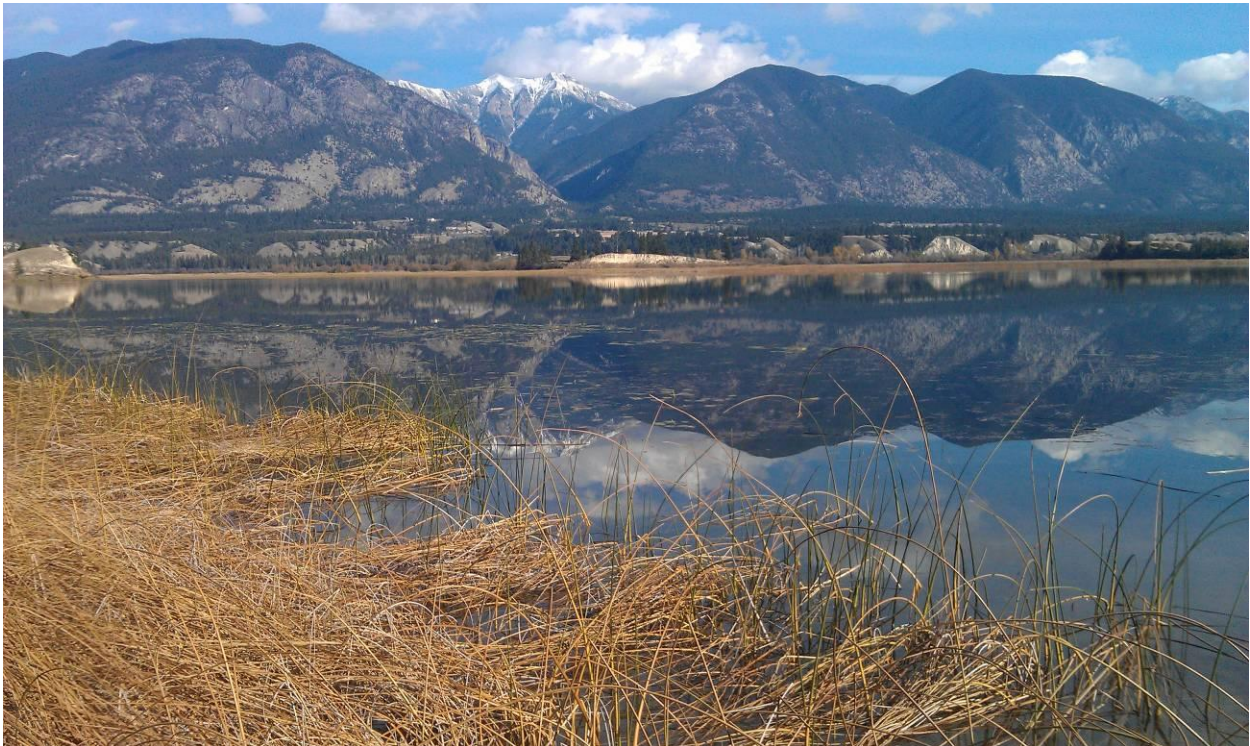# Manual for the
Wetland Ecosystem Services Protocol (WESP)

version 1.3

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Note that updates of both the manual and the WESP calculator spreadsheet will be posted
periodically at this location.

For more information about this protocol and opportunities to be trained in its use, please contact
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SUMMARY

The Wetland Ecosystem Services Protocol (WESP) is a standardized template for creating regionalized methods which then can be used to rapid assess ecosystem services (functions and values) of all wetland types throughout a focal region. To date, regionalized versions of WESP have been developed (or are ongoing) for government agencies or NGOs in Oregon, Alaska, Alberta, New Brunswick, and Nova Scotia. Chapter 6 provides guidance for developing such regionalizations.

WESP also may be used directly in its current condition to assess these services at the scale of an individual wetland, but without providing a regional context for interpreting that information. Nonetheless, WESP takes into account many landscape factors, especially as they relate to the potential or actual benefits of a wetland's functions.

