson 1990).

DOCUMENTATION OF VALUE: The commercial and wildlife values supported in part by PPH fish communities have generally not been adequately documented, with only a few attempts (e.g., Carlson and Berry 1990) having been made to link quantitative estimates of fish production in PPH wetlands to local economies. Still, public opinion surveys indicate that many PPR citizens (e.g., 67% in survey by Grosz and Leitch 1990) think that wetlands are important for the fishing opportunities they provide.

TEMPORAL EFFECTS: Fish production within individual basins may be greater during years that are relatively wet, if flooding opens up dispersal corridors among basins and allows colonization of new basins. Years with relatively mild or snow-free winters, or cool and windy summers, may allow survival of more juvenile fish in permanent basins otherwise prone to fishkills from anoxia.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape <u>inputs</u> of fish to PPH basins occur as a result of dispersal of fish from surrounding basins. This dispersal may be active (i.e., movements during high water conditions) or passive (e.g., stocked by humans or escaped from vertebrate predators). In the PPR, the <u>capacity</u> for supporting fish production (not diversity) at a regional scale would seem to be independent of interactions among basins. However, the rate of groundwater discharging into semipermanent basins may be important to overwinter survival of fish occurring in these basins. This discharge may be maintained locally by recharge focused in temporary and seasonal basins. If these basins are disrupted by drainage (i.e., local diversity of basin types is diminished), then fish production might decline (pers. comm., D. Hubbard, South Dakota St. Univ., Brookings). Also, fish production is influenced by climatic aspects of geographic position; in more northerly and easterly PPH basins, severe winter snow cover on ice-covered wetlands has the potential to reduce fish populations by aggravating anoxic conditions.

B. Site-level (Within-wetland) Indicators of Function

The **density of fish** or the "catch per unit effort" are fairly direct but imperfect indicators of fish production. Their use at this stage in a regional risk assessment is impractical given the current lack of representative data from all portions of the PPR.

Wetland water regime, (or less direct surrogates of wetland water regime, such as plant species, soil profile, landscape geology, relief, and geographic position) is probably the best indicator of fish production in PPH basins. Temporary, seasonal, and semipermanent basins cannot support sustained fish production because they periodically lack standing water. Fish occur only if (a) there is an intermittent connection to more permanent basins, or (b) fish are introduced intentionally, or accidentally by anglers or mobile vertebrates. Within semipermanent and permanent basins, overwinter survival may be greatest when oxygenated, natural **spring seeps** are present (Peterka 1989). **Shallower** basins are also less likely to have winterkill problems (e.g., Barica 1984). Basins not subject to drastic, **artificial hydrologic alteration**, such as sudden changes in water level, may also support greater fish production, as may basins whose shorelines are **not subject to** severe **grazing, mowing, tillage, burning, drainage, frequent human visitation**, or other factors discussed in section 4. Although most PPH basins are highly eutrophic, and thus not usually nutrient limited, wetland **soil type** may be a useful secondary indicator of fish production. Elevated production capacity may be indicated by the presence of fertile soils that are **moderately organic** and **not highly acidic**, because such soils support high densities of invertebrates fed upon by some fish. However, excessive production from fertile soils, followed by a winter with deep snow covering the ice, commonly causes fish to die from lack of oxygen or from ammonia toxicity (Baird et al. 1987, Barica and Mathias 1979). **Salinity** also limits use of some PPH basins by fish. Reproduction is sometime impaired at alkalinities of greater than 1000 mg/l (Peterka 1989). The particular anion that is dominant in a basin influences the precise tolerance threshold.

POSSIBLE INDICATORS OF VALUES: The values of fish production can be indicated partly by the ecological importance of the wetland **basins** in which the production occurs, the **commercial importance of the resource** (e.g., baitfish), and the **position and proximity** of wetland basins relative to important ecological and commercial users.

3.11 Waterfowl Production

DESCRIPTION: This function consists of the capacity of wetlands to annually produce ducks and geese. Although the discussion below emphasizes the **breeding** season, PPH wetlands also provide crucial stopover sites for **migrating** waterfowl. Wetlands of the PPR are also important to many other birds; those values are discussed in the section on biodiversity (section 3.14).

DOCUMENTATION OF FUNCTION OCCURRENCE: Waterfowl depend on PPH wetlands extensively during courtship, nesting, rearing of young, shelter during feather molting periods, and staging prior to migration. The PPR, including the Canadian portion, produces 40-60% of the waterfowl of North America (Smith et al. 1964, Batt et al. 1989). The U.S. portion of the PPR, which comprises 36% of the continental PPR, supports 25-30% of the continental production (Mineau 1987). During some years, North or South Dakota alone annually supports nearly half of the waterfowl production occurring in the conterminous United States (USFWS 1990a). Waterfowl species for which over half the continental population uses the PPR (including Canadian portions), are, in order of dependency: gadwall (95% of population), blue-winged teal, ruddy duck, redhead, northern shoveler, mallard, canvasback, northern pintail, and American wigeon (Batt et al. 1989).

Total duck production (i.e., ratio of broods per total ducks) has declined regionwide over the period 1955-85 (Batt et al. 1989). However, no consistent trend in nest success rates is apparent for most species (Klett et al. 1988). Only in Montana (of the U.S. portion of the PPR) is the decline in broods per total ducks statistically significant, and only in South Dakota are declines in average brood size statistically significant (Batt et al. 1989). Mallard and northern pintail are the only species appearing to have had a sustained population decline (Batt et al. 1989), and they consistently have had the lowest nest success rates (Klett et al. 1988). A nest success rate of 15-20% is needed to sustain continental waterfowl populations (Cowardin et al. 1985). Yet, within the PPR, the success rate in wetlands has consistently been less than this for all species (Klett et al. 1988). This rate has been attained for all waterfowl species only in idle grassland, and only in central South Dakota (all habitats combined).

ASSOCIATED POTENTIAL VALUES: The values of waterfowl production are mainly expressed at the landscape level. Migratory waterfowl produced by PPH wetlands support hunting in many states south and east of the PPR. Waterfowl are also enjoyed nonconsumptively by birders and other recreationists. Waterfowl production probably contributes to, or helps serve as a catalyst of, some other wetland functions, such as phosphorus retention (section 3.5), carbon cycling aspects of vascular plant production (section 3.8), and invertebrate production (section 3.9).

DOCUMENTATION OF VALUE: Public opinion surveys indicate that a large proportion of PPR citizens (e.g., 69% in survey by Grosz and Leitch 1990) think that wetlands are important for the wildlife they support. The North American Waterfowl Management Plan (USFWS and Canadian Wildlife Service 1986) recognizes the PPR as the highest priority region for protection. Waterfowl hunting, and the economy it supports, was valued at $21 million per year in North Dakota in 1986 (Baltezore et al. 1987). North Dakota has the greatest number of waterfowl hunters per capita of any state (Carney et al. 1983). In the Devils Lake Basin specifically, the values of wetlands for waterfowl hunting were theoretically valued at about $25 per wetland acre (Leitch and Scott 1984). In South Dakota, hunting in wetlands in 1985 generated $24 million per year (Johnson and Linder 1986). Other statistics documenting the value of hunting in the PPR are shown in Table B1. Some caution is required in interpretation because the data are not referenced to the source of the waterfowl production (e.g., an unknown proportion of the waterfowl may have been produced in Canada).

TEMPORAL EFFECTS: Waterfowl use of PPH wetlands varies according to annual water conditions and long-term weather cycles (Bellrose 1979, Hammond and Johnson 1984, Batt et al. 1989, Poiani and Carter 1991). Annual water conditions seem to have a greater effect on duck use of wetlands than on hatching success (average production); however, possible monitoring biases make this interpretation inconclusive (Batt et al. 1989). Comparing two years (or locations) with equal amounts of total annual precipitation, the number of basins with water is likely to be much greater for the year (or location) in which, during the preceding autumn, a major rainstorm was followed by freezing, which then was followed by a snow cover that persisted through the winter. Conversely, fewer basins may contain water during years (or locations) where winters are mild and lack continuous insulating snow cover. Although during most years potholes fill to less than 7 inches of standing water, during 100-year runoff events, many potholes will fill to a depth of at least 18 inches (Ludden et al. 1983), with corresponding increase in area. The type of basin water regime that waterfowl select also varies by year, with waterfowl becoming more dependent on permanent and semipermanent basins during drought years.

[Mark]

[Endmark]

Table B1. Extent of Hunting in PPR States.

# of Hunters and/or Anglers (x 1000)	Waterfowl Hunters (x 1000)	Waterfowl Hunting Days/Year (x 1000)
IA 746 (35%)[a]	52 (15%)	332
MN 1492 (48%)	181 (33%)	1578
MT 270 (45%)	23 (11%)	249
ND 220 (45%)	47 (40%)	419
SD 202 (40%)	35 (26%)	354

#

[a] Data are from 1985, as compiled by USFWS (1988) and Hay (1989).

Species whose use of PPH wetlands appears most sensitive to regional water availability include northern pintail, northern shoveler, blue-winged teal, ruddy duck, and redhead (Stewart and Kantrud 1973, Ruwalt et al. 1979, Batt et al. 1989).

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape inputs of waterfowl to PPH basins are indicated partly by **basin proximity to continental flyways and other traditionally used areas.** Subregional differences in waterfowl abundance are described by Brewster et al. (1976) and Batt et al. (1989). Also, **landscape connectivity** (or conversely, the degree of wetland isolation or wetland complex fragmentation) may be important for some waterfowl species in the PPR. Connectivity is defined somewhat differently than it would be in forested regions. Areas of the PPR with cumulatively greater waterfowl production may be those where wetlands are connected by ill-defined, semi-continuous corridors or networks of (a) lower-intensity land use (e.g., idle grassland, fewer roads, less frequent tillage, wetter soils) or perhaps (b) habitat with greater temporal predictability. Such conditions may represent reduced isolation among basins, provide greater nesting cover, and enhance landscape permeability for local movements, particularly of hens with broods.

The capacity of various subregions of the PPR for supporting waterfowl production is indicated somewhat by longitude--nesting success may be greater in the western portion of the PPR (USFWS 1990a). Capacity of landscapes to support waterfowl production is especially indicated by the **diversity (number and proportions) of basin types** within the subregions, as well as the **spatial arrangement of wetland basins relative to the most essential upland habitats** (idle grassland, planted cover). Within "complexes" comprised of diverse wetland types, waterfowl find conditions optimum for meeting many needs; indeed, individual females (depending on species and water conditions) may use up to 22 different wetland basins during a single summer (Dwyer et al. 1979). As expressed by Hubbard (1988):

> "Even if isolated, a semipermanent basin generally provides acceptable waterfowl breeding habitat; however, its status would be improved if it were part of a good complex. An isolated semipermanent basin may provide excellent breeding habitat if it contains large peripheral temporary and seasonal wetlands."

Temporary and seasonal wetlands are of greatest importance in landscapes where there is already at least one semipermanent basin per 4 square miles. Also, temporary and seasonal basins can provide the only suitable overwater nesting habitat during exceptionally wet years when peripheral nesting cover of semipermanent basins is completely inundated.

One expression of spatial arrangement of basins is the **contagion** (e.g., proportion of subregional wetland acreage that is dispersed vs. clumped). Wetland acreage occurring as scattered complexes rather than as single large wetlands should have a larger shoreline-to-area (or smaller depth-to-volume) ratio, and this is likely to be associated with greater secondary productivity.

Although some preliminary evidence suggests that at least during wet years, clustered wetlands (mainly temporary basins) may have lower brood densities than scattered basins (Wishart et al. 1984), this may represent sampling bias rather than actual differences in production.

A crucial question is: How far from the rest of a "wetland complex" can a wetland basin be before it is considered functionally disjunct from the complex? This depends on type of **functional use** (breeding or migration stopover), **species**, **surrounding habitat types**, **intrinsic productivity** of the compared wetlands, and **regional water conditions** during a particular year. Essentially nothing is known regarding how far apart wetlands may be spaced before waterfowl movements between them are so energetically draining that (a) **migration** is severely delayed (with *consequent increased mortality*) or (b) individual birds, once arriving on breeding grounds, are too nutritionally depleted to successfully rear broods. During the **breeding** season, dabbling ducks have home ranges of between about 75 and 1200 acres. For breeding functions, temporary and seasonal basins are of greatest value if within 0.15 mile of another wetland (Sousa 1985), and temporary and seasonal wetlands located more than about 0.5-1 mile from another wetland might be assumed to receive little use (Hubbard 1988). Regionwide studies currently being initiated by the USFWS (researchers are Cowardin and Klaus) will examine waterfowl recruitment as a function of the degree of basin isolation and intervening land use types. Computer simulations using energetics models may also be used to estimate configurations of wetlands necessary to maintain brood success.

Based on a consensus of regional biologists, Sousa (1985) suggested that, for at least one waterfowl species (blue-winged teal), the greatest benefit of wetlands occurs where (a) wetlands suitable as nesting habitat are present at a density of not less than about 480 acres per square mile, (b) wetlands suitable for territorial pairing of waterfowl are at a density of not less than 160 acres per square mile, and (c) wetlands suitable as habitat for broods comprise not less than 50 acres per square mile, whichever is most limiting. For pairs, the 160 acres should be distributed such that there are ideally 150 individual wetlands per square mile. For broods, the 50 acres should be distributed in about 6 wetlands per square mile (Sousa 1985).

B. Site-level (Within-wetland) Indicators of Function

The **density of waterfowl** is a fairly direct but imperfect indicator of waterfowl production. Its use at this stage in a regional risk assessment is impractical given the current lack of representative data from all portions of the PPR.

Opportunities for inputs of colonizing waterfowl may be highly indicative of waterfowl production capacity. As can be inferred from the landscape discussion above, basins likely to support greater waterfowl production are those located (a) closest to patches of low-intensity land use or wetland, and perhaps (b) where intervening land cover between patches or basins is relatively permeable to brood movements. The land cover surrounding wetlands, as well as land cover intervening among wetlands, is important. **Buffers** of natural vegetation surrounding wetland basins can enhance waterfowl production within wetlands by providing additional habitat (structural) diversity; providing dense, protective cover that shelters broods from predators and extremes of weather; intercepting and immobilizing contaminants that would otherwise diminish diversity of wetland food chains; and reducing noise and visual intrusion by people and vehicles (Burger 1981, Pomerantz et al. 1988). In some cases, certain types of buffer zones of cropland surrounding wetlands can provide feeding opportunities for some waterfowl. With regard to feeding, Pederson et al. (1989) noted, "Waterfowl use of agricultural habitats is related to the proximity of refuges and staging areas and to the type and abundance of agricultural grain in the area." For nesting, however, most agricultural land surrounding PPH wetlands supports low waterfowl densities, compared to natural land covers.

Capacity for supporting waterfowl production within an individual basin is indicated partly by **wetland water regime** (or less direct surrogates of wetland water regime, plant species, soil profile, landscape geology, relief, and geographic position). Temporary and seasonal basins supply migrating and early-nesting birds with abundant foods, partly because they warm up sooner in the season (Hubbard 1988). Surveys that have compared waterfowl occurrence in various types of PPH wetlands during the breeding season show less than 10% of the waterfowl using temporary basins (Ruwalt et al. 1979, Stewart and Kantrud 1972), as opposed to use of seasonal basins by from 16% (Ruwalt et al. 1979) to 47% (Stewart and Kantrud 1973) of the nesting population, and use of semipermanent and permanent basins by from 16% (Stewart and Kantrud 1973) to 47% (Ruwalt et al. 1979) of the nesting population. However, these simple measures of occurrence, sometimes made at one or a few points in time, do not necessarily correlate with the relative importance and substitutability of various basin types for sustaining waterfowl (pers. comm., L. Flake, South Dakota St. Univ., Brookings). Temporary and seasonal basins are particularly important during wetter years (Duebbert and Frank 1984). Semipermanent and permanent basins are essential for late nesting, brood rearing, molting, and staging prior to fall migration. These functions are served by the sustained water habitat, large density of invertebrate foods, and protection from predators which semipermanent and permanent basins supply. However, the productive capacity of these more permanently inundated basins depends largely on years elapsed since last drawdown, with basins that have been more recently drawn down usually supporting greater production. Preference for particular basin water regimes varies by species, with diving duck species using semipermanent and permanent wetlands to a greater degree than dabbling duck species, due partly to presence of higher densities of their preferred non-insect invertebrate foods in these types of basins (Swanson 1988).

Basins not subject to drastic, **artificial hydrologic alteration**, such as sudden changes in water level, may support greater waterfowl production. Wetlands which are **subject to moderate levels of grazing (particularly by muskrat), burning, or especially mowing** generally support conditions favoring greater waterfowl production, at least during the first year following treatment (Ball and Nudds 1989). Wetlands **not subjected to artificial drainage and/or tillage** have greater densities of waterfowl than those so altered (see sections 4.2 and 4.6). Basins that **lack fish populations** may support greater densities of aquatic invertebrates preferred by nesting waterfowl. Although most PPH basins are highly eutrophic, and thus not usually nutrient-limited, wetland soil type may be a useful secondary indicator of the capacity of wetlands to support waterfowl. Elevated production may be indicated by **fertile soils that are not highly**

acidic or saline. Although saline wetland basins provide some feeding habitat for adult waterfowl, their use by waterfowl broods is relatively limited. Recently hatched ducklings have difficulty surviving in basins where the specific conductance of waters exceeds about 20,000 μS/cm (Swanson et al. 1984).

Waterfowl production capacity is also indicated by **habitat heterogeneity** of a basin. Habitat patches can be defined according to various combinations of basin hydrologic permanence types, water depth, vegetation form and species, soil type, bank slope angle, natural disturbance frequencies, and other factors. The occurrence of **vegetated islands** suitable for nesting or roosting is one particularly good indicator of waterfowl production. Also, the presence of **multiple vegetation forms, well-interspersed with a relatively equal portion of open water,** strongly enhances waterfowl production. Under such conditions, ecotones between open water and vegetation provide birds with natural territorial boundaries (Weller and Spatcher 1965). For waterfowl, both the **ecotone length and degree of interspersion** with open water are important indicators. Waterfowl populations are more highly correlated with total length of wetland shoreline than total acreage of wetlands (e.g., Weller 1979). For ponds of equal area, higher brood densities have been observed on more irregularly shaped ponds (e.g., Mack and Flake 1980, Hudson 1983). Maximum waterfowl production is supported in basins where equal amounts of vegetation and open water are well-interspersed (Weller and Spatcher 1965, Kaminski and Prince 1981; Murkin et al. 1982, Weller and Frederickson 1974, Broschart and Linder 1986). At least for one species (mallard), open water patches in such a configuration should have a diameter of at least 150 feet (Ball and Nudds 1989). In an unmanaged marsh, the distribution and proportion of vegetation changes greatly from year to year. Over an idealized wet-dry cycle, the vegetation progresses from dry marsh, to regenerating marsh, to degenerating marsh, and finally to lake marsh before reversing (Weller 1981). Associated changes in interspersion and internal vegetative diversity profoundly affect waterbird community composition.

Wetland basins oriented so that they are **sheltered from extreme exposure to wind** may support greater waterfowl production. However, large open areas can be important for waterbird roosting (Hoy 1987).

POSSIBLE INDICATORS OF VALUES: The value of waterfowl production can be indicated by the **productive capacity of the wetland complexes** in which the production occurs, the **proximity** of these areas to nonconsumptive users, the **annual harvest of locally-bred waterfowl,** and the **proximity** of areas used by waterfowl during migration and wintering to both hunters and nonconsumptive users. In parts of the PPR where wetlands are leased for waterfowl hunting, a portion of the **cost of hunting leases** can be used to help estimate waterfowl value.

3.12 Winter Wildlife Shelter

DESCRIPTION: This function consists of the capacity of wetlands to reduce thermal stress to non-aquatic birds and mammals during winter. Most of the species that are benefitted are year-round residents of the region, but not necessarily of wetlands.

DOCUMENTATION OF FUNCTION OCCURRENCE: In many landscapes within the PPR, a few species depend on PPH wetlands almost exclusively during winter months, at least during periods of severe weather. Examples include Ring-necked Pheasant and White-tailed Deer. Wetlands in winter provide shelter from strong winds and frequent human disturbance, as well as a limited supply of food for some species (Kramlich 1985, Sather-Blair and Linder 1980, Fritzell 1988). In fact, wind velocity within some PPH wetlands is 95% less than in deciduous-wooded shelterbelts (Schneider 1985). In one area of South Dakota, over 70% of the suitable wintering habitat for pheasants was wetland, even though wetlands comprised a relatively small proportion of the landscape (Sather-Blair and Linder 1980).

ASSOCIATED POTENTIAL VALUES: Many of the wintering species support opportunities for hunting and nonconsumptive recreation, mainly at a local scale. In fact, these species support higher local levels of recreation (more hunter use-days) than species using the wetland predominantly in summer (Johnson and Linder 1986). Some characteristics which make a wetland attractive as winter shelter also make it attractive for some waterfowl functions (e.g., roosting) while making it less suitable for other waterfowl functions (e.g., loafing areas).

DOCUMENTATION OF VALUE: Available estimates of economic values associated with hunting in the PPR are mentioned in section 3.11. The economic values of hunting generally, and (less often) of pheasant and deer hunting specifically, have been quantified in a few cases. However, such estimates are either very site-specific (i.e., cannot be reliably extrapolated to all PPH wetlands), or are not referenced according to what portion of the harvested population had depended specifically on wetlands for winter survival.

TEMPORAL EFFECTS: The magnitude of this function will be greater during winters with severe winds and cold. The function may be lessened during winters of heavy snow, as many wetlands tend to trap drifting snow, and this can reduce access of some species to sheltering vegetation.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

The ability of wetlands to provide winter shelter for wildlife is best assessed at regional and landscape levels, because most species that benefit from winter cover disperse into non-wetland ecosystems during other seasons. Landscape inputs of upland wildlife to PPH basins during the winter are mainly a function of basin **proximity to populations of resident upland species**, and the proximity to **non-wetland habitat** that is suitable for overwintering. Use of wetlands for overwintering probably is directly related to **subregional climate** (e.g., latitude), and to habitat suitability of proximate uplands. That, in turn, is indicated partly by **crop type**, tillage

management practices, and extent of sheltering from **upland vegetation** (e.g., windbreaks). Natural factors, such as **surficial geology** and **topography** also play a role; for example, terminal moraines tend to have more woody cover than dead-ice moraines (Kantrud 1981). Capacity for supporting overwintering wildlife at a regional scale can be indicated by spatial **distribution patterns of basin types most suitable for wintering wildlife.** However, even basins that are not part of a complex can, if sufficiently large, provide essential cover to locally higher densities of resident species.

B. Site-level (Within-wetland) Indicators of Function

The **density of wildlife wintering in wetlands** is a fairly direct but imperfect indicator of overwintering capacity. Its use at this stage in a regional risk assessment is impractical given the current lack of representative data from all portions of the PPR.