A WESP assessment requires completing a single three-part data form, taking about 1-3 hours. Responses to questions on that form are based on review of aerial imagery and observations during a single site visit; GIS is not required. After data are entered in an Excel spreadsheet, the spreadsheet uses science-based logic models to automatically generate scores intended to reflect a wetland's ability to support the following functions: Water Storage and Delay, Stream Flow Support, Water Cooling, Sediment Retention and Stabilization, Phosphorus Retention, Nitrate Removal and Retention, Carbon Sequestration, Organic Nutrient Export, Aquatic Invertebrate Habitat, Anadromous Fish Habitat, Non-anadromous Fish Habitat, Amphibian & Reptile Habitat, Waterbird Feeding Habitat, Waterbird Nesting Habitat, Songbird, Raptor and Mammal Habitat, Pollinator Habitat, and Native Plant Habitat. For all but two of these functions, scores are given for both components of an ecosystem service: function and benefit. In addition, wetland Ecological Condition (Integrity), Public Use and Recognition, Wetland Sensitivity, and Stressors are scored. See Appendix A for detailed word descriptions of each model (i.e., how the scores are automatically calculated).

WESP's scoring is based on logic models programmed into the Calculator spreadsheet. Although this has the potential to create a "black box" wherein underlying assumptions and calculations are not transparent to the user, transparency has been assured by detailed explanations of the assumptions and mathematics of each scoring model (both in the spreadsheet and Appendix A of this manual). The spreadsheet contains a rationale, often with citation of supporting scientific literature, for use of each indicator in every model. Although most indicators are applied to estimate several wetland functions, values, and other attributes, users need only enter the data for each indicator in only one place on the data forms. The models also estimate a wetland's hydrogeomorphic (HGM) class and implicitly account for differences associated with HGM class. When not pertinent to the HGM class being assessed, indicators are automatically dropped from a model's calculations rather than being scored as a "0."

Scores generated by WESP may be used to (a) estimate a wetland's relative ecological condition, stress, and sensitivity, (b) compare relative levels of ecosystem services among different wetland types, or (c) compare those in a single wetland before and after restoration, enhancement, or loss. This information should be used to inform restoration design and performance standards. Where compensation of lost or degraded wetland functions is required, WESP can be used to adjust or

qualify mitigation ratios so they ensure mitigation sites have values and functions comparable to or greater than altered sites, as well as being in similar or better ecological condition.

Extensive testing of an earlier version of WESP, developed specifically for the state of Oregon, showed that among independent users, repeatability of the scores for most functions and values was found to be within ± 0.6 point or less on a 0-to-10 scoring scale.

WESP is a refinement of the first wetland assessment method used widely throughout the U.S. (Wetland Evaluation Technique, WET; Adamus 1983) and a protocol developed and adopted by Oregon Department of State Lands with funding from the US Environmental Protection Agency (EPA) (WESP, Adamus et al. 2009). WESP also incorporates elements of the Hydrogeomorphic (HGM) Approach (Brinson 1993, Smith et al. 1995) and the Millennium Ecosystem Assessment (Finlayson et al. 2005).

Acknowledgments

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1.0 Introduction

1.1 Background and Purpose

Policy goals for "no net loss" of wetlands pertain not only to wetland acreage but also to the ecosystem services (functions and values) that wetlands provide naturally. By providing these services, well-functioning wetlands can reduce the need for humans to construct alternative infrastructure necessary to provide those services, often at much higher cost (Costanza et al. 1997, Finlayson et al. 2005, Euliss et al. 2008). In addition, many laws and policies require compensation for wetland impacts, and further require that wetland functions and values be the basis for considering the adequacy of compensation.

The primary driver for developing WESP was the need for a rapid, well-documented wetland assessment method that could be used for all kinds of wetlands in all regions of temperate North America. WESP is designed to be used for multiple purposes by multiple agencies, including:

- Assessing individual wetlands or portions of wetlands for purposes of state and federal permitting and compensatory wetland mitigation (e.g., impact assessment, compensatory mitigation)
- Evaluating success of voluntary wetland restoration or enhancement projects
- Assessing all wetlands within a community or watershed (e.g., for characterizing watershed health, prioritizing restoration opportunities, or developing a wetlands management program)

In order to be practical for these purposes, WESP needed to be rapid (take less than a full day to complete an assessment) and require only a single site visit in any season. WESP is intended to provide consistent and accurate numeric estimates of the relative ability of a wetland to support a wide variety of functions and benefits important to society. To do so, WESP uses standardized data forms, procedures, and data processing models. Through a review of hundreds of peer-reviewed journal articles and other sources, the authors of WESP have attempted to incorporate the best and most recent scientific knowledge available on the ecosystem services of wetlands.

1.2 Conceptual Basis

Wetlands perform multiple *functions*. For example, they can store water, purify it, and warm or cool it. They support vegetation that in turn can support wildlife. The levels at which these functions are performed are in many cases determined more by natural factors (e.g., climate, topography, soils) than by factors associated directly with humans (pollution, invasive species). When the functions of a particular wetland have recognized utility to humans or ecosystems due to the wetland's context (e.g., position in the landscape) or other factors, this can be described as the wetland's *benefits* (or values). For example, "flood control" is a potential *benefit* of a wetland, but realization of this benefit depends as much on the wetland's context as on its intrinsic level of the "water storage" *function*.

WESP treats functions and their benefits as independent of one another. For example, a wetland that is extremely effective for removing whatever nitrate enters it is not considered to be of high *benefit* for that *function* unless it is exposed to significant loads of nitrate and/or its watershed

has been designated as "Water Quality Limited" as a result of ongoing problems with nitrate pollution. Likewise, even if a wetland's effectiveness for storing water is only moderate, the *benefit* of that function may be considered potentially high if the wetland is situated upstream from homes that are periodically flooded by heavy runoff. In concept, wetland ecosystem *services* are the combination of *functions* and the *benefits* of those functions, judged individually. Thus, for a wetland to be considered as providing a high level of services, *both* its functions and the benefits of those functions should be high. WESP does not combine estimates of function and benefit into a single score representing the wetland's service, but by estimating functions and their benefits separately it provides a foundation for doing so.

Several analyses (e.g., Hansson et al. 2005, Adamus et al. 2009) have concluded that it is unlikely that a single wetland can support all functions at a high level, regardless of the wetland's unaltered condition or special designations. Thus, even if a wetland occurs within a designated "Priority Area" for conservation, this does not necessarily mean it is effective for removing nitrate or cooling surface water, for example.

Fundamentally, the levels and types of *functions* that wetlands individually and collectively provide are determined by the processes and disturbances that affect the movement and other characteristics of water, soil/sediment, plants, and animals (Zedler & Kercher 2005, Euliss et al. 2008). In particular, the frequency, duration, magnitude and timing of these processes and disturbances shapes a given wetland's functions (Smith et al. 2008). Climate, geology, topographic position, and land use strongly influence all of these. The levels and types of *benefits* that wetlands provide, individually and collectively, are largely determined by the *opportunity* to provide a particular function and the local *significance* of that function (Adamus 1983). For many hydrologic and water quality values, opportunity is determined by what's upslope of a wetland (e.g., land use and buffers in the wetland's contributing area) and significance is predicted partly by what's downslope (e.g., floodplains, water-quality limited water bodies).

2.0 Procedures for Using WESP

The steps below provide an outline of the process and the instructions that follow. You will be completing three forms: an office form (Form OF); and two field forms (F and S).

1. Read this entire section (Section 2) before proceeding to follow the instructions and complete the forms.
2. Download the most recent version of the *WESP_ Calculator* spreadsheet.
3. Also download and print (from the same sites) the PDF files of the F and S data forms. Do not print anything from the Excel spreadsheet at this point.
4. Complete the "office" component, which involves viewing aerial imagery and filling out Form OF worksheet in the *WESP Calculator* file.
5. Visit the wetland and complete the "field" component by filling out data forms F and S and refine your answers to questions on Form OF if necessary.
6. Process and interpret the results.