The **effective patch (vegetated wetland) size, percent cover, and height of robust perennial plants** in a PPH basin largely determines its capacity for supporting overwintering wildlife. Pheasant use of one set of 15 South Dakota wetlands was greatest in wetlands larger than about 25 acres and within about one mile of other suitable wetlands (Sather-Blair and Linder 1980). To some degree, wetland size, percent cover, and vegetation height may be inferred from wetland **water regime** (or less direct surrogates of wetland water regime, such as plant species, soil profile, landscape geology, relief, and geographic position). Temporary and seasonal wetlands, if untilled, often have denser winter cover than semipermanent and permanent basins, although the latter may have larger patches of the more robust vegetation most valuable as winter cover. Basin capacity to support overwintering wildlife is also indicated by a relative lack of severe **grazing, mowing, tillage, burning, drainage, frequent human visitation**, or other factors discussed in Section 4.

POSSIBLE INDICATORS OF VALUES: The value of winter wildlife shelter can be indicated by the **sheltering capacity** of the wetlands, the **proximity** to hunters of autumn distributional ranges of wildlife that overwinter in these wetlands, and the proximity to nonconsumptive users of the distributional ranges (at any season) of the overwintering wildlife.

3.13 Furbearer Production

DESCRIPTION: This function consists of the capacity of wetlands to support mammals that are trapped for fur.

DOCUMENTATION OF FUNCTION OCCURRENCE: A few furbearing species depend on PPH wetlands almost exclusively, and others may do so locally or during severe weather. Muskrat is the predominant and most dependent species. Others include raccoon, skunk, coyote, red fox, and mink. Wetlands provide abundant food and shelter to these species.

ASSOCIATED POTENTIAL VALUES: Furbearers support opportunities for trapping and nonconsumptive recreation, mainly at a local scale. The habitat value for furbearers is expressed mostly at a site-specific scale for muskrat, and at a landscape scale for most other furbearers because of their larger home ranges. Furbearers are also important to some other wetland functions, notably Vascular Plant Production, Invertebrate Production, and Waterfowl Production.

DOCUMENTATION OF VALUE: Available estimates of economic values associated with furbearer trapping in the PPR cannot be referenced according to what portion of the harvested population had depended specifically on wetlands. Only in the case of muskrat can value be attributed almost solely to wetlands. In North Dakota, statewide income from furbearer harvesting during 1985-86 averaged $103,000/yr for muskrat, $64,000/yr for mink, $255,000 for coyote, $202,000 and for raccoon (S.Allen, cited in Kantrud et al. 1989). In South Dakota, statewide income from furbearers during 1986-87 averaged $617,000/yr for muskrat, $203,000/yr for mink, $350,000/yr for coyote, $368,000/yr for fox, and $715,000/yr for raccoon (L. Fredrickson, cited in Kantrud et al. 1989).

TEMPORAL EFFECTS: Furbearers, particularly muskrats, undergo wide annual fluctuations in population levels in response to water conditions. The dependency of furbearers on wetlands will be greater during drought years and winters with severe cold.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators of Function

Regional and landscape inputs of furbearers to PPH basins are mainly a function of basin **proximity to suitable habitat** located in surrounding wetland basins or uplands (e.g., conditions suitable for den sites). Indicators of the suitability of wetland basins are described below; indicators of upland suitability include **crop type**, tillage **management practices**, extent of **upland vegetation** (e.g., windbreaks), and **topography**. Landscape inputs are also indicated by geographic location within the PPR; due to climate and other influences, the current range of some furbearers includes only part of the PPR. For example, muskrat abundance is greater in the southeastern PPR; the species' northern limit is determined by freezing to bottom of wetland basins, and its western limit is determined by increasing drought frequency (Kantrud et al. 1989). Coyotes tend to increase in a westerly direction in the PPR. Capacity for supporting furbearers at a regional scale can be indicated by the spatial **distribution patterns of basin types** (as described below) **most suitable for furbearers**. Even basins that are not part of a complex can, if sufficiently large and of the right type, support considerable furbearer production.

B. Site-level (Within-wetland) Indicators of Function

The **density of furbearers**, as estimated from counts of dwellings, trapping records, or tracks, is a fairly direct but imperfect indicator of wetland capacity for supporting furbearers. Its use at this stage in a regional risk assessment is impractical given the current lack of representative census data on furbearers from all portions of the PPR.

The **effective patch size, percent cover, and height of the dominant plant species** in a PPH basin largely determines its capacity for supporting certain furbearers. Muskrat populations in particular are most productive in wetlands dominated by **bulrush, common reed, or especially, cattail.** Basins not subject to drastic, **artificial hydrologic alteration,** such as sudden changes in water level, may have greater capacity to support aquatic furbearers, as may basins **not subject to** __severe__ **grazing, mowing, tillage, burning, drainage, sustained and intensive furbearer harvest,** or other factors discussed in section 4.

POSSIBLE INDICATORS OF VALUES: The value of PPH wetlands for furbearers may be indicated by the **capacity of the wetlands and surrounding areas** to support furbearers, and the **proximity to trappers** of the distributional ranges of furbearing species which depend on wetlands. A portion of the **market price of fur** can be used to estimate wetland value, and this depends on furbearer species, subregion, and year. Fur prices in the PPR can vary by at least an order of magnitude between years (Hubbard 1988).

3.14 Biodiversity

DESCRIPTION: Biodiversity consists of the capacity of wetlands **both individually and cumulatively** to support a large variety of plants, invertebrates, and vertebrates. Biodiversity concerns the variety of genotypes, species, biotic communities, and trophic groups. For purposes of this report, biodiversity will be considered synonymous with species density (i.e., species richness per unit). It is recognized that wetland or landscape types capable of supporting a large number of species of one phylum (e.g., plants) are not always optimal for supporting maximum diversity of another phylum (e.g., aquatic insects). Also, it is recognized that genetic diversity is an intrinsic part of "biodiversity," and is not always associated with great species diversity or richness. Despite its potential importance, genetic diversity in this report is not considered because too little information is available on genetic diversity of PPH communities.

DOCUMENTATION OF FUNCTION OCCURRENCE: The number of PPR bird species is greater in landscapes with abundant wetlands than landscapes with fewer wetlands (Kantrud 1981). Many species depend on PPH wetlands almost exclusively, and others are dependent locally, seasonally (e.g., sandhill cranes and shorebirds, Krapu and Johnson 1990), or only during extreme weather conditions. **Not all "wetland" species are equally dependent on wetlands**; many also use non-wetland habitats, to an equal or greater degree.

Mammals that are particularly dependent on PPH wetlands are listed for part of the region by Fritzell (1988) and Kantrud et al. (1989); birds by Faanes (1982), and Kantrud and Stewart (1984); and plants by Reed (1988). Wetland plants considered by government or private groups to be threatened, endangered, or of special concern number 21 in South Dakota (SD Natural Heritage Program listing) and 62 in North Dakota (ND Chapter of the Wildlife Society 1986). A few native fish species, such as the finescale dace, are highly dependent on PPH basin wetlands (USFWS 1990a), as are at least three amphibians (Wheeler and Wheeler 1966, Kantrud et al. 1989).

ASSOCIATED POTENTIAL VALUES: Biodiversity may be considered both a function and a value. It is crucial to recognize its importance at multiple scales. One cannot assume that protecting wetlands or wetland types that have the most species results in protecting biodiversity, because some wetlands with few species can have the greatest incremental contribution to regional biodiversity, if those few species are present at no (or few) other wetlands. At all scales, biodiversity serves as one basis for nonconsumptive recreation (e.g., birding). Particularly at a landscape scale, biodiversity is important for contributions to maintaining regional pools of genetic material, as well as for maintaining communities that are resilient in the face of environmental change.

DOCUMENTATION OF VALUE: Public opinion surveys indicate that a large proportion of PPR citizens (e.g., 69% in survey by Grosz and Leitch 1990) think that wetlands are important for the wildlife they support. Estimates of economic values associated with biodiversity in the PPR are not available. Some general information exists on nonconsumptive values of wildlife, but cannot be attributed entirely to wetlands.

TEMPORAL EFFECTS: Temporal effects depend on scale, phylum, and wetland type. At one extreme, biodiversity of aquatic insects in temporary wetlands at a site-specific scale can fluctuate considerably among years. At the other extreme, biodiversity of bog-dwelling plants at a regional scale shows virtually no variation among years. Fluctuations of biodiversity are mostly related to severity of hydrologic conditions during particular sequences of years.

POSSIBLE INDICATORS OF FUNCTION

A. Regional and Landscape-level Indicators

Regional and landscape inputs of different species to various subregions of the PPR are partly indicated by **geographic location** within the PPR. A generally larger species pool may exist in the southeastern portion of the PPR, due to climate, proximity to flyways and continental biome boundaries, and other influences. Differences among subregions of the PPR may also be indicated by differences in **landscape heterogeneity,** defined as the number of distinct habitat patches per unit area, and the variety of their juxtapositioning combinations. **Landscape connectivity** (or conversely, the degree of wetland isolation or wetland complex fragmentation) may also be important for some PPR species, such as mammals, fish, and vascular plants, and is defined somewhat differently than in forested regions. Subregions of the PPR with cumulatively greater species density may be those where wetlands are connected by ill-defined, semi-continuous corridors or networks comprised of (a) lower-intensity land use (e.g., fewer roads, less frequent tillage, wetter soils) or (b) topographically low areas that during extreme wet years connect basins, or (c) habitat with greater temporal predictability. Such conditions may represent reduced isolation among basins and enhanced landscape permeability for species dispersal.

Capacity for supporting a high diversity of wetland species at a landscape or subregional scale is indicated partly by the presence of a wide range of conditions **among** wetlands of hydroperiod, water depth, soil type, vegetation form and species, water chemistry, natural disturbance frequency, and other factors. Some of the less common (but not necessarily rare) wetland types in the PPR, which may contribute the most to regional biodiversity, include:

- saline basins
- peat bogs (i.e., wetlands with hydroperiod classified as "saturated," and slightly acid conditions)
- fens (special recognition by Iowa and Minnesota Departments of Natural Resources; somewhat alkaline conditions)
- wild rice (Zizania) wetlands (special recognition by Minnesota DNR)
- all palustrine emergent prairie potholes in 35 counties of Iowa (special recognition by Iowa DNR)
- restored wetlands
- forested basin wetlands
- low-order riparian wetlands
- riverine wetlands along Missouri and Mississippi Rivers (special recognition by Iowa DNR), especially oxbow and forested wetlands
- basins of any type that have not recently been tilled, severely grazed, or otherwise directly altered by humans
- basins of any type not surrounded by high-intensity agriculture or residential uses.

In some subregions of the PPR, certain of these types may be encountered more widely, but on a regionwide basis they are a relatively small proportion of the entire resource. Also, some types that are widespread on a regional basis, but are rare within a particular watershed or locality, may be particularly important for their contribution to biodiversity. In considering this, it is important to use wetland "type" in a broad sense to mean not only basins containing a locally uncommon water regime, but also those with a locally uncommon chemical/soil regime, size class, juxtaposition, and/or other classifier of biological importance.

B. Site-level (Within-wetland) Indicators of Function

Landscape inputs of species may be as indicative of site-level diversity as of landscape-level diversity. As can be inferred from the above, basins having the greatest potential for supporting a larger species density are those located (a) near biome boundaries or closer to the southeasterly parts of the PPR, (b) where intervening land cover between patches or basins is relatively permeable to species movements, and (c) closest to patches of low-intensity land use or wetland, particularly those of a different or locally rare type (e.g., wet meadow, ungrazed native prairie, prairie thicket, shelterbelt; see Faanes 1982). Land cover surrounding wetlands, as well as land cover intervening among wetlands, is important. Buffers of natural vegetation surrounding wetland basins can enhance animal diversity within wetlands by providing additional habitat (structural) diversity; providing dense, protective cover that shelters young from predators and extremes of weather; intercepting and immobilizing contaminants that would otherwise diminish diversity of wetland food chains; and reducing noise and visual intrusion by people and vehicles (Vaske et al. 1983, Ream 1980, Dickman 1987, Simpson and Kelsall 1979, Ryder et al. 1980).

Buffer zones of cropland surrounding wetlands can provide feeding opportunities for some wetland wildlife in regions of low human population density and infrequent disturbance. However, agricultural land surrounding most PPH wetlands normally contributes little to biodiversity, compared to natural land covers. The importance of isolation to biodiversity (species density) in individual basins is documented by Brown and Dinsmore 1986.

Capacity for supporting great species densities within an individual basin is indicated partly by **habitat heterogeneity** within the basin. As with the landscape scale, this addresses the number of distinct habitat patches per unit area, the variety of their juxtapositioning combinations, and their spatial arrangement within a basin. Habitat patches can be defined according to various combinations of hydroperiod, water depth, vegetation form and species, soil type, bank slope angle, natural disturbance frequencies, and other factors. **Islands and sand/gravel bars** are particularly effective in increasing spatial heterogeneity. They are disproportionately used as resting and feeding sites by migratory shorebirds, and for nesting by many species, because of the protection they provide from small mammalian predators. Also, the presence of **multiple vegetation forms, well-interspersed with a relatively equal portion of open water**, contributes strongly to avian diversity within wetlands. Under such conditions, ecotones between open water and vegetation provide birds with natural territorial boundaries, and support habitat elements important both for open water species and species characteristically requiring more vegetated environments (Weller and Spatcher 1965). In addition, transition zones are inhabited by species which seem adapted specifically to the edge environment (e.g., yellow-headed blackbirds, gallinules, American coots, and least bitterns). Maximum wetland bird richness usually is favored by equal proportions of open water and emergent vegetation, well interspersed (Weller and Spatcher 1965, Kaminski and Prince 1981; Murkin et al. 1982, Weller and Frederickson 1974; Weller 1979; Broschart and Linder 1986). However, at some point, especially for animals with larger territories or requirements for isolation, too much interspersion of open water with vegetation might lead to within-basin fragmention of requisite shelter and territorial markers. Structurally heterogeneous wetlands also can support a greater diversity of macroinvertebrates (e.g., Dvorak and Best 1982). Invertebrate richness tends to be greatest where aquatic bed and emergent classes are interspersed with each other or with open water (Voights 1975).

Within-basin biodiversity is also correlated with **wetland water regime** (or less direct surrogates of wetland water regime, such as plant species, soil profile, landscape geology, relief, and geographic position). Although the greatest within-basin avian nesting density is supported by semipermanent basins, either semipermanent (Kantrud and Stewart 1984) or permanent basins (Faanes 1982) can support the largest mean number of species. The greatest within-basin floristic diversity is supported by untilled basins whose shorelines are not abrupt (Kantrud and Stewart 1984). Temporary wetlands may become less diverse after being exposed to sustained drought. Basins not subject to drastic, **artificial hydrologic alteration**, such as sudden changes in water level, may also be richer in species, as may basins **not subject to** severe **grazing, mowing, tillage, burning, drainage, frequent human visitation**, or other factors discussed in Section 4.

Basin size also is an indicator, but perhaps not a strong determinant, of species density. It may be expressed as acreage of basin, acreage of wetland (excluding open water), linear feet of shoreline (i.e., ecotone between open water and vegetation), or some combination of these. Plant diversity sometimes is correlated with size of nonpermanent wetlands (e.g., Ebert and Balko 1987), as is invertebrate diversity, at least of mollusks (e.g., Lassen 1975, Aho 1978), midges (e.g., Driver 1977), and crustaceans (e.g., Fryer 1985). Effects are difficult to separate from effects of increased permanency associated with larger basins, and some studies (Driver 1977, Ebert and Balko 1987) have suggested that the latter effect is more determining for invertebrates. One study (Brown and Dinsmore 1986) found greater aquatic bird species richness in larger PPH basins, and over a range of 0.5-450 acres, 10 of 25 species did not use wetlands smaller than about 2 acres. Large open basins can be important for shorebird feeding, waterbird roosting, and molting (e.g., Hoy 1987). However, because large basins in the PPR are often more spatially heterogeneous, it is also difficult to separate the effects of size from those of habitat heterogeneity (Patterson 1976). Also, if water levels in large isolated basins remain relatively constant over many years, diminished oxygen and reduced nutrient availability may restrict production and diversity.

Although most PPH basins are highly eutrophic, and thus not usually nutrient-limited, wetland soil type may be a useful secondary indicator of within-basin biodiversity. Elevated production and perhaps elevated biodiversity (e.g., Kantrud 1981) may be indicated by the presence of **fertile soils that are not highly acidic or saline.** Saline wetland basins generally have the lowest within-basin biodiversity (Ungar 1974), but the relatively few species they contain, e.g., piping plover, may be regionally rare or highly restricted (Faanes 1982). Thus, as noted above, the biodiversity value of such wetlands is primarily at a regional scale.

POSSIBLE INDICATORS OF VALUES: On a landscape scale, the biodiversity value of an individual wetland (or wetland complex) can be indicated by its **proximity to nonconsumptive users**, and the proportion of its wetland-dependent flora and fauna that is comprised of **species that are highly restricted** in their distribution within wetlands across the region. Indicators of wetlands likely to have the largest proportion of highly restricted species are described above. Many procedures exist for summarizing information on species restrictedness (or ubiquity) into indices useful for planning (e.g., Usher 1986, Cable et al 1989). On a site-specific scale, the biodiversity value of an individual wetland (or wetland complex) can be indicated again by its **proximity to nonconsumptive users**, and on its **species density**. Indicators of wetlands likely to have great species density are described above.

4.0 FUNCTIONAL LOSS

Wetland functions, and consequently, wetland values, can be lost when human activities physically convert wetlands to upland or deepwater. Often, however, the conversion is not complete, and areas which continue to exist as wetlands suffer degradational loss of functions and values.

Despite a lack of precise data on wetland losses in the PPR, it seems universally apparent that the long-term losses have been enormous. There is widespread agreement that the dominant land use in the region--agriculture--has been the primary cause of continuing wetland decline. Based on a review of mostly anecdotal estimates of wetland acreage losses in the PPR states, the USFWS (Dahl 1990) reported wetlands there may have experienced the following statewide losses since the 1780's:

Iowa:	89%
North Dakota:	49%
Minnesota:	42%
South Dakota:	35%
Montana:	27%

During a more recent period (1954-1974), the USFWS Status and Trends Survey estimated a wetland loss of 27% in South Dakota and 20% in Minnesota, but small sample sizes prohibited a truly complete estimation. During this period, wetland losses in North Dakota were estimated to occur at 15,000 to 20,000 acres/year, and probably continued at close to that rate until 1985 or 1986 (USFWS 1990a).

A regionwide stratified random survey of 422 plots, each about 10 km^2, indicated that wetland acreage which comprised 4.0% of the central North Dakota plots in the late 1960s-early 1970s, had declined to about 3.7% by the early 1980s; loss of some other habitats (e.g., planted cover) was much greater than wetland loss (Klett et al. 1988). An update of the USFWS Status and Trends Survey, covering the period of the mid-70's to mid-80's, will soon be released by the USFWS, but will also fail to indicate trends at state or sub-state levels within the PPR. Other possible sources of PPR wetland status and trend data are summarized in sections 4.1 and 6.0.

There is **considerable uncertainty regarding the degree to which PPH wetland losses are continuing in the United States portion of the PPR**. Within the past decade, increasing net costs to drain land, as well as new legislation at both the Federal level (e.g., "Swampbuster" provisions of the Food Security Act) and State level (e.g., North Dakota's "no net loss" law), may have reduced losses of some wetland types to some stressors. At the same time, efforts to restore and create wetlands in the PPR have been greatly expanded (see section 5.1 and Table B2). Also, 28,780 acres have been acquired in fee, and 47,171 acres by easement or lease under the North American Waterfowl Management Plan (NAWMP)(Table B2, p. B-62), and perhaps a much greater acreage has been protected by the Small Wetlands Program (pers. comm., H. Kantrud, U.S. Fish & Wildlife Service, Jamestown, ND). Some regional experts (e.g., Baltezore et al. 1987, 1991) have argued that only a small portion of the remaining wetland acreage may be currently threatened with conversion, assuming these positive new developments are sustained and enforced. This position is based partly on a study of one PPH county in North Dakota, where only 12% of the remaining wetlands were found to be at high risk of conversion due to lack of protective legislation or government ownership. The representativeness of this situation is uncertain. Within the PPR, North Dakota has by far the greatest portion of wetlands protected by federal easement or fee-title, followed by Minnesota, South Dakota, Iowa, and Montana. Although the basin types which are protected may serve well the needs of waterfowl for brood-rearing, more temporary types important for waterfowl feeding and courtship, as well as functions such as groundwater recharge and flood storage, are underprotected (Hubbard 1988).

For the most part, the new laws and programs address only losses in wetland acreage. More widespread losses of wetland function through **degradation** of the remaining wetlands are likely to continue unabated, because most of the loss factors discussed on the following pages are not regulated, even in wetlands "protected" in government refuges or by easements (and surely not in their contributing watersheds). Also, changing land ownership patterns and market conditions (e.g., agricultural commodity prices) could alter future threats of conversion. Degradation will continue to jeopardize several wetland functions valued by society, and in many cases will be essentially irreversible.

The following sections review the potential effects on wetland functions of several factors previously responsible for conversion or degradation of PPH wetlands. Although these loss factors are discussed individually, it is essential to realize that many which co-occur in time and/or space might cumulatively impact wetland functions to a greater degree than they do acting individually.

4.1 Losses Due to Conversion by Filling or Leveling

DESCRIPTION: This addresses the intentional placement of solid material (fill) in wetlands, as a means of disposal (e.g., incidental to ditching), or so that structures, roads, vehicles, center-pivot irrigation equipment, or crops may be placed in areas that formerly were too wet.

LOSS FACTOR STATUS AND TRENDS: Statistics on filling and leveling of wetlands are generally not kept unless the alteration involves more than 10 acres of wetland. Although complete filling and leveling of wetland basins in the PPR seems to be relatively uncommon (Kantrud et al. 1989), the intentional filling of **portions** of many individual wetlands continues to be done as part of road-widening projects and construction of travelways for center-pivot irrigation equipment. In Minnesota, the permitted loss of wetlands (all types statewide, mostly larger than 10 acres) from filling in 1988-89 was 1196 acres (Minnesota Pollution Control Agency 1990). However, in Minnesota portions of the PPR, the acreage of irrigated farmland increased fivefold from 1974 to 1984, and much of this expansion required placement of fill (generally not reported as part of section 404 permitting) within wetlands for support of center-pivot equipment (Peterson and Cooper 1991). Even if filling of wetlands within the PPR is not extensive, the associated conversion of wetlands to streets, landfills, houselots, travelways, and industrial parks represents an essentially irreversible loss, in contrast to cultivation and drainage losses which may be at least partially reversible.

Table B2. Acreage Protected Under the North American Waterfowl Management Plan, by State.

Data provided courtesy of the USFWS. Figures are current as of 9/91. First figure is wetlands only; figure in parentheses is wetlands plus associated habitats.

	Acquired-Fee	Acquired-Easement/Lease	Restored	Created	Enhanced
IA	1,977 (8,019)	0	2,401	0	0
MN	6,960 (11,388)	0	22,391	21,182	0 (256)
MT	9,124 (36,499)	1,396 (3,823)	1,756	1,857	3,965 (9,399)
ND	5,073 (12,682)	19,357 (42,081)	4,671 (18,296)	805	11,750+* (54,513+)
	5,646 (22,574)	26,418 (43,346)	5,118 (5,250)	8,028	7,608+ (8,196)

* an open marsh management system was developed on 2,094 of these acres

INDICATORS OF FILLING EXTENT: Conversion of wetlands to upland is easiest to accomplish in temporary and seasonal wetlands, with some conversion also being attempted in semipermanent basins during **drier years**. Thus, **wetland water regime** or (less directly) landscape geology, relief, and geographic position, can be used to identify subregions where conversion of wetlands is most likely. Filling also may be likeliest to occur **close to populations centers**, particularly those projected to have the greatest **future growth rates**. As noted above, relatively flat areas of the PPR where use of **center-pivot irrigation** is expanding are likely to be threatened with partial filling or drainage of wetlands. Land **ownership** also may predict the incidence of filling, as most wetlands owned or managed directly by private conservation groups or government agencies are not currently subject to filling.

CHARACTERISTICS OF FUNCTIONAL LOSS: In virtually all cases, filling and leveling, by removing a wetland, severely diminish **all** functions the wetland provided. Off-site effects can occur, too. Fill which covers only part of a PPH wetland basin but which fragments patterns of groundwater or surface water exchange can drastically affect water quality in the severed basins (Swanson et al. 1988) and increase predator access and nest flooding, thus reducing waterbird nest success (e.g., Peterson and Cooper 1991). Because temporary and seasonal basins are most often the types that are filled or leveled, wetland functions that occur to a greater degree in these basin types are more likely to be impacted by filling. These functions include Maintenance of Runoff Timing, Groundwater Recharge, and Nitrate Removal. Functions less likely to be impacted, because they occur predominantly in other basin types, include Fish Production and Furbearer Production. However, these can be impacted if filling of some wetlands causes changes in water levels of remaining nearby wetlands, as sometimes happens.

4.2 Losses Due to Artificial Drainage

DESCRIPTION: Artificial drainage consists of ditches, drainage wells, or subsurface (tile) pipes placed in wetlands or wet soils. Drainage networks are intended to lower seasonal water tables sufficiently to grow crops or improve human access. Ditches are commonly placed within PPH wetlands and connect them to open water areas within their basin, in other basins, or in nearby streams. Subsurface tile drains are also used to lower water tables, and are most prevalent in Iowa and southern Minnesota parts of the PPR. Drainage wells are used sporadically, with known clusters occurring in Iowa in western Humboldt, eastern Pocohontas, and central Wright Counties (Hoyer and Hallberg 1991).

Installation of drainage ditches and associated conduits can completely convert a wetland to upland, or can result in only partial conversion, which may resemble sustained drought (Weller 1981). Farmers commonly use partial drainage to improve pasture conditions. Drainage in some cases can result in conversion or degradation of 125 acres of wetland per mile of ditch (SRRRBC 1972); this figure will vary depending on soil type, ditch spacing, land slope, and other factors. In a study of the Red River, the U.S. Army Corps of Engineers St. Paul District (1989) assumed that networks of ditches on an average might alter some aspects of landscape hydrology up to 2 lateral miles away.

LOSS FACTOR STATUS AND TRENDS: The USFWS Regional Wetland Concept Plan (USFWS 1990a) asserted that artificial drainage is an important cause of wetland degradation and loss in all PPR states. In North Dakota between 1966 and 1980, private surveys conducted by the USFWS indicated that drainage was initiated in 32% of the wetlands in the Northeast Drift Plain (see map, Figure 1 of the summary report); 9% of the wetlands in the Southern Drift Plain and southern portion of the Missouri Coteau; and 3% in the Northwest Drift Plain and northern part of the Missouri Coteau (USFWS 1990a). Drainage that was occurring in temporary wetlands was not included in the survey, so the figures are probably underestimates. In the Devil's Lake area, up to 73% of the pre-settlement wetlands had been drained in one watershed (Devils Lake Basin Advisory Committee 1976).

In South Dakota, 14-36% of the PPH wetland acreage in three major watersheds (Big Sioux, Vermillion, Minnesota Rivers) had been drained by the early 1980's (Wittmier and Mack 1982, Wittmier 1985). In the portion of Minnesota included in the PPR, artificial drainage related exclusively to highways was reported to have resulted in loss of about 100,000 acres of wetlands (USFWS 1975). Also in Minnesota (Quade 1981), public drainage for agriculture as of 1979 was estimated for selected PPR counties as follows: Blue Earth County (40%), Brown County (46%), Le Sueur County (47%), and Nicollet County (59%). Only Blue Earth County had more miles of natural channels than miles of drainage ditches. However, the study author suspected that 40% of the drained soils were not wetland soils.

Reliable post-1960 drainage data are mostly not available for other PPR states. In the Red River of the North area of western Minnesota and eastern North Dakota, data compiled by the U.S. Army Corps of Engineers St. Paul District (1989) show that 10 of 44 watersheds have more than 60% of their area drained. Data in Brun et al. (1981) indicate 33% of the Goose River watershed in North Dakota had been drained as of 1979.

Since 1960, the only geographically broad survey of drainage was that of Smith et al. (1989), who focused exclusively on artificial drainage occurring adjacent to highways. Although the portion of all wetland drainage in the PPR that is related directly or indirectly to highway construction is unknown, artificial drainage of wetlands adjoining highway rights-of-way was reported to have resulted in loss of 55 acres of wetland per mile of road in South Dakota (Nomsen et al. 1986). Much of the artificial drainage occurs after highways are built, as landowners independently and often illegally construct outlets connecting isolated wetland basins to highway drainage ditches, thus effectively draining wetlands on private land. Similar behavior and impacts to wetlands occur when agencies channelize PPR streams. Channelization projects were reported to result in loss of 47% of the wetland acreage over the 20 years following project initiation (e.g., Erickson et al. 1979).

The following highway-related wetland drainage was estimated by Smith et al. (1989):

	Acres of Wetland Drained
ND: Agassiz Lake Plain	1,760
Drift Plain	13,958
Missouri Coteau	837
MN: Agassiz Lake Plain	2,431
Border Prairie	607
Sioux Drift Plain-Minnesota River Plain	1,354
SD: Drift Plain	2,284
Prairie Coteau	4,491
Missouri Coteau	48
TOTAL:	27,771

It is not apparent whether drainage-related wetland losses will continue at historic rates. On one hand, a trend toward consolidation of farm properties may increase the threat of drainage, as larger landholders may have greater fiscal resources and incentives (i.e., requirements for use of larger machinery) to construct drainageworks. As of 1982, approximately 5% of the wetland acreage of the PPR was considered to have medium or high potential for drainage, at least 50,000 acres of which was in North Dakota (Heimlich and Langer 1986). The 1990 section 305b water quality report for North Dakota comments that "Drainage continues to be the greatest threat to wetlands in North Dakota, while nonpoint source pollution problems such as siltation and pesticide contamination are gaining an increased awareness" (ND Dept. Health and Consolidated Laboratories 1990b). On the other hand, legislation to reduce drainage impacts to wetlands has come on line both nationwide (Swampbuster provisions of the Food Security Act of 1985) and in North Dakota (in 1985). Little new road construction is occurring in the region, and some agencies seem to be increasing efforts to monitor indirect drainage along highway rights-of-way. Also, much of the economically drainable wetland has already been drained, especially along highways. The SCS reports that since the 1985 implementation of the Swampbuster provisions, only 2239 acres of wetland have been drained by agriculture in North Dakota (pers. comm., J. Krause, USDA Soil Conservation Service, Fargo). At the same time, efforts to restore drained lands are increasing, with nearly 40,000 acres of formerly drained wetland being restored, mostly in Minnesota (Table B2, p. B-62). Differing opinions as to the severity of continuing wetland losses are sometimes clouded by differing definitions of what constitutes a "wetland;" certain soils that are being newly drained are not considered by some observers to comprise even temporary wetlands.

INDICATORS OF DRAINAGE EXTENT: Artificial drainage of wetland basins occurs mainly in temporary and seasonal basins in parts of the PPR with relatively flat terrain. During drier years some semipermanent basins are drained, but more for convenience than for agricultural value, because drainage usually causes salinity problems in their soils. Saline (alkali) basins are generally not drained because their soils are unsuitable for agriculture. Thus, wetland water regime, or (less directly) landscape geology, relief, and geographic position, can be used to some extent to identify subregions where artificial drainage of wetlands is most likely. However, historically most drainage has occurred in eastern parts of the PPR (Krapu and Duebbert 1989), particularly in the Central Lowlands portion of the Dakotas, whereas temporary and seasonal basins increase in a westward direction.

Agricultural land values (as predicted partly by the fertility of potentially-drainable soils), as well as the **proportion of farms dependent on government agricultural subsidies** are other indicators of potential extent of losses to drainage. Under 1985 "Swampbuster" policies, farmers lose government subsidies if they drain wetlands to grow commodity program crops. Also, the Conservation Reserve Program (CRP) pays farmers to minimize certain agricultural activities in specially-designated areas. In North Dakota, counties with the largest CRP signups include (from Mortensen et al. 1989, 1990):

> Kidder (>20% sign-up); Eddy, Rolette, and Burleigh (10-20% sign-up), and Divide, Mountrail, McHenry, Pierce, Steele, Sheridan, Stutsman, Emmons, McIntosh, Logan, and Ransom Counties (5-10% sign-up).

Crop type can be used as a gross indicator of the type of drainage. Drainage logically is not extensive in parts of the PPR with extensive ranching activities. Areas in the western part of the PPR where use of **center-pivot irrigation** is expanding are likely to be most threatened with wetland drainage, because irrigators commonly fill or drain temporary wetlands that hinder the movement of the rotating equipment (pers. comm., J. Leitch, North Dakota St. Univ., Fargo). Land **ownership** also may predict the incidence of drainage, as most areas owned or managed directly by private conservation groups or government agencies are not currently subject to drainage. As discussed elsewhere, inputs to wetlands depend on whether surrounding land is tile-drained or ditch-drained. Areas of corn cultivation are generally tile-drained, while areas of wheat, if drained at all, are ditch-drained.

CHARACTERISTICS AND INDICATORS OF FUNCTIONAL SENSITIVITY: Because temporary and seasonal basins are most often the types artificially drained, wetland functions that occur to a greater degree in these basin types have a greater chance to be impacted by drainage. Specifically, this includes functions such as Maintenance of Runoff Timing, Groundwater Recharge, and Nitrate Removal. Functions least likely to be directly impacted include Fish Production and Furbearer Production. However, these can be impacted if drainage of some wetlands causes changes in water levels of remaining nearby wetlands, as sometimes happens. When it occurs, drainage of any remaining wetlands in the southern and eastern parts of the PPR is less likely to result in functional losses than is drainage of wetlands in the western PPR. This is because the southeastern wetlands are primarily groundwater discharge or flow-through systems that are more resistant to drainage. The following paragraphs explain impacts on specific functions.

<u>1. Effects on Capacity to Maintain Runoff Volume and Timing</u>. Artificial drainage of PPR wetlands can potentially increase downstream flood stages and water level fluctuations (Hubbard

1988). According to PPH simulation studies by Moore and Larson (1980), artificial drainage is most likely to aggravate peak flows when runoff occurs at low volume over an extended period--a condition similar to spring snowmelt during many years in the PPR. Their models indicate complete drainage of wetlands would increase storm runoff 50-590%. However, whether drainage actually aggravates peak flows depends in part on **type of drainage (tile or drainage ditch); ditch or tile spacing; storm or runoff event intensity; season; watershed soil, slope, and shape characteristics; and watershed position of the drainageworks** (Campbell and Johnson 1979, Wilcock 1979). Drainage schemes that are (a) small relative to watershed area, (b) conducted in clayey soils where soil moisture contents exceed soil field capacity, and (c) located in the lower portion of a watershed may actually reduce flood peaks at the watershed outlet (or at an economically valuable service area located there) (Hill 1976). This is because drainage can remove water from this area before the arrival of the major storm pulse from headwater areas. Also, by increasing soil infiltration rates, artificial drainage under some conditions can beneficially increase the antecedent water retention capacity of soils (Penkava 1974, Andersson and Sivertun 1991).

The effect of reducing storage (by artificial drainage) in elongate watersheds is generally more severe than reducing storage in watersheds that are rounded in shape (Dreher et al. 1989). Wetlands and other storage areas high in a watershed may be more likely to influence downstream flooding, especially on a cumulative basis, because of the greater potential for desynchronizing flows and lesser chance of being overwhelmed by runoff. Simulation of a hypothetical 10-square-mile watershed indicated that detention basin networks are more effective if located in the upper 40-80% of a watershed than in areas farther downstream or upstream (Flores et al. 1982; Dreher et al. 1989).

However, wetlands along streams low in the watershed (fifth order streams) were found by Ogawa and Male's (1983) simulation studies to reduce flooding over a greater downstream area (exceeding 8 miles) than wetlands associated with first through third order streams, which reduced downstream flooding substantially only over an approximately 2-mile reach. Further, wetlands low in the watershed were influential regardless of the total amount of other storage available in the watershed, while individual wetlands high in the watershed (stream order 1 and 2) ceased to play a major role in floodflow attentuation as soon the acreage of other wetlands above them in the watershed exceeded 7 percent of the total (Ogawa and Male 1983).

2. Effects on Capacity to Recharge Groundwater. Potentially, artificial drainage reduces the amount of water available for recharge, as well as lowering the water table so that recharge occurs at a slower rate due to decreased hydraulic head (Winter ccc). This poses the possibility of drainage depleting aquifers and causing a lowering of long-term water table levels. This can occur regardless of the type of basin (temporary or semipermanent, recharge or discharge). Indicators such as those listed in (1) above predict the actual occurrence of this theoretical impact.

3. Effects on Capacity to Retain Sediment, Phosphorus. The effects are uncertain, for reasons given in paragraph (1) above. On one hand, subsurface drains and perhaps some ditching can

decrease antecedent moisture in soils and increase infiltration capacity, so that runoff is allowed to slowly trickle vertically, rather than be carried quickly into channels or other wetland basins. When this happens, sediment and phosphorus are retained on uplands. On the other hand, ditching can increase phosphorus and sediment concentrations, partly by reducing the time for solids to settle out and be processed. For example, water passing through two open, drained wetland complexes in North Dakota experienced a 200-to-600% tonnage increase in phosphorus and a 2000% increase in suspended sediment (Malcolm 1979). Phosphorus from another drained wetland complex was up to 3000% greater than in runoff from a summerfallow reference watershed (DeGroot 1979).

4. Effects on Capacity to Remove Nitrate and Detoxify Contaminants. The effects of artificial drainage are probably adverse, particularly when drainage is accomplished using drainage wells. When a wetland is drained, much of the organic substrate is volatilized and soil moisture declines dramatically. Nitrate runoff from recently drained wetland complexes can be measurably greater than nitrate from wetlands where artificial drainage systems have been in effect of a longer period of time (e.g., DeGroot 1979). Nitrate and pesticide removal functions are highly dependent on microbial activity, which requires ample soil moisture and organic material. Ditching and subsurface drains not only speed the movement of water among basins, allowing less time for microbial transformations to occur, but also increase infiltration capacity. Where wet soils have been tile-drained, denitrification processes assume less importance (e.g., Gast et al. 1978). Because nitrate and some pesticides are more chemically mobile than phosphorus, they are more likely to infiltrate and enter groundwater before being processed by microbes in the biologically active upper soil strata. Documentation exists from the PPR which demonstrates that draining wetlands can, indeed, increase nitrate in the receiving surface water (DeGroot 1979, Jones et al. 1976, Quade 1981, Larson-Albers 1981, Malcolm 1979); similar documentation seems to be lacking on the impact of drainage on nitrate in groundwater.

5. Effects on Capacity to Support Vascular Plant Production. The effects of artificial drainage are variable. In the years immediately following drainage, facultative and upland plants may thrive in the fertile drained soils, as natural and accumulated nutrients become very bioavailable. With time, primary production may return to levels at or below levels formerly occurring in the wetland before drainage. However, if drainage eliminates the ability of groundwater to move upward in winter to replenish moisture in frozen soil above it (e.g., Malo 1975), wetland vegetation and crops may be less productive the following growing season (Hubbard et al. 1988). Also, if soils are of a type tending to develop salinity problems upon drainage (e.g., many semipermanent basins), vascular plant production will be diminished (Richardson 1986). In these situations, if surface water frequently ponds in the drainage ditches and seeps into adjoining soils, salination of soils can be severe (Skarie et al. 1986), rendering the area unsuitable for cultivation.

6. Effects on Capacity to Support Production of Invertebrates, Fish, Waterfowl, Aquatic Furbearers, and Biodiversity. Drainage causes severe impacts to these resources mainly because it reduces the space available to species adapted to living in the water. Where wetlands are drained only partially, waterfowl are attracted by standing water in the early spring and initiate

nesting, only to suffer large nest and brood losses as the wetlands rapidly dry later in the season. At a landscape level, drainage has the effect of reducing the diversity of wetland sizes and types. This is because water that was formerly retained in small wetlands, which are generally drained first, is diverted into downstream basins, which increase in size and permanency with the overflow. If past rates of drainage continue, some PPR waterfowl populations are projected to decline 11% in the next decade (Cowardin et al. 1988). However, the benefits of halting drainage impacts may be less than the benefits of instituting no-till agricultural practices and some other management techniques (Cowardin et al. 1988). The literature on the effects of dehydration of wetlands on biodiversity of each major taxonomic group is reviewed by Adamus and Brandt (1990). The greatest impacts of drainage may occur to wetlands with saturated water regimes (e.g., prairie bogs and fens). Rare or highly restricted plants inhabiting these wetlands are very sensitive to water level changes. Also, any basins with soils that, because of their characteristic physical structure, can de-water quickly are more vulnerable to invasion by aggressive upland plants that can diminish landscape-level diversity (Pederson et al. 1989).

Artificial drainage of wetlands can also cause problems with trace metal contaminants toxic to wildlife, particularly if soils are of a type tending to develop salinity or trace element contamination problems upon drainage. Whether or not salination will occur following drainage may be indicated partly by basin type. Salination is most severe following drainage of groundwater discharge- or flowthrough-type basins, which are generally semipermanent and permanent basins located in topographically low positions (Richardson 1986). In the PPR, a few instances have been documented of wetland contamination. Arsenic, boron, selenium, and zinc from inputs of upslope drainage waters may have contaminated wetlands in the Milk River Project near Bowdoin National Wildlife Refuge, Montana (Willard et al. 1988). Contamination of PPR snow with mercury, selenium, and molybdenum has been documented. Potential contamination is also being presently investigated at the Lostwood National Wildlife Refuge.

4.3 Losses Due to Groundwater Pumping

DESCRIPTION: If groundwater is pumped for domestic use or irrigation at a rate faster than it can be recharged over the long term, local and even regional water table levels are affected. This has the potential to greatly shrink the acreage of functional wetlands (Winter 1988).

LOSS FACTOR STATUS AND TRENDS: There are few published accounts of long-term aquifer water level declines as a result of pumping by wells. Usually, the greatest local declines in water levels are the result of pumping by irrigation wells. In South Dakota, wells that penetrate the Dakota-Newcastle aquifer have declined more than 400 feet locally since the 1880's because of discharge from flowing wells. Between 1960 and 1980, the water level in one Aberdeen area well declined 13 feet as new wells were drilled in surrounding areas. Where well water levels have declined near Dolton, the current rate of recharge in this region has been judged insufficient to meet the 0.1 inches of recharge needed per year to sustain the aquifer (Barari et al. 1990). In the West Fargo area of North Dakota, levels of some wells have declined below land surface as much as 122 feet since 1895 (USGS 1984). Irrigation of crops with ground water has increased steadily in North Dakota since about 1960; statewide, irrigation accounts for nearly half of all groundwater used in North Dakota (Moody et al. 1988). High-capacity pumping of water from irrigation wells in the PPR can contaminate groundwater by drawing downward the younger water from overlying contaminated subsurface zones (e.g., Wall et al. 1989).

INDICATORS OF PUMPING EXTENT: Although georeferenced data on the extent of groundwater use are relatively easy to find, the vulnerability of aquifers to long-term drawdown problems is not indicated by many obvious characteristics. To some extent, subregions that have already lost much of their natural recharge through urban development or drainage of temporary and seasonal wetlands would be expected to be more likely to experience water table declines if pumping of aquifers was increased.

CHARACTERISTICS AND INDICATORS OF FUNCTIONAL SENSITIVITY: Most of the functions are affected in the generally same manner from Groundwater Pumping as they are from Artificial Drainage, described above. An exception may be Runoff Volume, Runoff Timing, and Recharge. As the water table is drawn down, additional pore space might be made available for absorbing and storing runoff. As a result, downslope flooding could be reduced, depending in part on where and when the pumped groundwater is released after use.

4.4 Losses Due to Dugout and Impoundment Construction

DESCRIPTION: Dugouts (or "pits") are small (<0.1 acre) ponds commonly excavated within temporary or seasonal wetlands, or in upland terrain. They often are constructed to provide both waterfowl habitat and water supplies for irrigation or livestock; such "stockponds" are generally steep-sided and rectangular. In contrast, impoundments (including "stock dams" and "retention reservoirs") result from blockage of gullies or intermittent or permanent streams, which in some cases contained wetlands prior to their alteration. The discussion below addresses both dugouts and impoundments, and in addition includes effects of artificial flooding of otherwise temporary or seasonal wetlands.

LOSS FACTOR STATUS AND TRENDS: No regionwide estimates exist regarding the extent or trends in dugout or impoundment construction, or artificial flooding. A study in eastern South Dakota reported that in 1976, there were about 2 dugouts per square mile, and about 77% of 55,855 dugouts were located in wetland basins or streams, probably most of them temporary or seasonal wetland basins (McPhillips et al. 1983). Another survey in part of South Dakota reported that stock ponds and dugouts comprised 15% of the acreage and 21% of the number of wetlands (Ruwalt et al. 1979). Some wetland basins in North Dakota are also being inundated by construction of the Garrison Diversion Project, and Weller (1981) stated that wetland losses in downstream areas due to impoundment of streams for irrigation were "increasingly common."