2.1 Office Procedures

Begin the office component of the assessment with the electronic version of Form OF in the file *WESP_Calculator.xls*. When you open that file, you may get a message asking if you want to enable "macros." Mark yes; the macros in this file will not harm your computer. They are necessary to automate all the calculations.

2.1.1 Obtain Aerial Images

A recent aerial image of the assessment area (AA) is needed to answer several of the questions in Form OF. See Section 2.1.5 for procedures required to delineate the AA. The image should be of adequate resolution, viewed at (zoomed to) and printed at a scale of 1:24,000 (1 inch = 0.5 mile) or finer, such that the entire AA nearly fills a printed page. If the AA does not comprise all of the wetland, the same aerial image should be printed again but covering the entire wetland.

Google Earth has made aerial imagery covering nearly the entire planet viewable online at no cost, so that is likely to be the most convenient source. However, it may be worth considering other sources which have imagery from different seasons or which used different imaging techniques, e.g., color infra-red, LiDAR.

2.1.2 Determine the Geographic Coordinates

Record the AA's geographic coordinates (latitude and longitude, NAD83 datum) as determined either from field measurement using GPS equipment or from zooming to the location in Google Earth and noting its coordinates as reported at the bottom of the image when the cursor is placed near the AA's center. Report the coordinates in decimal-degrees, e.g., 45.2434, -123.3425. For WESP's purposes, the precision of the coordinates need not be any greater than about half of the width of the wetland.

2.1.3 Interpret Aerial Images

Use the aerial images to answer several of the questions on Form OF. Ideally, the estimates should be made prior to the site visit, recorded on Form OF, and then a copy printed and taken with you during the site visit. Then, upon visiting the site, modify the estimates if appropriate, based on your observations of the site.
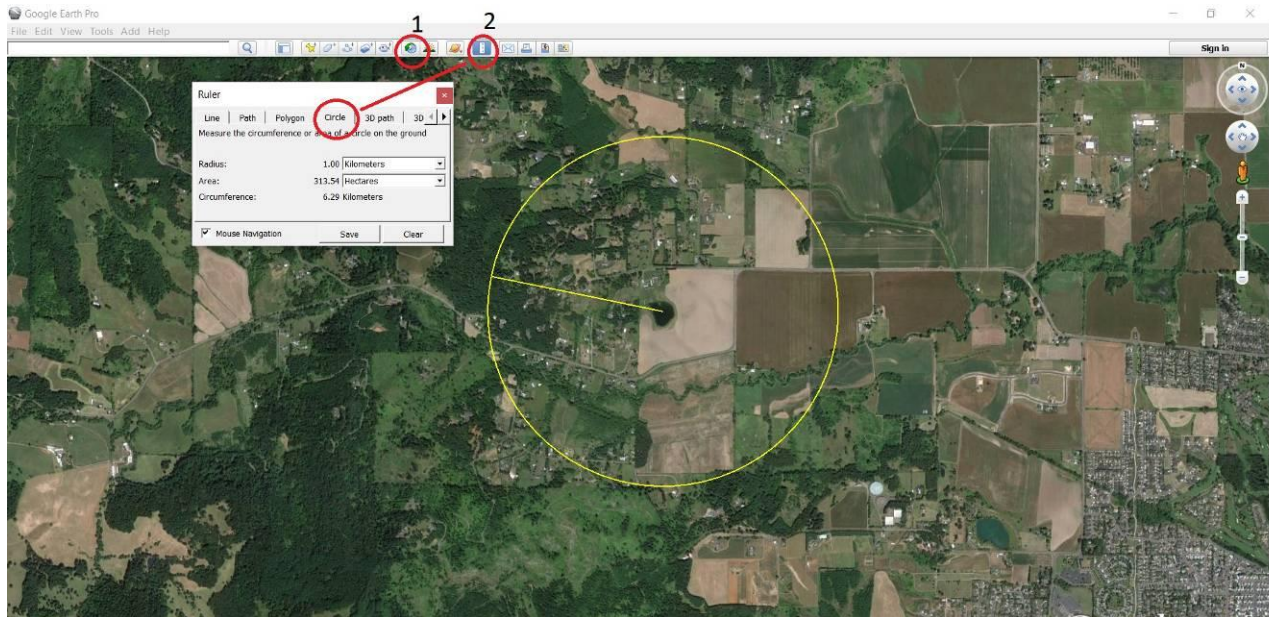
Figure 1. Aerial image from Google Earth Pro showing tool (#1) for displaying historical aerial images and tool (#2) for creating a circle of specified radius.