INDICATORS OF EXTENT OF DUGOUT/IMPOUNDMENT CONSTRUCTION: Dugouts are constructed mainly in temporary and seasonal basins, with perhaps fewer numbers being constructed by deepening of semipermanent basins during drier years. Thus, **wetland water regime**, or (less directly) landscape geology, relief, and geographic position, can be used somewhat to identify subregions where dugout construction in wetlands is most likely. Perhaps a better indicator is the extent of range and pastureland in an area.

CHARACTERISTICS AND INDICATORS OF FUNCTIONAL SENSITIVITY: The impacts of dugouts depend largely on whether they are constructed by excavating existing wetlands or by excavating uplands. Excavation and deepening of existing basins in eastern parts of the PPR can adversely impact wetland vegetation surrounding the basin, or can benefit waterfowl by providing standing water in the center of the basin during exceptionally dry years. Because temporary and seasonal basins are most often the types that are converted to deepwater by dugouts, wetland functions that occur to a greater degree in these basin types have a greater chance of being affected, either positively or negatively. These functions may include Maintenance of Runoff Timing, Groundwater Recharge, and Sediment Retention.

1. Effects on Capacity to Maintain Runoff Volume, Runoff Timing, and Groundwater Recharge. Dugouts and impoundments probably increase the capacity of wetlands to delay runoff, reduce its volume (via increased open-water evaporation), and perhaps increase the recharging of groundwater.

2. Effects on Capacity to Retain Sediment, Phosphorus. To the extent that dugouts create deeper depressions than previously existed in the local landscape, they may increase the capacity to intercept and store sediment and phosphorus.

4. Effects on Capacity to Remove Nitrate and Detoxify Contaminants. Slight deepening of temporary and seasonal wetland basins may increase the seasonal duration of moisture and thus enhance these functions. Major deepening, however, may encourage anoxic conditions under which nitrate and contaminants are removed only slowly by natural biological processes.

5. Effects on Capacity to Support Vascular Plant Production. Slight deepening of temporary and seasonal wetland basins may increase the seasonal duration of moisture and enhance wetland plant productivity. Major deepening, however, results in water too deep to support many of the most productive emergent plant species, and can contribute to local drops in the water table, drying out surrounding wetlands.

6. Effects on Capacity to Support Production of Invertebrates, Fish, Waterfowl, Aquatic Furbearers, and Biodiversity. At least in the drier and less-disturbed western portions of the PPR, properly-constructed stockdam wetlands appear to have a dramatic positive effect on production of waterfowl in which the construction has occurred (Ball and Eng 1989, Lokemoen 1973, Swanson 1959). This is because stockdams and small retention reservoirs increase habitat space and hydrologic predictability. Waterfowl production in these habitats also depends on years elapsed since construction, with more mature reservoirs supporting greater production (Ball et al. 1988), and on management schemes, e.g., fencing, construction of islands, provision of nesting cover. In eastern parts of the PPR, retention reservoirs during "average" water years are generally less attractive to waterfowl than natural marshes (pers. comm., R. Eng, Montana St. Univ., Bozeman). Excavation of temporary or seasonal basins for dugouts eliminates the

dense vegetation cover these natural wetlands contain, which in heavily cultivated areas is often the only such cover available for wildlife. Moreover, excavation can draw down the water level of nearby basins, with adverse biological impacts (Flake 1979). Effects on regional biodiversity will depend on the extent to which a scarcity of deepwater wetland habitats (as opposed to availability of dense vegetation cover) limits wildlife within a particular local area and subregion. Artificial flooding has the potential to adversely affect certain migrating waterfowl (i.e., canvasback) by impacting their primary food source, sago pondweed (pers. comm., H. Kantrud, U.S. Fish & Wildlife Service, Jamestown, ND). The literature on the effects of inundation on diversity of each major taxonomic group occurring in wetlands is reviewed by Adamus and Brandt (1990).

7. Effects on Winter Wildlife Shelter. As noted above, dugout construction and impoundment usually reduces the area of robust emergents and shrubs within a basin. This effect is particularly acute in the drier parts of the PPH where dugouts cause livestock grazing to be focused on areas of vegetation most important as wildlife cover. As a result, the capacity of the landscape to support resident wildlife that depend on wetlands for shelter in winter often is diminished.

4.5 Losses Due to Grazing and Mowing

DESCRIPTION: This addresses the effects of grazing by livestock, and mowing of forage hay by farmers, on the stand density and composition of wetland vegetation. Effects of prairie fires are similar in many respects, and different in others. Effects of livestock on sedimentation and addition of nutrients are addressed separately in sections 4.7 and 4.9, respectively.

LOSS FACTOR STATUS AND TRENDS: Grazing (e.g., by bison) occurred extensively in PPH wetlands even prior to settlement. Since the reductions in bison, domestic livestock have been widely allowed to graze in wetlands. However, livestock grazing in wetlands has declined somewhat in recent decades because of reduced diversification of farming operations and increased emphasis on cash crops (Krapu and Duebbert 1989). At the same time, the species of waterfowl most likely to be affected by mowing, due to their habit of nesting early in the season, are showing a long-term decline (Batt et al. 1989). In a 3877 square-mile area of North Dakota, one-third (33%) of the wetland basins were reported to be grazed, and 7% were mowed (Cowardin et al. 1981). Wetlands acquired as part of highway project mitigation agreements in North Dakota are supposed to remain unmowed, but enforcement of this provision is reportedly poor (USFWS 1990a). In the USFWS Regional Wetland Concept Plan (USFWS 1990a), grazing was mentioned as a substantial cause of degradation and loss of PPH wetlands in Montana. The Plan also noted that, "there is little to suggest that the traditional heavy grazing and other agricultural-related practices affecting wetlands may be easing, except for some temporarily reduced cropping adjacent to wetlands [in localized areas]."

INDICATORS OF GRAZING/MOWING EXTENT: The magnitude and recovery time from impacts of grazing can be indicated by the management regime, i.e., the **density of grazing animals** and the **frequency, duration,** and **seasons** of wetland use. Continuous, seasonlong grazing generally causes the most damage. Similarly, mowing impacts and recovery times are indicated partly by the **season, frequency, and extent** of mowing. Mowing or grazing prior to mid-July is most likely to destroy nests. Even late-season mowing can remove residual cover useful for nesting the following spring. the occurrence of grazing can largely be predicted by **region** within the PPR. Grazing and mowing occur mainly in temporary and seasonal basins in parts of the PPR where relief is hilly (thus discouraging cultivation of many row crops), as in the western part of the PPR. Some grazing and mowing occurs in semipermanent basins, especially during drier years. Thus, **wetland water regime** and **local landscape relief** can be used to indicate subregions where grazing or mowing occur most extensively within wetlands. Wetland basins located closest to feedlots, corrals, and farmsteads may be most likely to be subject to grazing or mowing. **Land ownership** may also predict the incidence of grazing or mowing, as some areas owned or managed directly by private conservation groups or government agencies have restrictions on grazing and mowing.

CHARACTERISTICS AND INDICATORS OF FUNCTIONAL SENSITIVITY: Because temporary and seasonal basins are most often the types that are grazed and mowed, wetland functions that occur mainly in semipermanent and permanent basins have less chance of being impacted. These functions include Fish Production and Furbearer Production.

1. Effects on Capacity to Maintain Runoff Volume, Runoff Timing, and Groundwater Recharge. These functions are unlikely to be affected. If effects occur at all, they would likely be due to reduced transpiration and snow trapping, and increased soil compaction, as a result of extreme levels of grazing/mowing over large areas (e.g., Branson et al. 1962).

2. Effects on Capacity to Retain Sediment, Phosphorus. The ability of shoreline wetlands to trap runoff-borne sediment and phosphorus that enters large basins could be impaired somewhat. However, effects would be on a basin level rather than on a landscape level.

3. Effects on Capacity to Remove Nitrate and Detoxify Contaminants. Impacts are uncertain but probably dependent on grazing/mowing intensity. At low intensities, manure from grazing has been demonstrated to stimulate microbes responsible for nitrogen removal processes (Paul and Beauchamp 1989, Rickerl and Smolik 1990). At high intensities, particularly when mowed hay is annually removed, the soil litter layer could potentially become depleted and soil compaction could reduce surfaces for microbial activity, thus decreasing wetland ability to remove nitrate.

4. Effects on Capacity to Support Vascular Plant Production. At low removal rates, the productivity of some wetland emergent plants can be stimulated by removal (e.g., Neckles and Wetzel 1989). Longterm effects depend on initial stand densities, the type of removal (burning may have less impact on longterm productivity than forage removal), and removal frequency. At high removal rates, erosion could threaten the plant production capacity of wetlands. Also, selective and intensive removal of emergents may cause shifts to (sometimes) less productive submerged and algal communities.

5. Effects on Capacity to Support Invertebrate and Fish Production, and Biodiversity. Although grazing can increase plant diversity within PPH wetlands (e.g., Bakker and Ruyter 1981), biodiversity at a regional level may decrease because grazing commonly results in invasion of natural wetland communities by ubiquitous weedy species, mainly upland annual and biennial forbs and grasses. Even onetime grazing can have detrimental long-term effects on wetland basins if too much of the filtering shoreline vegetation is removed and sediment is allowed to enter the basin, reducing invertebrates (Olson 1981). Severe grazing "removes vegetation detritus that fuels the aquatic food chain when the basin is reflooded" (Pederson et al. 1989). Overall avian richness, as well as densities of certain wetland birds (e.g., Wilson's phalarope, LeConte's sparrow, sedge wren, common yellowthroat, and red-winged blackbird) are distinctly greater in ungrazed or lightly grazed PPR wetlands (Kantrud 1981). However, moderate levels of grazing can increase invertebrate densities (Schultz 1987). Grazing-related declines in invertebrate populations may occur only when livestock are present at sufficient density to temporarily remove nearly all aquatic vegetation. Grazing and mowing are unlikely to impact PPH fish production because these loss factors seldom occur in the basin types used by fish. The literature on the effects of vegetation removal on diversity of each major taxonomic group occurring in wetlands is reviewed by Adamus and Brandt (1990).

6. Effects on Capacity to Support Waterfowl Production. Many studies have been conducted on the effects of various grazing and mowing regimes on waterfowl, and these are reviewed by Kantrud (1986). Severe grazing and repeated early-season mowing can reduce waterfowl nest success and overall habitat quality. Much grazing occurs on margins of basins because the basin center is too wet. As a result, valuable shoreline nesting cover can be destroyed. In a regionwide longterm study, Klett et al. (1988) found that nest success rates in unmowed, ungrazed grassland were much higher than in hayland, and somewhat higher than in grazed grassland. Nest success rates in hayland were inadequate to sustain continental populations of waterfowl. Nonetheless, under carefully prescribed circumstances, mowing and grazing can open up dense stands of wetland vegetation. This is particularly true during and immediately after drought years (USDA Soil Conservation Service 1985). The resulting increased interspersion can benefit waterfowl, provided that mowing occurs late enough in the season to avoid disturbing nesting birds. Impacts on ducks from grazing are much less than from cultivation, and waterfowl production on grazed lands was reported by Barker et al. (1990) to be sufficient to sustain and increase local waterfowl populations, provided that some cover was left undisturbed during the nesting season. Several other studies of PPH wetlands (e.g., Gjersing 1975, Mundinger 1976) support the value to waterfowl habitat of moderate grazing, while documenting damage that can occur if grazed areas are not periodically "rested."

7. Effects on Capacity to Provide Winter Wildlife Shelter. Nearly any level of grazing or mowing reduces vegetation important as winter cover for wildlife.

4.6 Losses Due to Tillage

DESCRIPTION: During the driest time of the year, the soil on the bottoms of some wetlands is tilled (plowed) and crops are planted. Tillage occurs even more frequently in areas surrounding wetlands and adversely impacts the wildlife cover there. This effect is also considered here. However, the effects of surrounding tillage on sedimentation and chemical runoff are not discussed immediately below, but rather in sections 4.7 and 4.8.

LOSS FACTOR STATUS AND TRENDS: In the late 1960s, tillage occurred directly within 50% of the basins in an area in North Dakota (Stewart and Kantrud 1973). More recent data are lacking, but basins that are cultivated but not drained are extremely common in the Dakotas (Kantrud et al. 1989). At the same time, the species of waterfowl most likely to be affected by tillage, due to their habit of nesting early in the season, are showing a long-term decline (Batt et al. 1989). In the USFWS Regional Wetland Concept Plan (USFWS 1990a), tillage was mentioned as an important cause of degradation and loss of PPH wetlands in Montana. Wetlands acquired under the USFWS's Small Wetland Acquisition Program are not protected from tillage.

INDICATORS OF TILLAGE EXTENT: Tillage within wetland basins occurs mainly in temporary and seasonal wetlands, with some also occurring in semipermanent basins during drier years. Thus, **wetland water regime**, or (less directly) landscape geology, relief, and geographic position, can be used to indicate subregions where tillage of wetlands is most likely. Most tillage occurs in temporary and seasonal basins, especially in relatively **flat** landscapes. **Soil type** is also a predictor of tillage. Saline (alkali) basins are generally not tilled because their soils are unsuitable for crops (except hay), whereas basins in areas having the most **fertile soils**, especially if located near major crop processing and transportation facilities, are likely to be tilled. Also, wetland basins located closest to farmsteads are most likely to be subject to tillage. **Land ownership** also predicts the extent of tillage, as most areas owned or managed directly by private conservation groups or government agencies prohibit or severely restrict tillage of wetlands.

CHARACTERISTICS AND INDICATORS OF FUNCTIONAL SENSITIVITY: In virtually all cases, the severest effects of tillage are probably reversible once the land is idled. Because temporary and seasonal basins are most often the types that are tilled, wetland functions that occur to a greater degree in these basin types are more likely, by chance alone, to be affected. These functions are likely to include Maintenance of Runoff Timing, Groundwater Recharge, and Nitrate Removal. Functions less likely to interact with tillage because of the types of basins in which they occur include Fish Production and Furbearer Production.

Environmental effects of tillage depend partly on the **type of tillage** that is used. Use of conservation tillage practices potentially can alleviate problems with excessive sediment, nutrient, and contaminant inputs to wetlands, particularly where croplands are irrigated. However, reductions in tillage or use of conservation tillage in some instances can, by increasing infiltration, actually increase transport of some contaminants into groundwater (Baker 1987, Starr 1990) and wetlands (Laflen and Tabatabai 1984). Organic practices (i.e., no chemical applications) are likely to benefit most wetland functions because of their ability to maintain soil moisture and structure, particularly during drought years (e.g., Rickerl and Smolik 1990). Continuous cropping systems are often used in areas prone to soil salination problems. In contrast, use of conservation tillage practices (e.g., reduced till practices which leave crop residue) appears to be increasing.

1. Effects on Capacity to Maintain Runoff Volume, Runoff Timing, and Groundwater Recharge. These functions might be affected if tillage severely increases sedimentation and infilling of the wetland basin, or if tillage increases infiltration by increasing the vertical cracking of clay soils (Granger et al. 1984).

2. Effects on Capacity to Retain Sediment, Phosphorus. If shoreline wetlands are converted to crops, the ability to trap runoff-borne sediment and phosphorus that enters large basins could be impaired somewhat. However, effects would be on a basin level rather than on a landscape level.

3. Effects on Capacity to Remove Nitrate and Detoxify Contaminants. Impacts are uncertain but probably depend on cultivation practices. Cultivation generally reduces soil organic matter and increases soil bulk density (e.g., Blank and Fosberg 1989), with probable negative consequences for nitrate removal (Parkin and Meisinger 1989). However, if crop residue is left standing in tilled-wetland soils, it may deplete soil oxygen and increase soil organic content, which in turn may stimulate microbes responsible for nitrogen removal processes (Rice and Smith 1982, Rickerl and Smolik 1990, Lemme 1988), just as wetland vegetation otherwise might. If little crop is left, the soil litter layer could potentially become depleted of organic carbon and soil compaction from harvest machinery could reduce surfaces for microbial activity, thus reducing the ability of a wetland to remove nitrate and contaminants, and allowing nitrate to infiltrate and contaminate groundwater.

4. Effects on Capacity to Support Vascular Plant Production. The domestic varieties of plants that replace wetland species may or may not be more productive, depending on crop type and management practices.

5. Effects on Capacity to Support Invertebrate Production. Invertebrate production is generally less in the temporary and seasonal basins where it is feasible to grow crops than in semipermanent and permanent basins. Repeated tillage and cultivation often destroy eggs and dormant phases of aquatic and soil invertebrates. Particularly when this is coupled with often simultaneous increases in soil salinity, it can cause severe declines in invertebrates important to waterfowl (Edwards and Lofty 1975).

6. Effects on Capacity to Support Waterfowl Production. Although waterfowl frequently use tilled wetlands during the nesting and migration seasons, use is generally lower than in untilled wetlands (Talent et al. 1982, LaGrange and Dinsmore 1989). Waterfowl (particularly pintail) also nest in tilled uplands that adjoin wetlands. Nesting success in uplands is generally lower than in wetlands (e.g., Cowardin and Johnson 1979). However, if uplands are untilled, nesting success may actually be greater than in wetlands. This is particularly true if untilled uplands are planted cover or idle grassland (Klett et al. 1988). Some species (e.g., gadwall, northern shoveler) actually have greater success nesting in cropland than along the edges of wetlands

(Klett et al. 1988). Among these species, densities can be up to 16 times greater in untilled than in tilled areas (Higgins 1977). In particular, where no-till methods are used to cultivate cropland (or where robust crop residue is left), nest success rates can be great enough to sustain populations of these species (Cowan 1982, Duebbert and Kantrud 1987). Of the several possible management strategies simulated in the model by Cowardin et al. (1988), the institution of no-till practices provided the greatest benefit to waterfowl. Benefits were even greater than acquiring more wetlands and halting artificial drainage.

Agricultural chemicals used on the planted crops can poison or alter the food supply of wildlife (Borthwick 1988, Sheehan et al. 1987, Wayland and Boag 1990), as will be discussed in section 4.8. Although spring plowing can disrupt migration patterns on southeastern areas of the PPR (Pederson et al. 1989), crops such as barley, durum, corn, and bearded wheat are often heavily used by migrating waterfowl, whereas soybean may be mostly avoided in the PPR (LaGrange and Dinsmore 1989).

Questions have also been raised concerning whether cultivation of particular crops or use of particular management practices tends to (a) increase predator populations by increasing overwinter survival of predators, or (b) reduce predation on waterfowl by providing a source of "buffer" prey to predators. Waterfowl predators in the U.S. portion of the PPR mainly include red fox, raccoon, skunk, mink, badger, Franklin's ground squirrel, and of course (during non-breeding seasons) recreational hunters. Rates of waterfowl nest predation are quite high (e.g., 54 to 85%), particularly in western Minnesota and eastern North Dakota, and where wetland basins have been internally fragmented by road corridors or travelways for center-pivot irrigation equipment (e.g., Peterson and Cooper 1991). Yet, at least 15-20% of waterfowl attempts to nest must succeed in order to sustain continental populations (Cowardin et al. 1988, Klett et al. 1988). Local trapping and removal of predators can sometimes increase waterfowl hatch rates by 10% (e.g., Greenwood 1986), and fencing can increase nest success from a usual rate of about 10% to a rate of up to 65% (Lokemoen et al. 1982). Predation also seems to be less in areas where coyotes (a competitor of red fox) are numerous (Klett et al. 1988). Waterfowl predation rates are generally less in wetter years, perhaps because of greater availability of "buffer" prey and more dense protective cover. Predator densities in many local areas are probably determined largely by numbers of trappers and the annual market prices for fur. Although some biologists have suggested that changing land use patterns in the PPR might be increasing the populations of predators (e.g., raccoon) or waterfowl vulnerability to them, this has not been quantified sufficiently to determine the severity of impact on waterfowl overall.

7. Effects on Capacity to Provide Winter Wildlife Shelter. Although waste grain may provide limited food, tillage generally reduces the winter wildlife cover function of wetlands.

8. Effects on Capacity to Support Biodiversity. Not only waterfowl, but many nongame species avoid using tilled wetlands; only American avocet, killdeer, and Wilson's phalarope (species most commonly associated with saline conditions) may prefer wetlands that have been tilled (Kantrud and Stewart 1984), but perhaps only if activities associated with tillage (e.g., pesticide

applications) have not disrupted food chains. In addition to removing native wetland vegetation, tillage commonly results in invasion of natural wetland communities by ubiquitous weedy species, mainly upland annual and biennial forbs and grasses.

4.7 Losses Due to Sedimentation

DESCRIPTION: Runoff carries soil particles from agricultural fields and urban areas into depressions on the landscape, which are generally wetland basins. Because most of these basins in the PPR lack outlets, sediment has accumulated since glacial times. Ultimately, sediment accumulates to the point where the entire basin is filled and no longer can sustain wetland functions.

LOSS FACTOR STATUS AND TRENDS: Sedimentation problems may be increasing in the PPR as conversions from pasture to row crops occur (Kantrud et al. 1989). In the USFWS Regional Wetland Concept Plan (USFWS 1990a), sedimentation was mentioned as an important cause of degradation and loss of PPH wetlands in Montana. In a 3877 square-mile area of North Dakota, 40% of the wetland basins were reported to be cultivated right up to the wetland edge (Cowardin et al. 1981). One large South Dakota basin experienced a 24% (2022 acre-foot) increase in silt volume within eight years (Churchill et al. 1975). Annual sediment accretion in four Montana PPR basins ranged from 0.09 acre-feet/mi^2 to 2.00 acre-feet/mi^2 (Frickel 1972).

INDICATORS OF SEDIMENTATION EXTENT: The rate of sedimentation can be represented partly by indicators of **precipitation** and **water yield**. Inputs are additionally represented by indicators of soil erosion, such as the **proximity** to wetlands of **soil types**, **land covers**, and **slope conditions** that are considered highly erodible. The Soil Conservation Service office in each county of the PPR has integrated these factors to identify and list soil mapping units considered to be **Highly Erodible Land** (HEL). Where these HEL units are based on vulnerability to non-wind related erosion (as predicted mainly by slope), these data can be used to assess relative sedimentation risks of various wetland complexes and other water bodies. Perhaps ironically, **artificial drainage** of wetlands might reduce sediment inputs to remaining wetlands by allowing farm operators to shift row crops and small grains to drained lands from areas subject to erosion, while putting these former marginal cropland acres in a permanent cover such as hay (Danielson and Leitch 1986).

The vulnerability of wetlands to sedimentation is also indicated by **wetland water regime** or (less directly) landscape geology, relief, and geographic position. Because they are often smaller and shallower than other basin types, the temporary and seasonal basins would seem more vulnerable to filling by sediment. However, semipermanent basins generally have larger watersheds (drainage areas), so may receive larger amounts of sediment, particularly if upslope storage areas (temporary and seasonal basins) have been drained.

The extent of sediment input also depends strongly on the **type, frequency, and season(s) of tillage**. In a survey of 118 eastern South Dakota basins, Dieter (1991) found that turbidity was 24 times greater in tilled than in untilled wetlands. Wetlands that were only partially tilled, and which often had a surrounding buffer strip, were similar to untilled wetlands. In a similar study, Martin and Hartman (1987a) reported that basins encompassed by tilled land received twice as much sediment as those surrounded by untilled land. Conservation tillage (e.g., reduced till practices that leave crop residue), which in the mid-1980s was used on 20% of the arable land in North Dakota (Grue et al. 1989), appears to be increasing. Use of conservation tillage practices potentially can reduce sediment inputs (Laflen and Colvin 1981), provided crop residue is left (Lindstrom and Onstad 1984). In contrast, use of summer fallowing and fall tillage aggravates sedimentation. Fall tillage is required when incorporated pre-emergence herbicides are used.

CHARACTERISTICS AND INDICATORS OF FUNCTIONAL LOSS: In virtually all cases, sedimentation diminishes all natural functions of wetlands. It does so mainly by impeding water circulation, infiltration, oxygen exchange, and light penetration. Moreover, much sediment runoff contains adsorbed contaminants. For example, one of the most widely used herbicides in the PPR (trifluralin) is commonly transported with sediment (Neely and Baker 1989). The literature on the effects of sedimentation in wetlands on diversity of each major taxonomic group occurring in wetlands is reviewed by Adamus and Brandt (1990). In PPR wetlands specifically, Niemeier and Hubert (1986) suggested that increasing turbidity was at least partially responsible for a loss in a basin's plant species richness from 52 species in 1896 to 19 in 1981, with a gain of only 5 species. Churchill et al. (1975) sampled and characterized the biota of a PPR basin exposed to heavy siltation from agriculture, and compared it with the biota of another PPR basin exposed to domestic sewage but limited agricultural sediment. Ongoing research suggests that seed bank germination and seedling survival may be profoundly affected by even minor increases in sedimentation (pers. comm., A. van der Valk, Iowa St. Univ., Ames).

Because temporary and seasonal basins are vulnerable to sedimentation, the wetland functions that occur to a greater degree in these basin types are at greater risk of being impacted. These include Maintenance of Runoff Timing and Groundwater Recharge. Functions with less chance of being impacted by sedimentation, because they predominate in more permanent basins, include Fish Production and Furbearer Production.

4.8 Losses Due to Pesticide Use

DESCRIPTION: Pesticides include **herbicides** used for weed control, **insecticides**, and **fungicides**. Impacts to wetland functions occur when pesticides are applied directly to crops within tilled wetlands, or when carried by runoff, groundwater, wind, or animals into wetlands.

LOSS FACTOR STATUS AND TRENDS: Herbicides are by far the most extensively used category of pesticide, with Iowa ranking first in the nation for herbicide use (Minnesota, South Dakota, North Dakota, and Montana are ranked 3rd, 12th, 15th, and 30th, respectively; Giannessi and Puffer 1990). Between 80 and 90% of the acreage of principal crops in North Dakota (Grue et al. 1988), and about 93% of the corn acreage in the Iowa PPR (Kross et al. 1990) is treated annually. The herbicide dicamba, used in all PPR states, is considered to pose a particularly severe threat to groundwater (Tim and Mostaghimi 1991). In the Iowa part of the

PPR, herbicides such as atrazine, which are not highly adsorbed to soil, can and do leach into shallow groundwater during routine field use (Kross et al. 1990), and may persist (Isensee et al. 1990). For medium-sized watersheds in the Midwest, the median post-application concentration of atrazine in streams is reported to be 10 μg/l (Goolsby and Thurman 1990), whereas atrazine is toxic to algae at concentrations of only 1-10 μg/l (deNoyelles et al. 1982, Johnson, D.H. 1986).

Insecticides (mainly organophosphates) are applied to 20% of the corn in the Iowa PPR (Kross et al. 1990) and to about 4% of total crop acreage in North Dakota (Grue et al. 1988). However, for certain crops such as sunflowers, the majority of planted acreage is treated. Moreover, the PPR's major crop (small grains) may soon be threatened by the expanding range of a major pest, the Russian wheat aphid (Grue et al. 1989), which will result in extensive spraying. The primary threat from this pest as of 1987 was to the northern Montana parts of the PPR. Insecticide spraying for grasshopper control is also extensive in some years. In all, the extent of insecticide use in the PPR would be expected to vary inversely with worldwide prices for small grains.

Although claims are sometimes made that aquifer contamination by insecticides is almost always attributable to infrequent, point-source spills (ND Dept. Health and Consolidated Laboratories 1990b), in Iowa only 25% of the groundwater contamination found in a statewide survey could be traced to such spills (Kross et al. 1990). This might be the result of within-region geographic differences in handling practices, use, and geophysical vulnerability of groundwater.

About one-third of the PPR acreage treated by fungicide is treated more than once during a year, whereas pesticides and especially herbicides usually are applied only once annually (Grue et al. 1988). Herbicides and fungicides are applied from the ground, while insecticides in the PPR are usually applied from aircraft, thus enhancing their potential drift into non-target areas. Insecticides are generally one to two orders of magnitude more toxic to birds and aquatic invertebrates than are herbicides (Grue et al. 1988). Effects of fungicides on burrowing invertebrates that help support waterfowl production generally have not been investigated.

The amount of pesticides used within the PPR has increased substantially in the last decade (Grue et al. 1988). In North Dakota, herbicide use increased about 53% between 1978 and 1984 (McMullen et al. 1985). Insecticide applications by aircraft, while relatively limited, are increasing. Planted sunflower crops are most often subject to insecticides applied aerially. Even in carefully controlled situations where skillful pilots applied insecticides under ideal weather conditions, wetland invertebrate populations and waterfowl have been severely impacted, as described below. Moreover, some pesticides are persistent. For example, monitoring in South Dakota indicated that 25% of the pesticide detections involved chemicals that had not been applied to the soil for at least three years prior to sampling (SDRCWP 1990). The USFWS Regional Wetland Concept Plan (USFWS 1990a) mentioned pesticide use as a substantial cause of degradation and loss of PPH wetlands in Montana, and indicated that usage in South Dakota appears to be increasing. Usage of agricultural chemicals generally may increase in the PPR if proposed irrigation projects allow economically marginal farmland to be cultivated more intensively.

INDICATORS OF PESTICIDE EXPOSURE: Pesticides are applied directly to wetlands that are capable of supporting crops. These are generally temporary and seasonal basins, with some cultivation also occurring in semipermanent basins during drier years. Thus, **wetland water regime**, or (less directly) landscape geology, relief, and geographic position, can be used to indicate subregions where effects of direct pesticide applications are most likely. At the time of the season when insecticides are applied, temporary basins generally do not contain water, whereas they do contain water when most herbicides are applied (Grue et al. 1986). **Land ownership** also may predict the incidence of direct exposure of wetlands to pesticides, as pesticide use is prohibited or severely restricted on most areas owned or managed directly by private conservation groups or government agencies.

Indirect entry of pesticides into wetlands is probably more extensive. The chance of contamination from pesticide treatment of surrounding uplands depends on characteristic **methods, rates, frequencies, and seasonal timings of pesticide application**, as well as the pesticide's physicochemical mobility (e.g., transported by sediment vs. rapidly infiltrated), persistence, and bioaccumulation potentials. These can be inferred directly from **pesticide type** and indirectly by **crop type** (i.e., assuming particular pesticides are associated with particular crops). Pesticide input also depends on (a) soil leaching potential, as indicated by **soil type and drainage systems**; (b) **proximity** of wetlands and treated areas, (c) transport mechanisms, as indicated by **precipitation** and **water yield** or their surrogates (e.g., **rainfall/snowmelt intensity, watershed shape, soil type**, and **slope**); and, for insecticides, (d) the **wind direction and velocity relative to the spatial positions of crop acreage and wetlands** at the time of spraying. Wetlands with high **alkalinity** or salinity are particularly effective in immobilizing many non-pesticide contaminants (e.g., certain metals). Wetland exposure to pesticides also depends partly on the **type of tillage** that is used. Use of conservation tillage (e.g., reduced till practices which leave crop residue) appears to be increasing, and potentially can alleviate problems with runoff of sediment-borne pesticides. Organic practices (i.e., no chemical applications) are also likely to benefit most wetland functions because of their ability to maintain the soil moisture and structure that sustains detoxifying microbes, particularly during drought years (e.g., Rickerl and Smolik 1990).

CHARACTERISTICS AND INDICATORS OF FUNCTIONAL LOSS:

1. Effects on Capacity to Maintain Runoff Volume and Timing, Recharge Groundwater, Retain Sediment and Phosphorus. Insecticides are unlikely to have any effect on these functions. Herbicides which alter plant density and community structure could, in theory, alter transpirative losses of water from wetlands.

2. Effects on Capacity to Remove Nitrate and Detoxify Contaminants. If plants killed by herbicides are removed (e.g., burned), the ability of wetlands to remove nitrate and detoxify pesticides could be diminished because plant litter is essential to the microbes responsible for

these functions. There are few data on the direct effects of pesticides on microbes most responsible for denitrification or detoxification. Herbicides generally may be more toxic to microbes than insecticides, and are more widely used in the PPR. Microbial functions were not inhibited by atrazine in controlled experiments by Johnson, B.T. (1986), and Fraser et al. (1988) found no adverse effects on denitrification or microbial biomass during applications of herbicides, pesticides, or fertilizers to corn. However, they found some reduction in soil microbial activity when corn received a combined dose of fertilizer, herbicides, and insecticides. Herbicides tested were alachlor (Lasso), metribuzin (Sencor), and cyanazine (Bladex); fertilizers were manure and ammonium nitrate; and the pesticide was terbufos (Counter 15 G). No microbial inhibitory effects of terbufos were found by Laveglia and Dahm (1974) in three Iowa soils.

3. Effects on Capacity to Support Vascular Plant Production. Herbicides have an obvious detrimental effect on some wetland plant species. Effects on primary production of non-target plant species has generally not been studied in the PPR.

4. Effects on Capacity to Support Invertebrate and Waterfowl Production. Sources of information on risks of pesticides to PPR wildlife are described by Facemire (1991). The risks of adverse effects of insecticides are summarized by Grue et al. (1986, 1988):

> "The potential for agricultural chemicals to enter prairie wetlands and affect the reproduction and survival of waterfowl appears to be great, particularly for the most toxic and widely used insecticides. Of the 16 most widely used insecticides in North Dakota in 1984, 9 have been implicated in wildlife mortality elsewhere, and of these, 4 (carbofuran, chlorpyrifos, methyl and ethyl parathion) have been associated with deaths of waterfowl. In addition, 13 of the 16 insecticides used the most in North Dakota in 1984 were either highly toxic to aquatic invertebrates or to birds. In 1984, 39% of the crop acreage in North Dakota was treated with compounds toxic to **both** birds and aquatic invertebrates, 58% was treated with compounds highly toxic just to aquatic invertebrates, and 0.5% was sprayed with compounds considered directly toxic just to birds.

Although herbicides are generally less toxic than insecticides, certain ones that are widely used in the PPR (e.g., triflualin, atrazine, and 2,4-D) are moderately toxic to aquatic food webs. By substantially reducing nesting cover, herbicide applications can inhibit nesting, decrease the supply of "buffer" prey for predators, and expose waterfowl to much greater predation as they are forced to search more widely for scarce food (Dwernychuk and Boag 1973). Nonetheless, Duebbert and Kantrud (1987) detected no reduction in nest success from application of herbicides and fungicides to one study area.

Moreover, combinations of herbicides and insecticides can act synergistically to create a greater toxic effect. Inadvertent combinations can result from reuse of spray containers, from drift into adjoining fields treated with another pesticide, or from application to fields previously treated with another pesticide (Borthwick 1988). Also, some of the "inert" chemical agents with which pesticides are mixed can have synergistic toxicity effects on nontarget organisms (e.g., Buhl and Faerber 1989).

5. Effects on Capacity to Support Fish and Furbearer Production. In the temporary and seasonal basins where most pesticide is sprayed, these functions either do not occur, or occur to a more limited extent.

6. Effects on Capacity to Provide Winter Wildlife Shelter. Herbicides potentially reduce the winter wildlife cover function, unless robust crops (e.g., corn stubble) are left standing or waste grain is left (O'Connor and Shrubb 1986).

7. Effects on Capacity to Support Biodiversity. Pesticides would be expected to simplify community structure, food webs, and genetic diversity in wetlands. Surviving species are likely to be mainly ubiquitous, opportunistic species, as discussed in the review by Adamus and Brandt (1990).

4.9 Losses Due to Excessive Nutrient Inputs

DESCRIPTION: Wetland functions can be altered by excessive nutrient inputs. These inputs may originate from fertilizer applications, livestock, dry deposition, or sewage/septic systems. "Excessive" inputs are considered to be those which wetlands are incapable of assimilating without long-term detrimental impacts on wetland functions.

LOSS FACTOR STATUS AND TRENDS: Fertilizers are probably the main source of excessive nutrients in runoff in the eastern PPR, particularly when applied at greater than recommended rates. A survey in Nebraska found that in one region 14% of the agricultural land was fertilized at a rate greater than recommended for protection of groundwater (Schepers et al. 1991). However, in northwestern parts of the PPR, livestock probably contribute more to aquatic enrichment than does cropland. In Montana, phosphorus is the predominant plant nutrient applied as fertilizer (Bauder et al. 1991). In Iowa, corn farming contributes 47-66 lbs./acre phosphorus and 91-142 lbs./acre nitrogen (Kross et al. 1990). In South Dakota, feedlots contribute about 350 lbs./acre phosphorus and 530 lbs./acre nitrogen (Dornbush and Madden 1973). Many towns, at least in South Dakota, use wetlands intentionally or incidentally for sewage treatment (USFWS 1990a). However, in a statewide survey of nitrate-contaminated groundwater in Iowa, suburban septic systems were a minor contributor compared to current or former animal feedlots (Kross et al. 1990). About 43% of the wells near such feedlots were severely contaminated. Acidic precipitation has also been theorized as a possible factor in increasing eutrophication. Acids can increase the dissolution of carbonate minerals that characterize many PPH wetlands, and perhaps increase nutrient concentrations by dissolving nutrients bound in sediments (USGS 1984).

The USFWS Regional Wetland Concept Plan (USFWS 1990a) mentions fertilizer use as a substantial cause of degradation and loss of PPH wetlands in Montana, and this is probably true elsewhere in the PPR as well. Use of agricultural chemicals generally may increase in the PPR if proposed regional irrigation projects facilitate the increased cultivation of economically marginal farmland.

INDICATORS OF FERTILIZER EXPOSURE: Fertilizers are applied directly to wetlands that are capable of supporting crops. These are generally temporary and seasonal basins, with some cultivation also occurring in semipermanent basins during drier years. Thus, **wetland water regime**, or (less directly) landscape geology, relief, and geographic position, can be used to indicate subregions where effects of direct fertilizer applications are most likely.

Indirect applications are probably more extensive. The chance of wetland exposure to fertilizers applied to surrounding uplands depends on characteristic **methods, rates, frequencies, and seasonal timings of fertilizer application**. This can be inferred directly from **fertilizer type** (e.g., manure vs. ammonium nitrate) and **crop management practices** (e.g., continuous corn vs. corn following soybeans) and indirectly by **soil and crop type** (i.e., assuming particular fertilizers and management schemes are associated with particular soils and crops). Fertilizer input to wetlands also depends on (a) **proximity** of treated soils to wetlands and connecting subsurface flow zones; (b) transport mechanisms, as indicated by **precipitation** and **water yield** or their surrogates (e.g., **rainfall/snowmelt intensity, watershed shape, soil type,** and **slope**), and (c) soil leaching potential, as indicated by **soil type**, **crop type**, and **management practices**. Although one study (SDRCWP 1990) showed denitrification rates being higher in soils underlying corn and alfalfa (45-80 kg/ha/yr) than in those underlying grass (1-30 kg/ha/yr), groundwater nitrate concentrations did not reflect crop type or tillage practices (conventional vs. conservation tillage).

CHARACTERISTICS AND INDICATORS OF FUNCTIONAL LOSS:

1. Effects on Capacity to Maintain Runoff Volume and Timing, and Recharge Groundwater. Manure fertilizers can increase infiltration (Odell et al. 1982). Thus, if applied extensively, manure fertilizers might indirectly increase recharge and help alter timing of runoff on a very local scale.

2. Effects on Capacity to Retain Sediment and Phosphorus. Effects of nutrients on these functions are unlikely to be measurable, at least in the short-term. Specific phosphorus loading rates, at which the phosphorus assimilative capacities of various types of PPH wetlands are overwhelmed, are unknown.

3. Effects on Capacity to Remove Nitrate and Detoxify Contaminants. Manure fertilizers can increase denitrification in soils, and thus, if extensively applied, can indirectly help wetlands remove additional nitrate runoff. If nutrient runoff increases the root mass density of wetland vegetation, it might have the same effect on denitrifying and detoxifying microbes (Fraser et al. 1988). Unlike the phosphorus retention function, the capacity of wetlands for denitrification does not seem to diminish much with repeated loadings over time (Richardson 1989). Specific pesticide loading rates, beyond which the detoxification capacities of various types of PPH wetlands are overwhelmed, are unknown. It is unknown whether the capacity of PPH wetlands

for detoxifying pesticides diminishes or increases with repeated loadings over time, or is affected by nutrient levels.

4. Effects on Capacity to Support Vascular Plant Production, Winter Wildlife Shelter. In situations where nutrients severely limit production in PPH wetlands, additional enrichment may enhance this function, at least temporarily. Saline wetlands may respond differently than nonsaline wetlands (e.g., Loveland and Ungar 1983).

5. Effects on Capacity to Support Invertebrate, Fish, Waterfowl Production. The effects of enrichment on these functions are essentially unstudied in the PPR, and probably depend on the initial trophic status and soil type of the wetland receiving the inputs. Specific rates of organic accumulation, at which the decomposition and carbon cycling capacities of various types of PPH wetlands would be overwhelmed (e.g., as evidenced by acidification and total anaerosis), are unknown. Invertebrates generally become more abundant with increased nutrient concentrations (e.g., Cyr and Downing 1988, Belanger and Couture 1988, Sedana 1987), but species richness may decrease (Johnson and McNeil 1988, Wiederholm and Eriksson 1979). Moreover, shifts in invertebrate community composition are likely to cause shifts in waterbird community composition. For Great Lakes wetlands, Crowder and Bristow (1988) hypothesized the following series of events that might lead to a waterfowl decline in deeper basins as a result of eutrophication:

> "For the waterfowl, the effect of inshore eutrophication is an initial increase in food plants, a gradual replacement of favorite species by less desirable plants, and finally a total loss of submersed and floating-leaved plants coincident with an extension of cattail marsh. The extended marsh in turn declines, having been exposed to wave erosion through loss of the deeper zones of vegetation."

If extreme nutrient enrichment results in formation of monotypic stands of dense vegetation, wetlands will provide less suitable habitat for waterfowl. Effects of excessive nutrients on fish are also likely to be adverse in PPH basins, because excess nutrients trigger growths of algae which, as they decay beneath the ice in winter, deplete oxygen and kill fish (e.g., Barica and Mathias 1979). Effects of excessive nutrients on algal production in saline PPH basins may not conform to paradigms based on studies in freshwater basins (e.g., Bierhuizen and Prepas 1985).

6. Effects on Capacity to Support Biodiversity. Enrichment probably poses the greatest threat to bog wetlands of the PPH, because of the delicate nutrient status and highly restricted ranges of many of the species they contain. The literature on the effects of eutrophication on diversity of each major taxonomic group occurring in wetlands is reviewed by Adamus and Brandt (1990). Limited evidence suggests that extreme enrichment (e.g., as possibly associated with sustained wetland use by high densities of livestock) might lead to formation of monotypic stands of vegetation, perhaps with related decreases in species richness of other flora and fauna. In PPR wetlands specifically, Niemeier and Hubert (1986) suggested that increasing turbidity related to excessive phytoplankton biomass was at least partially responsible for a loss in a basin's plant species richness from 52 species in 1896 to 19 in 1981, with a gain of only 5 species.

4.10 Losses Due to Excessive Human Visitation

DESCRIPTION: Too frequent or oppressive human visitation to wetlands, whether for farming activities or for recreation, can cause long-term impairment of certain valued functions.

LOSS FACTOR STATUS AND TRENDS: Historically, human population densities have been low in the PPR and the regionwide trend is toward decreasing population growth. Nonetheless, disturbance of wildlife in some wetlands may be increasing due to improved methods for access (e.g., off-road vehicles). Hunting and fishing activities, despite the fact that for decades they have spurred commitments to wetland conservation, continue to remove a portion of the annual production of wildlife. Whether such activities merely represent compensatory mortality or a drain on production has yet to be conclusively resolved for all harvested species.

INDICATORS OF HUMAN DISTURBANCE: Human activity within wetlands depends partly on physical access. Temporary and seasonal basins are probably visited most often, with some visitation of semipermanent and permanent basins occurring along their edges and during drier years. Thus, **wetland water regime**, or (less directly) landscape geology, relief, and geographic position, can be used to indicate subregions where wetland exposure to excessive human visitation is most likely. **Ownership patterns and policies** and **proximity to population centers** also influence the rate of human visitation.

CHARACTERISTICS AND INDICATORS OF FUNCTIONAL LOSS: Impacts are likely to occur mainly to Biodiversity, Wildlife Production, and Winter Wildlife Shelter functions. Generally it is the rarer, larger, more mobile and migratory species that seem most sensitive to human approach. Buffer zones of **tall vegetation** (e.g., shrubs) surrounding some wetlands can help reduce stress to wildlife by screening visual sources of disturbance, as well as improving water quality. Also, wetlands that are **smaller, narrower, or crossed by dikes or travelways for irrigation equipment** may be subject to greater functional loss, through increased predator access (e.g., Peterson and Cooper 1991), sedimentation, more severe hydrologic and chemical variability, and more frequent exposure to human disturbance. The literature on the effects of human visitation on each major taxonomic group occurring in wetlands is reviewed by Adamus and Brandt (1990), and for waterfowl specifically in an upcoming USFWS report (pers. comm., C. Korschgen, U.S. Fish and Wildlife Service, Madison, Wisconsin).

5.0 REPLACEMENT POTENTIAL

Assessing replaceability of wetland functions involves considering both (a) the **probability** that attempts to replace wetland functions will succeed, and (b) assessing the **timespan** required for the functions to reach a desired state. Arrival at the desired state is determined largely by initial state of the wetland (or reconfigured upland) and subsequent rates of soil development, colonization, and vegetative succession.