If you are viewing aerial images with Google Earth, you can use its *ruler tool* (#2 in Figure 1) to measure the distance to specified features, as well as to measure areas (after clicking on the "Polygon" tab of the pop-up menu), and to draw a circle of any radius you specify (after clicking on the "Circle" tab of the pop-up menu). Note that some WESP questions ask the percentage of just the *land* area of the circle that is occupied by the specified land cover, whereas others ask this as a percentage of the *entire* circle (even if it is mostly ocean). Also note that Form OF specifies that some distances be measured from the center of the AA, and others from the wetland-upland edge. To estimate the *percentages* of a given land cover class (e.g., herbaceous vegetation) within a circle of specified radius, imagine all the patches of that type being "squeezed together" and determine the approximate fraction of the circle they would occupy. Using a GIS to measure features in the aerial imagery is may increase precision but is not essential.

2.1.4 Obtain a Topographic Map

You will need a topographic map on which to draw boundaries of the assessment area (see next section) and to estimate the boundaries of its contributing area (see Section 2.1.6). The topographic maps having the finest resolution and which are easiest to read are usually the hard copy versions (1:24,000 or finer scale) purchased from an outdoor supply store. For most places in the U.S., topographic maps and several maps with relevant themes can be viewed online via the National Map Viewer: http://viewer.nationalmap.gov/viewer/ . A similar tool for Canada (Toporama) is at http://www.nrcan.gc.ca/home .

2.1.5 Obtain Wetland Map and Draw the Assessment Area (AA) Boundaries

Obtain a map of the delineated wetland if one exists. If not, draw approximate wetland boundaries on the aerial image by interpreting that image and, if available, consulting topographic and/or soils maps. Whenever possible WESP should be applied to an entire wetland, not to individual cover types within a wetland. However, there are a few situations where it may be necessary or advisable to visit and assess less than the entire wetland, or to identify multiple assessment areas (AAs) within a wetland and assess each separately. These situations include:

- The wetland extends across property lines and access permission to part of the wetland was not granted.
- A man-made feature (e.g., road berm with no functioning culverts) entirely separates one part of the wetland from the rest, or disrupts water flow so severely that vegetation and/or chemistry on opposite sides of the feature differ greatly.
- The wetland is so large (e.g., >50 acres, 20 hectares) and internally varied that an accurate assessment cannot be completed in a day.
- A project or activity will occur in only part of a wetland and the effect on functions of just that project or activity needs to be determined.
- There is a clearly visible line separating parts of the wetland that have and have not been persistently altered (e.g., by fire, severe grazing).

Where you draw the boundaries of the AA can dramatically influence the resulting scores. Here are guidelines for delineating the AA in some specific situations:

a. **Dissected Wetland.** If a wetland that once was a contiguous unit is now divided or separated from its formerly contiguous part by a road or dike (Figure 4), assess the two units separately unless a functioning culvert, water control structure, or other opening connects them, and their water levels usually are simultaneously at about the same level.
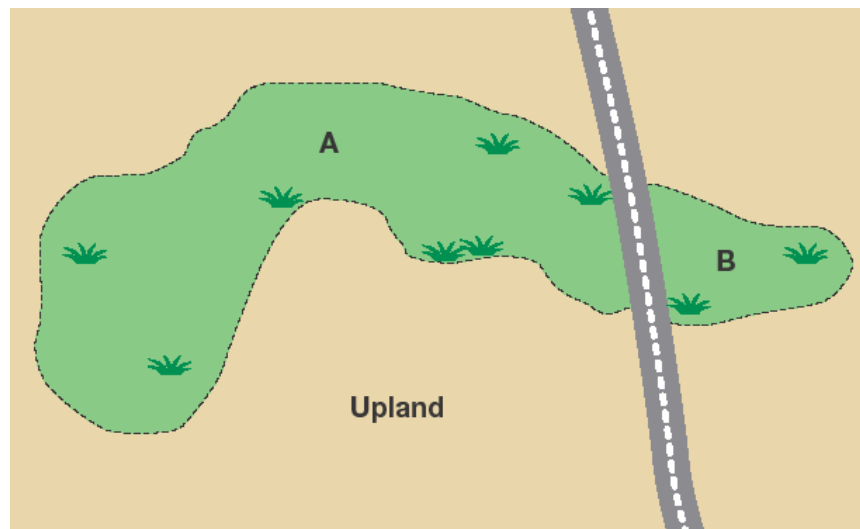
Figure 2. Dissected Wetland. A wetland is crossed by a road or filled area. Separate the wetland into two AA's and assess separately if A and B have different water levels and circulation between them is significantly impeded.

b. **Ponds**. If a wetland contains or is adjacent to a pond smaller than 8 hectares (20 acres), the pond -- regardless of its depth -- should be included as part of the Assessment Area (AA). Streams that flow through or along the edge of a wetland should also be included in the AA, unless they are wider than the average width of the zone along their shoreline that contains wetland vegetation (in that case, see below).

c. **Fringe Wetland**. If a wetland is adjacent to a pond or lake larger than 8 hectares (20 acres), or to a bay, estuary, or river in which the contiguous stretch of open water is **wider than** the vegetated wetland during most of the growing season, *the AA should include the adjacent open water within a distance that is equal to the average width of the vegetated part of the wetland*. (Figure 5).
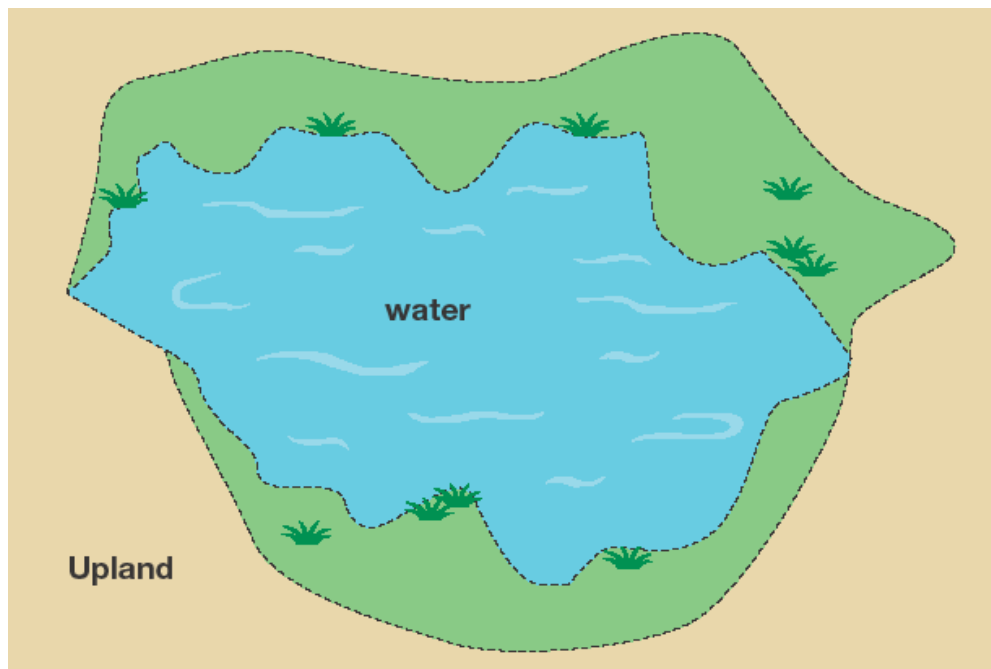
Figure 3. Fringe Wetland Type 1. The open water area is much wider than the average width of the vegetated wetland, making this a fringe wetland. If the open water is smaller than 8 hectares (20 acres), the AA should include the open water.