5.1 Status of Replacement Efforts

A variety of techniques are used to restore, create, or enhance PPH wetlands. These include the following, for example:

Block drainage ditch with clay core dam
Block natural drainageway
Raise outlet culvert
Put standpipe on existing drain
Dredge to remove sediment, contamination
Control cattails with herbicide or other techniques
Idle cropped wetlands
Break or remove tile drains
Delay hay cutting
Delay or halt fall tillage
Erect nest structures
Fence wetlands to exclude predators
Remove predators
Use no-till or conservation tillage techniques
Increase July brood water
Plant nesting cover
Reduce salinity (by using shallow or flow-through flooding during drawdowns, rather than complete drawdowns)

However, in this report, the term "replacement" covers only efforts to restore or create wetlands; wetland acquisition (e.g., shift from private to public ownership) and wetland enhancement activities are not included. Efforts to replace wetland losses appear to be increasing in the PPR. Replacement activities are being conducted as part of many government programs, including but not limited to the North American Waterfowl Management Plan (NAWMP) Prairie Pothole Joint Venture, the ASCS Conservation Reserve Program, "Swampbuster" provisions of the Food Security Act of 1985, and mitigation requirements related to wetland fill permits under Section 404 of the Clean Water Act. Under some of these initiatives, activities focus on protecting both wetlands and adjoining uplands, in order to maximize ecological benefits and enhance the investment of time and funds in wetlands. Groups most involved with wetland replacement have included the U.S. Fish and Wildlife Service, U.S.

Bureau of Reclamation, Soil Conservation Service, Federal Highway Administration, Farmers Home Administration, Ducks Unlimited Inc., and state fish and game departments.

Table B2 (p. B-62) summarizes recent wetland restoration and creation efforts under the NAWMP. By far the most extensive efforts have been in Minnesota, followed by South Dakota, North Dakota, Montana, and Iowa. Regionwide, restoration and creation efforts cover roughly equal acreages, but show some differences by state. Iowa and North Dakota have much more restoration than creation, whereas the opposite is true for South Dakota. There appears to be considerable potential for restoration under several government programs. For example, under the Conservation Reserve Program (CRP), 2,325,980 acres of erodible land in the PPR were enrolled as of January 1988. Estimating that restorable drained wetlands cover 5% of the CRP acreage would mean that there are 116,300 acres of wetland habitat potentially available for restoration (Dornfield and Warhurst 1988).

Choice of a particular restoration technique depends mainly on which function(s) one wishes to replace or restore, the costs, legal or policy constraints, and the landscape setting. General principles for creating and restoring PPH wetlands are described by Hollands (1990), and the SCS and Bureau of Reclamation are currently developing more detailed manuals on the subject. The primary objective of most projects in the region has traditionally been to create or restore wildlife habitat. Optimizing for this objective (e.g., during the engineering design of the new wetland and the selection of location in the landscape) cannot be assumed to always be compatible with optimizing for all other wetland functions. Recent studies have focused almost exclusively on the waterfowl production function, and as explained under this function below, restoration and creation of this function has generally been judged successful. The potential for restoring or creating most other functions is undocumented in the PPH.

5.2 Potential for Replacing Specific Wetland Functions

1. Replacing the Runoff Maintenance Functions. Replacement of runoff functions is most likely to be desired in situations where temporary and seasonal wetlands are converted or degraded by filling, sedimentation, or artificial drainage. There is considerable engineering literature and experience in the use of constructed detention basins for runoff maintenance (a particularly useful review and analysis is that of Dreher et al. 1989). In many ways created PPH wetlands are hydraulically similar to constructed detention basins. Inasmuch as the effectiveness of detention basins for runoff maintenance has been widely demonstrated, it is likely that created or restored wetlands, if properly designed and positioned in the landscape, could replace or augment the ability of natural wetlands to maintain runoff timing, and perhaps runoff volume as well. However, new basins that are situated at improper positions in the landscape can aggravate peak flows (McCuen 1979). Basins constructed to reduce peak flows from major (100-year) events may extend the duration of high flows, as well as having little affect on more frequent (e.g., 2-year) runoff events that may be of greater consequence to ecological and water quality functions (Dreher et al. 1989). Basins constructed in watersheds larger than about 10 square miles are usually unlikely to maintain pre-development peak flow conditions (Dreher et al. 1989).

2. Replacing the Ability of Wetlands to Recharge Groundwater. The groundwater recharge function may be more feasible to replace through wetland creation than through restoration. Most wetland basins in the PPR are intricately interconnected by groundwater flows. The ability to restore these connections once wetlands are altered is highly uncertain. For example, hydraulic conductivity of underlying soils and sediments is an important determinant of recharge rates, and in newly constructed basins, hydraulic conductivity is often less than in natural soils (Potter et al. 1988). On the other hand, a number of technical studies, including some in North Dakota (Pettyjohn 1981), have demonstrated the ability to artificially increase recharge (e.g., through construction of wetland-like artificial recharge pits or water spreading areas), given the proper geologic and topographic conditions. In South Dakota, Emmons (1987) mapped areas near Aberdeen where such artificial recharge might be feasible, using criteria of mean aquifer thickness of > 20 feet and mean thickness of overlying fine-grained sediments of < 10 feet. Caution would be necessary to avoid causing salination of surrounding cultivated soils, especially in irrigated areas (Skarie et al. 1986, Bischoff et al. 1984). Replacement of the recharge function is most likely to be desired in situations where temporary and seasonal wetlands are converted or degraded by filling, sedimentation, dugout construction, or artificial drainage.

3. Replacing the Ability of Wetlands to Retain Sediment and Phosphorus. Retention of sediment and phosphorus within PPH basins is directly related to hydraulics of the basins. From the discussion above (#1), it would seem that these functions could easily be replaced either through restoration or creation. In fact, a few wetlands have been created or modified in the PPR specifically for this purpose. In Ames, Iowa, a series of created wetlands has been used to remove nutrients and odors from a hog feedlot (pers. comm., A. van der Valk, Iowa St. Univ., Ames). In Steele County, North Dakota, hypereutrophic water from the bottom of Golden Lake is being pumped into a **natural** wetland to reduce the lakewater nutrient load and thus reduce problems with nuisance algae in the recreationally important lake. If functional losses are to be compensated by creating wetlands, these new basins should be excavated from soils that have high adsorption potential for phosphorus, are low in leachable phosphorus, and are relatively erosion-resistant. Twenty years after being constructed by dynamiting, 19 Iowa wetlands had lost 71% of their depth due to erosion and sedimentation. Also, the new basins should be situated where they are most capable of intercepting phosphorus-bearing runoff at rates compatible with their assimilative capacity.

4. Replacing the Ability of Wetlands to Remove Nitrate and Detoxify Contaminants. Some efforts have been made to create wetlands for treating contaminants. In Mandan, North Dakota, created wetlands are used for treating oil refinery wastewater (Litchfield and Schatz 1989), and groundwater from the solid waste landfill in Brookings, South Dakota empties into a trench and series of wetland ponds designed and created to intercept, dilute, and treat its contaminants (Dornbush 1989). Replacement of the nitrate removal and contaminant detoxification functions is most likely to be desired in situations where temporary and seasonal wetlands have been converted or degraded by filling, sedimentation, or artificial drainage.

Replacing natural functions through wetland **restoration** may be more certain than replacement through wetland creation. Nitrate removal and detoxification functions depend on microbial communities that flourish in mature hydric soil profiles with abundant organic matter (see section 3.7). These conditions are typically deficient in newly created soil profiles (e.g., Gersberg et al. 1983, Potter et al. 1988). Although some level of denitrification has been documented in recently created wetlands (Stengel et al. 1987), microbial biomass would be expected to be greater in restored wetlands than in created wetlands, because restored wetlands would be expected to have greater remnant carbon sources. Also, in order to effectively detoxify certain pesticides, the microbial communities might first need to be "conditioned" by several years of applications of the pesticide (e.g., Kolberg 1990). If wetlands are to be created to support this function, the new basins should be excavated from soils that have adequate organic matter and moisture regimes, and are unlikely to be in a position to recharge groundwater or contaminate wildlife. Also, the new basins should be situated where they are most capable of intercepting nitrogen- or contaminant-bearing runoff or groundwater at rates compatible with their denitrification or detoxification capacity.

5. Replacing the Ability of Wetlands to Support Vascular Plant and Furbearer Production, and Winter Wildlife Shelter. If "percent cover" is accepted as a gross indicator of plant production, then creating PPH wetlands, and particularly restoring them, generally succeeds in restoring primary production. In doing so, the suitability of wetlands for furbearer production and as winter wildlife shelter increases. It can take up to five years for created PPH wetlands to develop natural densities of vegetation (Hudson 1983). The exact duration depends on wetland and soil type, location, intensity of prior disturbance, and other indicators discussed in sections 3.8, 3.13, and 3.14.

6. Replacing the Ability of Wetlands to Support Invertebrate and Waterfowl Production. Research data are not available to substantiate the precise densities of various wetland types that are optimal for waterfowl production, but suggestions of Hubbard (1988) others may be summarized as follows. **Where wetlands have been removed completely from a local landscape (i.e., an area approximately equal to the home range size of most waterfowl, or about 1 to 4 square miles), waterfowl populations will be increased the most by restoring or creating a semipermanent or permanent basin. However, in extensively drained landscapes where there is at least one semipermanent basin per 4 square miles, waterfowl populations may derive the most benefit from adding temporary or seasonal wetlands.** These basin types typically have suffered the greatest losses from drainage, provide complementary support functions, and provide ideal nesting habitat during exceptionally wet years when the usual peripheral nesting cover of semipermanent basins is completely inundated. Depending on waterfowl species, such "satellite" temporary/seasonal basins should be located less than 0.25-2.0 mile from the remaining suitable semipermanent basin, and **should be positioned so that adequate cover (e.g., CRP or other idle land, few highways, not grazed continuously) is present in the corridors connecting them with semipermanent basins.** Where such cover does not already exist as a result of the CRP or other factors, restoring the upland cover will probably contribute more waterfowl breeding success than restoring additional wetlands in the vicinity (Cowardin et al. 1988). Little is known at a landscape level of the ratio of idle upland to wetlands (of each type) that is needed to sustain waterfowl production. For at least one species (blue-winged teal), creating wetlands in parts of the PPR may yield the

greatest benefit where (a) wetlands suitable as nesting habitat are present at a density of not less than about 480 acres per square mile, (b) wetlands suitable for territorial pairing of waterfowl are at a density of not less than 160 acres per square mile, and (c) wetlands suitable as habitat for broods comprise not less than 50 acres per square mile, whichever is most limiting. For pairs, the 160 acres should be distributed such that there are ideally 150 individual wetlands per square mile. For broods, the 50 acres should be distributed at a density of between 6 (Sousa 1985) and 12 (Bellrose and Trudeau 1988) wetlands per square mile, and wetlands within clusters should be spaced less than about 0.15 mile apart. Although the number of nesting ducks may continue to increase as wetlands are added above these levels, duck increases may be at a lesser rate than initially.

Replacement of the invertebrate and waterfowl production functions is most likely to be desired where there has historically been the most conversion of diverse complexes of wetlands, or where the most productive waterfowl basin types (seasonal and semipermanent) have been converted or degraded by filling, groundwater pumping, tillage, sedimentation, or artificial drainage. Cost-benefit aspects of PPH waterfowl habitat restoration are addressed by Sousa (1985) and Beekie (1990).

A number of PPR studies have examined invertebrate and/or waterfowl use of restored or created wetlands. In Minnesota, Dornfield and Warhurst (1988) reported that, two years after restoration, it was often difficult to tell that wetlands had ever been drained, even those converted to agriculture for more than 70 years. They reported that duck nesting pairs were found in much greater densities on these restored wetlands than on natural undrained wetlands. Other biological aspects of restored wetlands are reported by Sewell (1989). In North Dakota, Rossiter and Crawford (1981) and Kreil and Crawford (1986) studied 20 PPH wetlands created by highway construction. They reported that waterfowl brood densities on created wetlands compared favorably with those on natural wetlands. However, invertebrate densities were lower than in natural wetlands. The created wetlands were generally smaller than the natural wetlands. Also, considerable data document the value of "dugout" wetland creation projects to waterfowl production (see section 4.4).

It can take up to five years for created PPH wetlands to develop enough emergent vegetation to fully support nesting waterfowl (Hudson 1983). The exact duration depends on wetland and soil type, location, intensity of prior disturbance, and other indicators discussed in sections 3.8, 3.13, and 3.14.

7. Replacing the Ability of Wetlands to Support Fish. Numerous fish ponds have been successfully created throughout the PPR, so it seems reasonable to assume that fish production functions could be fully replaced by appropriately designed and created/restored wetlands. Replacement of the fish production function is most likely to be desired in situations where permanent or semipermanent basins have been converted or degraded by filling, groundwater pumping, sedimentation, or artificial drainage.

8. Replacing the Ability of Wetlands to Support Biodiversity. Biodiversity is unquestionably one of the most difficult functions to restore or recreate fully. This is because natural assemblages of species are often so finely adapted to slight spatial and temporal variations in their environment, that it is impossible to recreate exactly the same species compositions, or even the same functional groups and food webs, if indeed that is desired or necessary. One less demanding biodiversity objective may simply be to prevent species or functional groups from becoming extinct (extirpated) in the region as a whole, without regard to their changing status in each particular wetland. From this perspective, if appropriate conditions for particular restricted species are reproduced and sustained in restored or created wetland complexes, and if those species which are less dispersive are (where necessary) artificially introduced to the new areas, then biodiversity may be maintained. However, usually very little is known about the environmental requirements of the rarest and most restricted species.

The ability of restored or created PPH wetlands to maintain biodiversity at landscape scales has generally not been studied. A recent retrospective study of created wetlands in Iowa found substantial changes in plant and bird species composition in a dugout wetland 27 years after construction, as compared to rates of species change in a natural wetland that had remained unaltered (pers. comm., M. Weller, Texas A & M University, College Station).

Replacement of the biodiversity maintenance function is most likely to be desired in situations where rarer wetland communities (e.g., as listed on page B-56) have been altered by any of the loss factors discussed in section 4.3, or by invasion of aggressively competing species following such disturbances. Data from Brown and Dinsmore (1986) suggest that in Iowa, at least 6-30 acres of wetland per square mile would be needed to maintain most of the wetland avifaunal diversity (about 24 species).

5.3 Indicators of Replacement Potential

Site-Specific and Landscape Conditions

A fundamental prerequisite for successful creation or restoration of PPH wetlands is that a **water source** be present. In the case of semipermanent and permanent wetlands, an important water source may be groundwater, so these created/restored wetlands must be deep enough to intercept the water table during the intended seasonal periods. In the case of temporary and seasonal wetlands, the water source is usually overland runoff. Thus, potential water yields must be determined (e.g., through measurement of drainage area and estimation of evapotranspiration and precipitation) to assure that runoff will be sufficient to predictably maintain moisture in the created/restored wetland for the intended duration and frequency.

The more promising sites for wetland restoration/creation may be those surrounded by large areas of land that is geotechnically suitable for constructing new wetlands. Geotechnically suitable landscapes for wetland construction include those with mostly **flat slopes**, and **soils** which are (a) relatively **impervious**, (b) **not prone to subsidence or erosion** due to their intrinsic characteristics or physical setting (e.g., wave exposure), and (c) lacking extreme concentrations of **nutrients, salts, metals,** or **acids** that would cause water quality problems when flooded. Soils at risk of becoming saline if inundated are well known by PPR soil scientists, and should be avoided if temporary or seasonal wetlands are being created. Landscapes might be avoided where excavation and increased evapotranspiration associated with wetland creation could adversely draw down water levels of nearby natural wetlands, or where new wetlands could impede flood conveyance and synchronize flood peaks (e.g., McCuen 1979).

The **basin water regime** is itself an indicator of the feasibility of PPH wetland creation/restoration. Creation and restoration efforts probably have most often have involved permanent, semipermanent, and seasonal basin hydrologic types. Although often the type most available for purchase or lease, temporary basins are the most costly to acquire and develop because of their competing value (except on CRP land) as cropland. In contrast, most semipermanent basins, if drained, would be unsuitable for crops due to high salinity and thus are more willing to be sold by owners. In Douglas, Grant, and Otter Tail Counties of Minnesota, 228 Ducks Unlimited restoration projects were located mostly in seasonal and semipermanent wetlands with a mean size of 4.4 acres and range of from 0.5 to 35 acres (Dornfeld and Warhurst 1988).

Presence of a dense and diverse **seed bank** is also a contributing indicator of probable restoration/creation success. Although former wetlands that have been drained for fewer than 5-10 years generally have sufficient density and diversity of dormant seeds to support restoration of normal wetland plant communities (Wienhold and van der Valk 1988), restoring older cultivated lands is more problematic. Seed banks are also impoverished in saline (alkali) wetlands and impounded lacustrine wetlands (Pederson and Smith 1988). Vegetation structure is one of the most important determinants of wetland function, so sites where propagules of **rapidly- and aggressively-propagating vegetation** (e.g., duckweed) are present may hold more potential for rapid development of many wetland functions than very isolated sites devoid of such species.

The feasibility of replacing a wetland hinges not only on the intrinsic characteristics of its type, but also on surrounding landscape characteristics. Certain wetlands or wetland types are typically located in landscape types or geographic areas where construction of new wetlands from existing non-wetland habitats is especially feasible. For example, replacement sites that are **surrounded by large areas of publicly-controlled or undeveloped land** might be considered to have greater potential for successfully creating or restoring wetlands, as compared to sites surrounded by urban development or land unalterably dedicated to non-wetland uses as a result of legal/institutional policies. Also, sites whose surrounding landscape could provide a diverse surplus of individual organisms (especially low-mobility plants, non-insect invertebrates) to colonize a new wetland (e.g., **landscapes with large nearby habitat patches and/or numerous connecting corridors**) might be considered to be most attractive for siting of self-sustaining wetlands. A host of other indicators of restoration potential -- measured both at landscape and site-specific levels -- are presented throughout section 3.0 under discussions of indicators of the individual functions.

Historic Conditions

A decision of whether to attempt restoration of a wetland, or (on the other hand) to consider a degraded wetland a loss and proceed to attempt creation of a new wetland elsewhere, depends partly on the type of loss that has occurred and its extent, the natural resilience and recovery characteristics of the wetland type, and the amount of time and resources one is willing to spend. Physical losses of wetlands due to groundwater pumping are virtually irreversible. Losses due to filling/leveling (section 4.1), dugouts (section 4.4), sedimentation (section 4.7), and excessive nutrient inputs (section 4.9) are relatively costly to undo. Less difficult to reverse may be losses due to artificial drainage, impoundment, and nonpersistent pesticides. If parties responsible for the impacts are cooperative, losses due to grazing and mowing, tillage, and excessive human visitation may be relatively easy to reverse or minimize.

6.0 LANDSCAPE STUDIES AND INDICATORS

6.1 Previous Landscape Studies in the Region

Relatively few research studies in the PPR have taken a regionwide, landscape-level, comparative approach. Perhaps the most common studies of this type have been hydrologic statistical analyses involving regression of watershed characteristics against streamflow in multiple watersheds. For example:

In North Dakota: Crosby 1974, 1975, U.S. Army Corps of Engineers St. Paul District 1989
In South Dakota: Becker 1974
In Minnesota: Guezkow 1977, Moore and Larson 1979, Jacques and Lorenz 1988, U.S. Army Corps of Engineers St. Paul District 1989
In Iowa: Melvin et al. 1971, Lara 1973, 1974
In Montana: Dodge 1972, Johnson and Omang 1976, Johnson et al. 1976, Cunningham and Peterson 1983

The streamflow regression studies contain abundant data on geomorphic characteristics (e.g., sizes, soil types, slopes) of a large number of watersheds, and in a few cases include estimated acreages of wetlands, drained areas, or surface storage areas specifically (e.g., Moore and Larson 1979, Jacques and Lorenz 1988). Other data sources (e.g., Benson et al. 1987) provide watershed boundaries but do not include geomorphic information. Issues surrounding use of regression and simulation modeling approaches, as applied specifically to the PPR, are summarized by Moore and Larson 1979, Miller and Frink 1984, and U.S. Army Corps St. Paul District 1988, 1989. Simulation approaches have been used in several instances in the PPR to understand groundwater and runoff processes at a landscape level (e.g., DeBoer and Johnson 1971, Larson 1975, Crowe and Schwartz 1981, Emmons 1988, Winter and Carr 1980), but few have included an explicit wetland component.

Few broadscale regression studies involving water purification functions of wetlands have been published in the PPR. In northwestern Iowa, Jones et al. (1976) regressed nitrate and phosphorus against land cover variables from 34 watersheds. In eastern Montana, Lambing (1984) regressed sediment yield against land cover and soils data from 121 areas. Landscape-level simulations of nutrient or sediment runoff also have been conducted for several PPR watersheds (e.g., Felderman and Eno 1976). Some have used the AGNPS model, but have not focused specifically on the role of wetlands.

Several regression studies relating waterfowl use to landscape characteristics have been published. These include studies by Ducks Unlimited (see Koeln et al. 1988), Brewster et al. 1976, Brown and Dinsmore 1986, Evans and Kerbs 1977, Flake et al. 1977, Heitmeyer and Vohs 1984, Hudson 1983, Klett et al. 1988, Mack and Flake 1980, Kantrud and Stewart 1977. Only one landscape-level simulation (Cowardin et al. 1988) of waterfowl dynamics has been published, and this did not explicitly examine consequences to production of different wetland configurations and type combinations.

Few time-series regression studies have been done in PPR landscapes, in which changes in drainage, crop management practices, or other potential loss factors have been regressed against changes in streamflow, waterfowl production, or water quality. Most of these few studies have involved trends analyses of streamflow (e.g., Brun et al. 1981).

Landscape data are also becoming available in a few localities for use in runoff simulation models. Specifically, such data are being digitized and compiled for use in applications of the AGNPS model in the state of South Dakota's Oakwood Lakes-Poinsett Research Project (Brookings, Hamlin, and Kingsbury Counties). That 10-year, watershed-scale project is evaluating the effects of crop management practices, and fertilizer and pesticide applications, on groundwater and surface water quality (SDRCWP 1990). In South Dakota, land cover and soils are being digitized for AGNPS applications to the following watersheds: Canyon, Punished Woman (Minnesota River Basin), Redfield (James River Basin), Richmond (James River Basin), State (James River Basin). Similar information is being compiled in the Big Sioux Basin for Lakes Norden and Campbell. About 60 other lake watersheds in South Dakota are being delineated and digitized as part of Section 314 planning studies, but there are no current plans to compile their attribute data. Non-digitized land cover and road mileage maps also are available for all watersheds designated as priority watershed for nonpoint management by the state of North Dakota.

6.2 Sources of Data on Indicators

Future multi-function research and planning efforts in the PPR may be limited by the high cost of acquiring new data at a landscape scale. Despite the paucity of existing sets of comparable, digitized, landscape-level data, such data are perhaps the most practical to use in future analyses. At least for planning-level, relative categorizations, such data can be used to quantify and map the indicators described in previous chapters. In Table B3 (p. B-99), indicators presented in section 3.0 are summarized by function. Then, datasets that might be used to estimate these indicators are indexed to the specific indicators in Table B4 (p. B-101). In some cases, indicators considered to be dependent variables in some analyses may be considered to be independent variables in other analyses. For example, wetland acreage could be used as a dependent variable in a regression against "miles of drainage ditch", but could be used as an independent variable (indicator) in a regression against peak flow. Major characteristics of each data set are briefly summarized at the end of Table B4 (page B-101), with emphasis on current status of regional coverage; a more thorough analysis of each of their strengths and limitations is presented by Adamus (1992).

6.3 Existing GIS Capabilities

In general, there appear to be few central repositories of diverse, digital resource data in the region. In Montana, a Geographic Information System (GIS) and database called "MAPS" is capable of summarizing data on about 20 resource themes by 8 square-mile cell for anywhere in the state (Nielsen et al. 1990). Minnesota also has a raster-based statewide GIS (MLMIS) with information on land use and soil landscape unit, with a minimum resolution of 40 acres. They anticipate completing the vector digitization of NWI maps covering the entire state by June 1992, and are proceeding with an update of the land cover data. Iowa is in the process of developing statewide GIS resource databases, with initial focus on detailed mapping of soils (pers. comm., K. Kane, Iowa Dept. Natural Resources, Des Moines). Of the Dakotas, only South Dakota appears to be moving ahead with GIS capabilities. Their developing GIS currently includes digital versions of 32 NWI quad maps. They expected to complete the 1:100,000 digital soils coverage (STATSGO, State Soil Geographic Database) for the entire state in 1992; more detailed (SSURGO) digitization has nearly been completed for 6 PPR counties ("GIS News in South Dakota" newsletter, SD State Univ.). They hope (in work done jointly with the East Dakota Water Development District) to complete digital coverage for six eastern South Dakota counties in FY92. This coverage will include 1:24,000 scale wetlands, soils, geology, aquifers, floodplains, land cover, and elevation. North Dakota produced a statewide land cover map at 1:500,000 scale in 1978 (Mower 1978), and digital data on land cover and irrigation suitability are available for the Oakes and Lincoln Valley areas from the Bureau of Reclamation.

Table B3. Summary of Indicators, by Wetland Function and Measurement Scale

C= indicator of capacity, I= Indicator of landscape input.

		FUNCTIONS													
	GEO	Maintenance of Runoff Volume	Maintenance of Runoff Timing	Groundwater Recharge	Sediment Retention	Phosphorus Retention	Detoxification	Nitrogen Removal	Vascular Plant Production	Invertebrate Production	Fish Production	Waterfowl Prodction	Furbearer Production	Wintering Wildlife Cover/Shelter	Rare/Restricted Species/Communities
REGIONAL-SCALE INDICATORS															
Position relative to flyway												I			I
Position relative to biome edge															I
Precip-evapotranspir. ratio	4	IC	I	I	I	I	I	I							
Rainfall/snowmelt intensity	4	I	I	I	I	I	I	I							
Growing season length	4	C	C	C	C	C	C	C	C	C	C	C	C		C
LANDSCAPE-SCALE INDICATORS															
Wetland-watershed acre ratio (position in watershed)	3	IC	IC	C	IC	IC	IC	IC							I
Distance to another wetland (contagion)	3	C		C	IC	IC	IC	IC				C	I	I	I
Local basin type diversity	2			C	C	C	C	C	C	C			C	C	C
SITE-SPECIFIC INDICATORS															
Basin type (hydrologic regime)	4	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Frequency of basin connections	2		C		IC	IC	IC	IC			I				I
Years of constant wet or dry (successional status)	2	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Water chemistry															
salinity	3	C			C	C	C	C	C	C	C	C	C		C
other				C											
Sediment type															
organic content	2						C	C	C						
permeability	3	C	C	C	C	C	C	C							
general fertility	3						C	C	C	C	C	C	C	C	C
Basin depth/volume ratio	3	C	C	C	C	C	C	C	C	C	C	C	C		C
Open water % (% veg. cover)	2	C			C	C	C	C	C	C	C	C			C
Open water interspersion (o.w. edge complexity)	2					C	C	C	C	C	C	C	C		C
Vegetation form richness	3								C	C		C		C	C
Islands & upland inclusions	1											C			C

FUNCTIONS

	GEO	Maintenance of Runoff Volume	Maintenance of Runoff Timing	Groundwater Recharge	Sediment Retention	Phosphorus Retention	Detoxification	Nitrogen Removal	Vascular Plant Production	Invertebrate Production	Fish Production	Waterfowl Prodction	Furbearer Production	Wintering Wildlife Cover/Shelter	Rare/Restricted Species/Communities
Vegetation types															
evapotranspiration rates	2	C		I											
root mass density	2						C	C		C					C
primary productivity	1								C	C			C		
typical stand density	2				C	C	C	C	C	C		C	C	C	C
submerged aquatic %	2	C							C	C	C	C			C
eaten by wildlife	1								C			C	C	C	C
In-basin stressor exposure															
pesticides	4							I	C	C	C	C	C	C	C
fertilizer/sewage/manure	1					I	I		C	C	C	C	C		C
artificial drainage	4	C	C	C	C	C	C	C	C	C	C	C	C	C	C
tilled often	3	C	C	C	C	C	C	C	C	C		C	C	C	C
burned often	2	C			C	C	C	C	C	C		C	C	C	C
mowed often	1	C			C	C	C	C	C	C	C	C	C	C	C
visited often	2										C	C		C	C
water level changes often	1		C	C	I	I	I	I	C	C	C	C	C		C
Upslope watershed or buffer zones:															
land slope	4	I	I	I	I	I	I	I							
storage (% lakes, wetlands)	3	I	I	I	I	I	I	I							
Soil types															
erodibility	4	I	I	I	I	I	I	I							
permeability	4	I	I	I	I	I	I	I							
Vegetation/crop types															
evapotranspiration rate	2	I	I	I	I	I	I	I							
root mass density	1	I	I	I	I	I	I	I							
general cover density	1	I	I	I	I	I	I	I				C	C	C	C
eaten by wildlife	1											C	C	C	C
tillage practices	3	I	I	I	I	I	I	I				C	C	C	C

Abbreviations

GEO = Is this indicator likely to exhibit regionwide spatial trends?
1=no; distribution is entirely random and unpredictable, or is even.
3=distribution is somewhat predictable from geography, despite moderate local spatial variation.
5=yes; distribution is geographically distinct; very little local spatial variability.

Some examples:

- The geographic distribution of basin types generally follows definable regional geologic patterns (=4), and vegetation density is somewhat correlated with basin type, so vegetation type is rated "3."
- The regional patterns in landform/slope are generally known, and wetland density (distance to another wetland) and frequency of wetland connections have a greater probability of occurring in flatter subregions.

Table B4. Data Sets of Possible Use for Quantifying Indicators.

Numbers are keyed to specific data sources footnoted in Table B5. Indicators are rated as D= direct, P= partial, I= indirect or inferred estimate of indicator (this does not necessarily imply good accuracy or high spatial resolution).

POTENTIAL DATA SOURCES[a]

	1	2	3	4	5	6	7	8	9	10	11
I. QUANTIFICATION OF FUNCTION											
Wetland effects on streamflow	I			I		I					
Wetland effects on water quality				I		I		D			
Wetland effects on habitat			D	D				I			
II. INDICATORS OF FUNCTION											
REGIONAL-SCALE INDICATORS											
Position relative to biome edge			D								
Precip.-evapotranspiration ratio	I					D					
Rainfall/snowmelt intensity	I			I		D					
Growing season length						D					
LANDSCAPE-SCALE INDICATORS											
Wetland-watershed acre ratio (position in watershed)				D							
Distance to another wetland (contagion)				D							
Local basin type diversity				D							
SITE-SPECIFIC INDICATORS											
Basin type (hydrologic regime)				D							
Frequency of basin connections				I							
Years of constant wet or dry (successional status)	I	D									
Water chemistry (salinity/other)				D							
Sediment type:											
organic content				I		D					
permeability				I		D					
general fertility				I		D					
Open water% (% veg. cover)				D							
Open water interspersion (o.w. edge complexity)				D							
Vegetation form richness				D							
Islands & upland inclusions				D							
Vegetation types:											
evapotranspiration rates				I		I					
root mass density				I							
primary productivity				I							
typical stand density				D							
submerged aquatic %				D							
eaten by wildlife			I								

	1	2	3	4	5	6	7	8	9	10	11
Upslope watershed or buffer zones											
land slope				I	I	D					
storage (% lakes, wetlands)				D			I				
soil types											
erodibility				I		D		I			
permeability				I		I					
vegetation/crop types											
evapotranspiration rate				I	I	I					
root mass density				I							
general cover density				D	I						
eaten by wildlife			I								
tillage practices				D	I			I			

INDICATORS OF VALUE

A. HYDROLOGIC VALUES

	1	2	3	4	5	6	7	8	9	10	11
Number of floodplain residences				D					D		
Value of floodplain residences									D		
Proximity of floodprone developments to upslope wetlands				D					D		
Number of groundwater users	D									D	
Proximity of wells to wetlands										I	
Usual season of flooding	I							D			
Livestock density					I						
Cropped wetland acreage				D	D			I			
Drought vulnerability of crops				I	I						
Average depth of wells	I										

(see also Water Quality Values below)
(see also Habitat Values below)

B. WATER QUALITY VALUES

	1	2	3	4	5	6	7	8	9	10	11
Number of groundwater users	D										
Relative importance of the receiving waters											
Proximity of important receiving waters or aquifers to upslope wetlands				D							

(see also Habitat Values below)

C. HABITAT VALUES

	1	2	3	4	5	6	7	8	9	10	11
Annual moisture condition	I	D									
Fish/wildlife licenses/leases											D
Fish/wildlife harvest											D
Person-days of use											D
Threatened/endangered status of wetland species locally present			D								D
Proximity of wetlands to urban centers				D	D	I		I			

INDICATORS OF FUNCTIONAL LOSS	1	2	3	4	5	6	7	8	9	10	11
Population growth								D			
Wetland conversion trends		D						I			
Filling and leveling activity		I						I			
Proximity and frequency of:											
artificial drainage		I		I	I	I	D	I			
groundwater pumping	D	I						I			
dugout/impoundment construction				D	D						
grazing/mowing		I			D			D			
tillage		I		I	I	I		D			
sedimentation		I				I					
pesticide exposure								D			
fertilizers/sewage/manure		I			I			I			
human visitation				I	I			I			

Table B5. Potential Sources of Existing Regionwide Indicator Data in the PPR

1= Long-term changes in watershed hydrology and water quality:

(a) Data for streams, rivers and wetlands.
Much data, some of it long-term, is available from gauging stations supported by the U.S. Geological Survey and/or state agencies. However, in many cases, gauges are located below impoundments or channelized reaches that would be expected to confound most wetland influence. Seasonal flow duration tables have been prepared for 81 South Dakota rivers by Dornbush (1985). Many of the USGS stations also have simultaneously-collected water quality data. Additional stream water quality data have been collected by state and other federal agencies, as have limited data on contaminants in wetland sediments and fauna.

(b) Data for groundwater.
USGS water quality data, collected at a three-year interval from about 40 North Dakota wells, might be analyzed to determing if groundwater levels and water quality have changed in concert with wetland drainage. However, few monitoring wells in South Dakota are located where the effects of wetland loss would be detectable (pers. comm., D. Hubbard, South Dakota St. Univ., Brookings). There also is a series of county-level summaries of water resource information (data on use, recharge and runoff rates and their variability) for North Dakota (e.g., Randich and Kuzniar 1986) and South Dakota (e.g., Koch and McGarvie 1988). Data on groundwater quality are available from some state water resource agencies (e.g., DeMartino and Jarrett 1991).

2= Long-term changes in wetland and wildlife distribution and/or abundance.

(a) USFWS annual aerial counts of "ponds."
These wetland counts have been conducted along standard transects by federal and state wildlife agencies since the mid-1960's, to be used to index annual climate changes. Waterfowl brood densities have been estimated along these same transects, and USFWS has computed 10-year and long-term means. Data from both the pond counts and the waterfowl brood surveys have been aggregated such that it is not possible to reference the data to exact spatial locations within the transect. Other regionwide surveys of waterbirds have also been sponsored in a few instances by the USFWS Northern Prairie Wildlife Research Center and state wildlife agencies.

(b) Breeding Bird Survey routes; Christmas Bird Counts.
These datasets cover decades, but spatial and annual coverage is spotty. Specific areas can be located within a few miles; accuracy and representativeness is quite variable.

(c) USFWS National Wetlands Trends Surveys (Tiner 1984, Dahl et al. 1991).
This periodic survey does not include a sufficient number of plots in the PPR to reliably estimate trends in wetland acreage within the PPR, either mid-50s to mid-70s, or mid-70s to mid-80s.

(d) USFWS Northern Prairie Waterfowl Research Center database.
The NPWRC has interpreted 1980-84 land cover and wetland types from airphotos of a stratified random sample of 422 plots, each about 10 square kilometers in size and covering all but the Montana part of the PPR (Cowardin et al. 1983). Recent wetland loss rates have been estimated from this (e.g., Klett et al. 1988).

(e) National Resource Inventory (NRI) database.
This database is a successor to the "Conservation Needs Inventories" conducted in the 1960's and 1970's. It can be used to compute changes in the 1982-1987 acreage of nonfederal wetlands in a county, major river basin, or major land resource area. However, results are coarse, sample-based estimates of wetland acreage (as of about 1986). Data are difficult to interpret because of uncertainty in how wetlands were defined.

3= Fish and wildlife distribution, abundance, and species characteristics.

(a) State Fish and Wildlife Departments.
Agencies in various PPR states are developing computerized fish and wildlife information systems (CFWIS) that are databases in which species are referenced to habitat needs, geographic distribution, life history characteristics, and other features.

(b) State Natural Heritage Programs/The Nature Conservancy.
Computerized data are available for some PPH states on distribution of wetland species by county, and (as part of the Vertebrate Characterization Abstracts) on life history characteristics.

4= Wetland maps and/or regionwide data on wetland distribution:

(a) National Wetlands Inventory maps.
These are the most reliable, precise, and widely used source of information on wetland distribution in the PPR. However, map coverage is not yet complete for the region, and only a small portion of the maps have been digitized. For general information, contact Ronald Erickson, USFWS, Federal Building, Fort Snelling (AS/BSP), Twin Cities, MN 55111. To order maps, contact Earth Science Information Center, U.S. Geological Survey, 507 National Center, Reston, VA (phone 1-800-USA-MAPS).

(b) Thematic Mapper (TM) data.
Ducks Unlimited, Inc., has assembled remotely sensed Landsat TM scenes for the entire PPR (Koeln et al. 1988). These have not been converted to maps or compiled with regard to their spatial data characteristics, but could be. The TM scenes were both from 1986 (a wet year) and 1987 (a dry year). For general information, contact Dr. Gregory Koeln, Ducks Unlimited Inc., One Waterfowl Way, Long Grove, IL 60047 (phone 312-438-4300).

(c) "Swampbuster" wetland maps.
USDA Soil Conservation Service staff have hand-drawn wetlands, especially those subject to periodic cultivation, on airphotos at scales of about 1:12,000 or 1:20,000. The basis for these approximate delineations was presence of surface water visible in airphotos, and/or presence of hydric soils based on available county soil survey maps. Only a single copy of these delineations exists, usually at SCS county offices; accuracy of the delineations is unknown.

(d) STATSGO soil distribution + SOILS5 soil attribute data.
These digital maps of soil series, prepared by the USDA Soil Conservation Service, could be used to indicate wetlands by showing hydric soils, depth-to-water table, or drainage condition as a percent of polygon area. They can be produced at a 1:250,000 scale (about 100 acres minimum resolution). Although the digital soils maps have been completed in all PPR states except North Dakota, the SCS timeframe for completing STATSGO's linkages with attribute data (that would allow crude portrayal and summarization of wetland distribution) is uncertain. Much of the PPH wetland resource may not be included because at the coarse scale used, wetland basins may have been categorized not as wetland, but as water or (more often) lumped with adjoining upland soil types. For general information, contact state office of the USDA Soil Conservation Service.

(e) Groundwater or water table maps.
Some state water agencies and the USGS state offices have such maps, or data that could produce such maps (e.g., NDWCA 1991, Hoyer and Hallberg 1991). These might be tested for their ability to infer presence and function of wetlands.

(f) Federal Emergency Management Agency (FEMA) maps.
These maps potentially depict river-associated wetlands. Map scale varies depending on locality, and ranges from 1"=2000 feet to 1"=200 feet. A small subset of the maps (some of the first ones prepared) were also printed on

USGS quadrangles, at 1:24,000 or 1:62,500 scale; printed copies of these are no longer available for purchase, but they can be obtained on microfiche or reviewed in government map libraries. FEMA has budgeted for the eventual digitization of all its floodplain maps; digital versions for about 40 densely-populated counties will be available beginning in mid-1992. For maps, contact Flood Map Distribution Center, Federal Emergency Management Agency (FEMA), 6930 San Tomas Rd., Baltimore, MD 21227-6227 (phone 1-800-333-1363). For general information, contact state office of FEMA.

(g) James River wetland maps.
As part of assessments for the Garrison Diversion Project, the Bureau of Reclamation digitized emergent and aquatic bed vegetation (at scales of 1:12,000 and 1:24,000) within wetlands of four national wildlife refuges only along the James River.

(h) National Resource Inventory (NRI) database.
This is not a map source, but rather a database from which the acreage of nonfederal wetlands in a county, major river basin, or major land resource area may be compiled. It is a successor to the "Conservation Needs Inventories" conducted in the 1960's and 1970's. These are coarse, sample-based estimates of wetland acreage (as of about 1986). Accuracy is unknown, but in 1982 the NRI estimated the PPH wetland acreage at 4,213,000 acres, somewhat lower than most other estimates (Heimlich and Langner 1986). Contact the Resources Inventory Division, USDA Soil Conservation Service, P.O. Box 2890, Washington, D.C. 20013.

5= Other land cover/land use maps or regionwide data on land cover distribution:

(a) USGS Land Use/Land Cover (LUDA) maps.
Digital map data are at 1:250,000 scale (about 40 acres minimum resolution), and show land cover only as of the 1970's or early 1980's. For obtaining maps, contact Earth Science Information Center, U.S. Geological Survey, 507 National Center, Reston, VA (phone 1-800-USA-MAPS).

(b) Thematic Mapper (TM) data.
See 1(b) above for information.

(c) USDA National Resource Inventory (NRI) database.
Data on land cover and management practices are compiled by county, river basin (USGS accounting unit), or major land resource unit, and are for nonfederal lands during 1982 and 1987. Contact the Resources Inventory Division, USDA Soil Conservation Service, P.O. Box 2890, Washington, D.C. 20013.

6= Soil, landform, or climate characteristics (data and/or maps showing actual/potential erosion, salinization, productivity):

(a) STATSGO soil distribution + SOILS5 soil attribute data.
When fully developed (in about one year), this source could be linked to soil attribute information in SCS's SOILS5 computerized database, allowing estimation of the proportion of soils within a polygon (at 1:100,000 scale) that have steep slopes, severe erosion potential, high organic matter, moderate water retaining capacity, and/or other characteristics potentially useful as indicators of wetland function. For general information, contact state office of the USDA Soil Conservation Service.

(b) USDA National Resource Inventory data.
Data on erosion, landform, and slope are compiled by county, river basin (USGS accounting unit), or major land resource unit, and are for nonfederal lands during 1982 and 1987. Contact the Resources Inventory Division, USDA Soil Conservation Service, P.O. Box 2890, Washington, D.C. 20013.

(c) USGS digital elevation model (DEM) data.
Altitude/elevation data are available in digital format by contacting the state USGS office or the USGS-EROS Data Center, Sioux Falls, South Dakota.

(d) U.S. Geological Survey's National Atlas.
This contains coarse-scale maps of annual runoff, evapotranspiration, and water yield.

(e) Soil fertility data.
A series of reports for South Dakota (e.g., Malo et al. 1990) describes general fertility of soils, including some hydric series.

7= Artificial drainage of wetlands.

(a) State water agency data.
Some state agencies compile data on artificial drainage by county. For example, in Minnesota, the extent of artificial drainage was measured in a few watersheds included in the Willey (1988) regression study, as well as in reports prepared for Nicollet County (Dunsmore and Quade 1979a), Blue Earth County (Dunsmore and Quade 1979b), and Brown County (Dunsmore et al. 1979).

(b) Data on center-pivot irrigation.
In northwestern parts of the PPR, extent of new wetland drainage might be crudely estimated from data on increases in center-pivot irrigation in areas of high wetland density, because much wetland loss results from new irrigators draining wetlands that pose obstacles to rotating equipment (J. Leitch, North Dakota St. Univ., pers. comm).

8= Other existing impairment/disturbance of wetland/landscape functions:

(a) State section 305(b) water quality reports.
Each state's semi-annual report rates the water quality of each assessed lake and river, and identifies possible causes of water quality degradation.

(b) U.S. Census Bureau data.
Data on population density by county or municipality might be used to infer degradation risks to wetlands and use of some wetland functions.

(c) USDA National Agriculture Survey (NAS) database.
For annual data reports (data compiled only by county), contact the state agricultural statistics office:

IA: phone (515) 284-4340
MT: phone (406) 449-5303
ND: phone (701) 239-5306
SD: phone (605) 330-4235

(d) Resources for the Future database.
To arrange for county-level estimates and mapping of pesticide use, phone (202) 328-5036.

9= Beneficiaries of flood storage functions:

(a) Federal Emergency Management Agency (FEMA) data.
These computerized data, which are easily converted to maps, describe number and value of residences located in floodplains (current and projected for the year 2002), and past economic losses due to flooding. Data are indexed to community and county. For general information, contact state office of FEMA.

(b) Data on distribution of ecological resources that potentially benefit from wetland hydrologic functions is available partly from databases listed in (3) above.

10= Beneficiaries of water quality functions:

(a) USGS databases.
Some state offices of the USGS have computer files that quantify users of surface and groundwater in specific counties and river basins.

(b) State water resource agencies.
Some state agency efforts to define risks to groundwater have quantified users of potentially vulnerable or contaminated aquifers (e.g., DeMartino and Jarrett 1991).

(b) Data on distribution of ecological resources that potentially benefit from wetland water quality functions is available partly from databases listed in (3) above.

11= Beneficiaries of habitat functions:

(a) State Fish and Wildlife Department data.
These agencies may have current statistics on hunting, fishing, trapping (licenses and harvest), and nonconsumptive uses. As indicated partly in (3) above, these agencies as well as state heritage programs have information that might be used to indicate where wildlife would be most expected to benefit from wetland functions.

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A PROCESS FOR REGIONAL ASSESSMENT OF WETLAND RISK

APPENDIX C: Conceptual Process Model for Basin-type Wetlands of the Prairie Pothole Region

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INTRODUCTION

The conceptual model on the following pages was prepared as an aid in identifying appropriate indicators of wetland functions. The indicators that resulted partly from consideration of this model are discussed in Appendix B. This conceptual model is organized hierarchically and is intended to show qualitative linkages among major processes or forcing functions (I., II., etc.) and their supporting processes and/or indicators. The model was constructed from literature, theory, and experience. Its purpose is to help identify important indicators and forcing functions, for possible use in landscape function studies. **It is not intended to show all possible linkages.** Unless otherwise noted, the model is read from top to bottom and from left to right. For example, the lines at the beginning of the model (part I.) show that Runoff Volume and Timing is affected partly by runoff event seasonal timing, which is partly affected by temperature (A.3.b), which is affected partly by latitude (A.3.b.2). The major forcing functions and processes that are considered are as follows:

I. Runoff Volume and Timing
II. Groundwater Exchange
III. Sedimentation
IV. Adsorption/Desorption
V. Denitrification
VI. Biological Uptake/Storage/Dispersal (of Nutrients/ Chemicals)
VII. Ecosystem Production

In part VIII., specific PPR stressors are listed and connected to other model components, allowing qualitative assessment of potential impacts to wetland forcing functions.

I. RUNOFF VOLUME and TIMING (peak flows, low flows, desynchronization)

Affects the following: I.D.1.a.(1)(b), I.D.1.a.(2), I.D.2.a, I.D.2.d.(4)(b)(i), II.A, III.A.2, III.A.5, III.C, III.F.2.d, III.F.10, IV.C.2.c, IV.F, V.A.3.b.(5), V.A.5.b.(3)(a), V.A.5.b.(6), V.B.2.f, V.C.1, V.G, VI.A, VI.B.1, VII.B.7

Is affected by the following:

- A. REGIONAL FACTORS:
  - 1. Precipitation
  - 2. Runoff Event Intensity (seasonal and hourly distributions)
    - a. Region
    - b. Elevation
  - 3. Runoff Event Seasonal Timing
    - a. Snow/ice as % of annual precipitation
    - b. Temperature (seasonal pattern; snowmelt/icemelt sequencing)
      - (1) Light (intensity, seasonal and daily duration) (Affected by: VII.B.2)
      - (2) Latitude
      - (3) Elevation
      - (4) Wind (Affected by: I.C.1.d)
      - (5) Salinity/Specific Conductivity
        - (a) Groundwater inputs (Affected by: II)
        - (b) Soil type (calcite, gypsum, etc.)
        - (c) Evapotranspiration (Affected by: I.D.1)
        - (d) Extent of drainage/vegetation removal
        - (e) Input from irrigation return waters
      - (6) Artificial drainage
      - (7) Groundwater inputs (Affected by: II)
      - (8) Reflectance (heat sink, albedo)
        - (a) Soil type/color
        - (b) Vegetation type and density (Affected by: VII)
        - (c) Topography
- B. LANDSCAPE FACTORS (upslope from wetland):
  - 1. Input Runoff Volume (per unit time)
    - a. Catchment area (i.e., basin position in catchment)
    - b. Artificial water subsidies (e.g., transbasin or transcatchment pumping)
    - c. Extent of upslope catchment storage (Affected by: I.D.3)
    - d. Catchment shape
    - e. Drainage density
    - f. Linearity of delivery channels
    - g. And all factors in C and D below, accumulated over all areas draining to the wetland.
- C. SITE-SPECIFIC (within wetland) INPUTS:
  - 1. Condensation (fog drip, dew)
    - a. Vegetation Surface Area
      - (1) Vegetation density (Affected by: VII)
      - (2) Number of vertical strata
    - b. Edge/area ratio of vegetated portion of wetland
    - c. Vegetation edge contrast
    - d. Wind or Air Movement (duration, velocity, seasonality)
      - (1) Region
      - (2) Basin position relative to prevailing wind direction
      - (3) Fetch
      - (4) Vegetation density (Affected by: VII)
      - (5) Vegetation height (Affected by: VII)
      - (6) Vegetation vertical roughness (height variation, layering)
      - (7) Topographic vertical roughness
  - 2. Horizontal Interception (e.g., snowdrift accumulation)
    - a. Slope
    - b. Surface Roughness
      - (1) Topographic irregularity
      - (2) Soil surface irregularity
      - (3) Vegetation density (Affected by: VII)

            - (4) Vegetation height relative to runoff depth
    - 3. Vertical Interception
        - a. Vegetation Surface Area
            - (1) Vegetation density (Affected by: VII)
            - (2) Number of vertical strata
        - b. Seasonal duration of foliage (evergreen vs. deciduous; annual vs. perennial)
        - c. Antecedent saturation status of foliage
            - (1) Precipitation amounts
            - (2) Precipitation seasonal timing
            - (3) Precipitation intensity
- D. SITE-SPECIFIC (within-wetland) OUTPUTS/STORAGE:
    - 1. Evapotranspiration
        - a. Transpiration Efficiency
            - (1) Water Table Position (relative to plant roots) (field capacity, wilting coefficient)
                - (a) Groundwater exchange (Affected by: II)
                - (b) Runoff inputs (Affected by: I)
                - (c) Infiltration (Affected by: I.D.2)
                - (d) Evapotranspiration (Affected by: I.D.1)
            - (2) Runoff timing (runoff inputs peak during the season of maximum plant growth)(Affected by: I)
            - (3) Foliage biomass (Affected by: Ecosystem Production, VII)
            - (4) Rooting depth and total root mass biomass (Affected by: III.E.1)
        - b. Evaporation Efficiency
            - (1) Basin's Depth-to-Volume Ratio (or edge/area index)
                - (a) Basin size
                - (b) Basin shape
                - (c) Depth factors (see III.F.2)
            - (2) Salinity/specific conductivity (Affected by: I.A.3.b.(5))
            - (3) Wind (Affected by: I.C.1.d)
            - (4) Temperature
                - (a) Factors listed in I.A.3.b
                - (b) Mean depth (Affected by: III.F.2)
            - (5) Ground Cover Density (% cover including plant litter)
                - (a) Ecosystem production (Affected by: VII)
                - (b) Prior decomposition (Affected by: V.B.2)
    - 2. Infiltration (in some cases, aquifer recharge as well)
        - a. Antecedent Saturation Status
        - b. Land slope
        - c. Pumping (wellheads)
        - d. Permeability or Conductivity
            - (1) Soil/Subsurface Type (Affected by: III)
                - (a) Clay %
                - (b) Organic matter, % or density (Affected by: V, V.B)
                - (c) Other impermeable aquicludes
            - (2) Freezing (probability, extent, duration, depth) (Affected by: Temperature, I.A.3.b)
            - (3) Compaction
                - (a) Animal density (trampling)
                - (b) Paving
                - (c) Ground cover and foliage biomass (Affected by: I.D.1.b.(5))
                - (d) Freeze/thaw (frequency, magnitude) (Affected by: I.A.3.b)
                - (e) Tillage practices
            - (4) "Piping"
                - (a) Rooting depth and total root mass biomass (Affected by: III.E.1)
                - (b) Burrowing vertebrate density (e.g., moles, prairie dogs)
                    - i) Soil saturation (Affected by: Runoff Volume and Timing, I)
                    - ii) Soil texture (Affected by: V.D.1)
                - (c) Artificial drainage
    - 3. Surface Storage
        - a. Basin Volume
            - (1) Basin area
            - (2) Mean depth (Affected by: III.F.2)
            - (3) Volume reduction by ice (extent, duration)

            - (a) Temperature (Affected by: I.A.3.b)
            - (b) Salinity (Affected by: I.A.3.b.(5))
- b. Outlet Cross-sectional Area and Shape
    - (1) Height relative to high water level
    - (2) Width at high water level
    - (3) Blockage by ice (extent, duration)
        - (a) Temperature (Affected by: I.A.3.b)
        - (b) Salinity (Affected by: I.A.3.b.(5))
- c. Capillarity of Soils/Sediments
    - (1) Soil particle size (clay %) (Affected by: III)
    - (2) Organic matter % (Affected by: V, V.B)
    - (3) Organic matter type
    - (4) Duration of frost-free season

II. GROUNDWATER EXCHANGE (recharge, discharge, lateral flow, low flow augmentation, soil water conservation)

Affects: I.A.3.b.(5)(a), I.A.3.b.(7), I.D.1.a.(1)(a), V.A.2

Affected by the following:

- A. Runoff Volume and Timing (Affected by: I)
- B. Water Table Slope
  - 1. Regional
  - 2. Local
- C. Infiltration (Affected by: I.D.2)

III. SEDIMENTATION (particle deposition, stabilization, entrapment, agglomeration, precipitation)

Affects: I.D.2.d.(1), I.D.3.c.(1), III.E.1.b, IV.B, V.C.2, V.D.1.a, IV.A, V.B.3, VII.B.3.c.(1)

Affected by:

- A. Incoming Sediment Concentration
  - 1. Erosion in Catchment (proximity of wetland to)
    - a. Sediment/soil type
    - b. Wind (Affected by: I.C.1.d)
    - c. Ice (Affected by: I.A.3.b)
    - d. Precipitation intensity and form (rain vs. snow, storm vs. drizzle)
    - e. Tillage practices
    - f. Artificial ditching or drainage
    - g. Human visitation (machinery, trampling)
    - h. Animal activities (e.g., grazing) (extent, duration, seasonality)
  - 2. Runoff volume and timing (Affected by: I)
  - 3. Presence of input channels
  - 4. Dry Deposition
    - a. Proximity to sources
    - b. Wind (Affected by: I.C.1.d)
  - 5. Extent of upslope runoff retention (Affected by: Runoff Volume and Timing, I)
- B. Velocity (Wave Height) Reduction in Wetland
  - 1. Plant community composition
    - a. Vegetation height relative to water depth or wave height
    - b. Vegetation rigidity
    - c. Vegetation seasonal persistence (annual vs. perennial)
  - 2. Vegetation density (Affected by: Ecosystem Production, VII)
  - 3. Vertical roughness (e.g., microtopographic variation)
- C. Hydraulic Residence Time (Affected by: Runoff Volume and Timing, I)
- D. Settling Time
  - 1. Gravity Settling
    - a. Sediment particle type (mass, shape, size, charge)
    - b. Temperature (Affected by: I.A.3.b)
  - 2. Flocculation
    - a. Salinity/specific conductivity (Affected by: I.A.3.b.(5))
    - b. Sediment particle type (mass, shape, size, charge)
    - c. Ecosystem Production (Affected by: VII)
      - (1) Filter-feeder density at season of sediment input (flocculation via fecal pellets)
      - (2) Microbial density at season of sediment input (flocculation via agglomerates)
  - 3. Physicochemical Precipitation (e.g., calcitic)
    - a. Temperature (Affected by: I.A.3.b)
    - b. Photosynthesis (Affected by: Ecosystem Production, VII)
    - c. Acidity/pH (Affected by: IV.D)
- E. Stabilization by Plant Community
  - 1. Root Biomass and Rooting Depth
    - a. Plant community species composition (typical root length)
    - b. Soil hydrologic regime: anaerobiosis limitation (Affected by: III)
    - c. Soil type: penetrability

            - (1) Texture (Affected by: V.D.1)
            - (2) Compaction (Affected by: I.D.2.d.(3))
    - 2. Mat- or Sod- forming Ability
        - a. Plant community species composition
        - b. Wave or current velocity (Affected by: Wind, I.C.1.d)
- F. Erosion, Resuspension, and Mixing (within-wetland)
    - 1. Sediment/soil type
    - 2. Water depth
        - a. Original landform
        - b. Sedimentation (all of III)
        - c. Subsidence
            - (1) Artificial drainage
            - (2) Soil type
            - (3) Soil organic matter (Affected by: Carbon, V, V.B)
        - d. Runoff volume (Affected by: I)
    - 3. Wind (Affected by: I.C.1.d)
    - 4. Ice (Affected by: I.A.3.b)
    - 5. Precipitation intensity and form (rain vs. snow, storm vs. drizzle)
    - 6. Tillage practices
    - 7. Artificial ditching or drainage
    - 8. Human visitation (machinery, trampling)
    - 9. Animal activities/bioturbation (e.g., presence of carp, ducks) (Affected by: Ecosystem Production, VII)
    - 10. Runoff volume and timing (Affected by: I)
    - 11. Boat wakes (magnitude, extent, frequency)

IV. ADSORPTION/DESORPTION (cation exchange, anion exchange)

Affects: V.A, VI.B.2, VII.B.1

Is affected by:

- A. Hydraulic Residence Time (Affected by: Sedimentation, III)
- B. Soil/sediment type (Affected by: Sedimentation, III)
- C. Aluminum-iron-calcium content
    - 1. Geologic parent material
    - 2. Degree of weathering
        - a. Wind (Affected by: I.C.1.d)
        - b. Ice (Affected by: I.A.3.b)
        - c. Water level fluctuations (Affected by: Runoff Volume, I)
    - 3. Particle size
    - 4. Organic matter % (Affected by: V, V.B)
- D. Acidity/pH
    - 1. Geologic parent material
    - 2. Anaerobiosis (Affected by: V.C)
    - 3. Contaminated precipitation
    - 4. Runoff exposure to mining activities (Affected by: I)
    - 5. Fire (frequency, type, probability)
- E. Anaerobiosis (Affected by: V.C)
- F. Fluctuating Hydrologic Conditions
    - 1. Extent (Affected by: Runoff Timing and Volume, I)
    - 2. Season of Fluctuation
- G. Ambient concentration of nutrient or chemical substance (Affected by V, VI)

V. DENITRIFICATION (rate and proportional amount of N2 or N20 release)

Affects: I.D.2.d.(1)(b), I.D.3.c.(2), III.F.2.c.(3), IV.C.4, V.C.3, V.D.1.b, VI.B.2, VII.B.1

Is affected by:

- A. Available Nutrients
  - 1. Geologic erosional sources
  - 2. Groundwater sources (Affected by: II)
  - 3. Land Use Sources
    - a. Dry deposition
      - (1) Wind (Affected by: I.C.1.d)
      - (2) Soil wind-erodibility (rating, proximity)
    - b. Runoff
      - (1) Soil erodibility (rating, proximity) (Affected by: Erosion, III.A.1)
      - (2) Animal density (seasonality, proximity)
      - (3) Fertilizer extent (seasonality, proximity)
      - (4) Subsidence/mineralization following drainage
      - (5) Runoff volume (Affected by: I)
  - 4. Animal immigration
  - 5. Internal Sources
    - a. Fixation
      - (1) Plant community composition (bluegreen algae)
    - b. Mineralization/remobilization
      - (1) Fire (extent, frequency, type, probability)
      - (2) Decomposition (Affected by: V.B.2)
      - (3) Fluctuating hydrologic regime
        - (a) Extent (Affected by: Runoff Timing and Volume, I)
        - (b) Season of fluctuation
    - c. "Pumping" from sediments and release to water column (Affected by: Community Uptake, Storage, and Dispersal VI)
    - d. Concentrating Effects
      - (1) Evapotranspiration (Affected by: I.D.1)
      - (2) Freezing (Affected by: I.A.3.b)
  - 6. Upslope Uptake/Removal (Affected by: Runoff Volume and Timing, I; also VI and B-G below)
- B. Carbon (amount, type, seasonality)
  - 1. Plant and animal production (Affected by: VII)
  - 2. Decomposition (decay rates)
    - a. Vegetation type
    - b. Salinity (Affected by: I.A.3.b.(5))
    - c. Invertebrate density (Affected by: Ecosystem Production, VII)
    - d. Anaerobiosis (Affected by: V.C)
    - e. Hydrologic fluctuation
    - f. Extent (Affected by: Runoff Volume and Timing, I)
    - g. Season of fluctuation
  - 3. Sedimentation (Affected by: III)
  - 4. Fire History
- C. Anaerobiosis/Reducing Conditions (extent, duration, frequency, probability):
  - 1. Hydrologic regime (Affected by: Runoff Volume and Timing, I)
  - 2. Soil pore space and volume (Affected by: III, V.D)
  - 3. Organic load (Affected by: V, V.B)
  - 4. Temperature and ice (extent, duration, frequency, probability) (Affected by: I.A.3.b)
  - 5. Chemical input (chemical oxygen demand)
  - 6. Subsurface oxidation of anaerobic zones by plant roots (Affected by: V.C)
- D. Pore Space and Volume
  - 1. Soil Texture (bulk density, porosity)
    - a. Clay % (Affected by: III)
    - b. Organic matter % and type (Affected by: V, V.B)
    - c. Tillage practices (tillage generally increases porosity)
    - d. Burrowing invertebrate density (Affected by: Ecosystem Production, VII)

        - e. Compaction/trampling (Affected by: I.D.2.d.(3))
- E. Salinity/specific conductivity (Affected by: I.A.3.b.(5))
- F. Acidity/pH (Affected by: IV.D)
- G. Hydraulic retention time in upper soil layer (Affected by: Runoff Volume and Timing, I)
- H. Temperature (Affected by: I.A.3.b)
- I. Sulfur availability

VI. COMMUNITY UPTAKE/STORAGE/DISPERSAL of NUTRIENTS/CHEMICALS

Affects: V.A.5.c, V.A, VI.B.2, VII.B.1

Is affected by:

- A. Hydraulic retention times of substances in upper soil layer (Affected by: Runoff Volume and Timing, I)
- B. Concentration of substance (during season of maximum organism growth/uptake)
    - 1. Runoff volume and timing (Affected by: I)
    - 2. Available nutrients/chemicals (Affected by: V.A)
- C. Ecosystem production (Affected by: VII)
- D. Organism Types
    - 1. Proximity of usual microhabitats to spatial maxima of the substance
    - 2. Food habits
    - 3. Intrinsic growth rates
    - 4. Modes of uptake
    - 5. Tenacity of Uptake
        - a. Lifespans of organisms comprising the community
        - b. Anatomical locus of accumulation
    - 6. Emigration rates

VII. ECOSYSTEM PRODUCTION (respiration, photosynthesis)

Affects: I.D.1.a.(3), I.D.1.b.(5)(a), III.B.2, III.D.2.c, III.D.3.b, III.F.9, V.B.1, V.B.2.c, V.D.1.d, VI.C, VII.B.3.c.(2), VII.H.4

Is affected by:

- A. Organism Types (species composition)
  - 1. Intrinsic growth rates
  - 2. Tolerance for crowding (size, metabolic needs, etc.)
- B. Food and Substrate Conditions (required by component organisms)
  - 1. Nutrients (Affected by: V.A)
  - 2. Temperature (Affected by: I.A.3.b)
  - 3. Light Availability
    - a. Depth (Affected by: III.F.2)
    - b. Shade (from topographic relief, vegetation, clouds/fog)
    - c. Transmissivity of air/water (e.g., turbidity)
      - (1) Sedimentation (Affected by: III)
      - (2) Plankton blooms (Affected by: Ecosystem Production, VII)
      - (3) Snow covering ice
    - d. Latitude
    - e. Aspect
    - f. Elevation
  - 4. Dissolved oxygen (Affected by: Anaerobiosis, V.C)
  - 5. Acidity/pH (Affected by: IV.D)
  - 6. Salinity/specific conductance (Affected by: I.A.3.b.(5))
  - 7. Hydrologic regime (Affected by: Runoff Volume and Timing, I)
  - 8. Spatial/temporal interspersion of above, as optimal for most productive combination of species
- C. Extent of contamination (Affected by: Available Nutrients, V.A -- the processes are similar).
- D. Extent of disturbance by human visitation
- E. Competition
- F. Biological Removal/Recycling Processes
  - 1. Predation/harvest
  - 2. Herbivory (e.g., muskrat, livestock)
- G. Physical Removal Processes
  - 1. Fire (extent, frequency, type, probability)
  - 2. Wind (Affected by: I.C.1.d)
  - 3. Ice scour (Affected by: I.A.3.b)
  - 4. Geological phenomena (e.g., subsidence)
  - 5. Tillage
- H. Immigration/Emigration
  - 1. Intrinsic characteristics related to seed dispersal or behavioral mobility of species
  - 2. Suitability of core habitat area
    - a. Size
    - b. Habitat quality
  - 3. Suitability of connections to similar habitat patches
    - a. Permeability of surrounding landscape matrix vs. corridors
    - b. Distance to nearest other suitable habitat patch
  - 4. Suitability of target habitat patch (Affected by: Ecosystem Production, VII)

VIII. FUNCTIONAL EFFECTS OF STRESSORS

Direct effects of stressors are listed below. The theoretical, secondary effects of these activities can be traced by turning to the cited entries, then tracing relationships to other functional components by searching leftwards in the hierarchical arrangement of processes and/or in their referenced processes. When a major process heading (roman numeral) is reached, continue the chain by branching to each of the entries listed following the subheading, "Affects:".

A. DRAINAGE
1. Artificial Drainage (I.A.3.b.(6), I.D.2.d.(4)(c), III.A.1.f, III.F.2.c.(1), III.F.7)
2. Surface Storage (I.D.3)

B. GROUNDWATER PUMPING
1. Groundwater Exchange (II.)
2. Surface Storage, Infiltration, Evapotranspiration (I.D, I.E, I.F)

C. DUGOUTS/IMPOUNDMENTS
1. Groundwater Exchange (II.)
2. Runoff Volume and Timing (I.)

D. GRAZING
1. Herbivory (VII.F.2)
2. Compaction (I.D.2.d.(3))

E. MOWING
1. Vegetation Density (I.A.3.b.(8)(b), I.C.1.a.(1), I.C.1.d.(4), I.C.2.b.(3), I.C.3.a.(1), I.D.1.a.(3), I.D.1.b.(5)(a), III.B.2, III.D.2.c, III.D.3.b, III.F.9, V.B.1, V.B.2.c, V.D.1.d, VI.C, VII.B.3.c.(2), VII.H.4)
2. Compaction (I.D.2.d.(3))

F. TILLAGE and SEDIMENTATION
1. Tillage (I.D.2.d.(3)(e), III.A.1.e, III.F.6, V.D.1.c)
2. Topographic vertical roughness (I.C.2.b.(1), III.B.3)

G. BURNING
1. Fire (IV.D.5, V.A.5.b.(1), V.B.4, VII.G.1)

H. PESTICIDE USE
1. Contaminants (for protection of crops from weeds or insects) (VII.C)

I. EXCESSIVE NUTRIENT INPUTS
1. Nutrients (V.A, VI.B.2, VII.B.1)

J. EXCESSIVE HUMAN VISITATION
1. Human Visitation (III.A.1.g, III.F.8, VII.D)
2. Compaction (I.D.2.d.(3))