d. **Fringe Wetland Patches**. If patches of fringe wetlands share the same margin of a river, lake, or estuary and are separated from each other by upland over a distance of greater than 100 ft, they should be assessed as separate AA's (Figure 6) unless they appear to be the same in nearly every aspect (dominant vegetation, soil texture, hydrology, landscape position, Cowardin classification, adjoining land use, etc.) and are within 1000 ft. of each other.
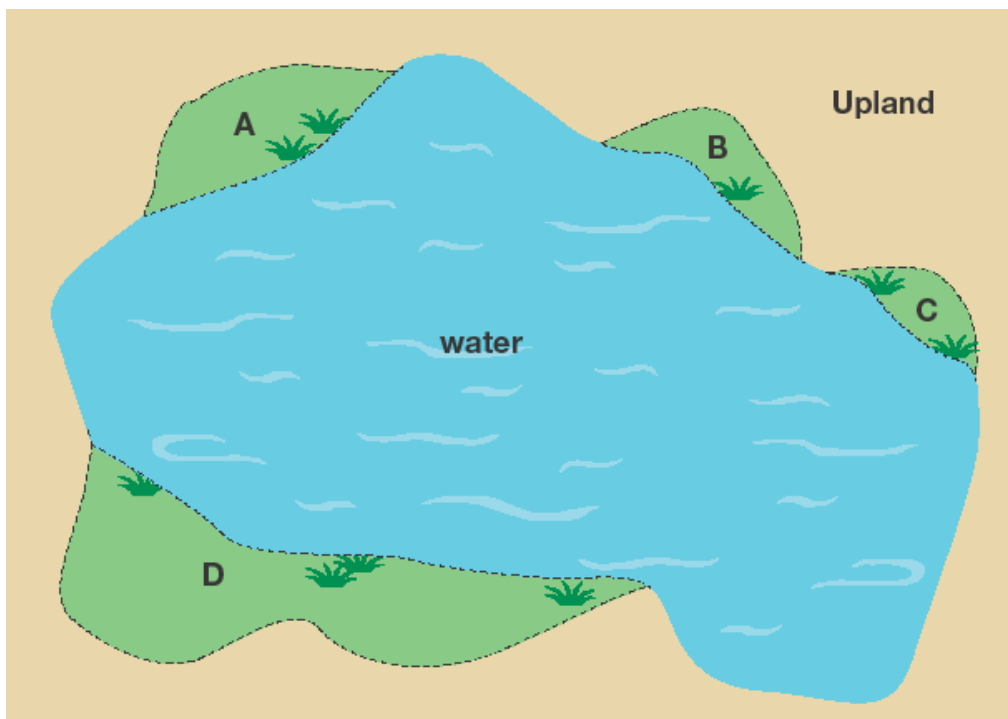
Figure 4. Fringe Wetland Type 2 (fringe wetland patches). Wetland patches B and C would be included in the same AA if separated by no more than 100 ft. by water, bare substrate, algal flats, or upland. Wetland patches A and D would be in the same AA if separated by 100 ft or less, or if they are within 1000 ft of each other and their vegetation, soil texture, water regime, and adjoining land use is the same.

d. Lacustrine Wetland With Tributary. If a lacustrine (lakeside) wetland is intersected by an inflowing stream, the wetland should be considered lacustrine except for the part that is more subject to seasonal overflow from the stream than from fluctuations in lake levels. That part should be assessed separately.

e. Wetland Mosaic. If the wetland is a patch in a mosaic of wetlands within uplands or other non-wetland waters (Figure 7) and none of the above rules apply, the entire mosaic should be considered and delimited as one AA if:
• Each patch of wetland is smaller than 1 acre, and
• Each patch is less than 50 ft from its nearest neighboring wetland and is not separated from them by impervious surface, and
• The areas of vegetated wetland are more than 50% of the total area. The total area is the wetlands plus other areas that are between the wetlands (such as uplands, open water, and mudflats).
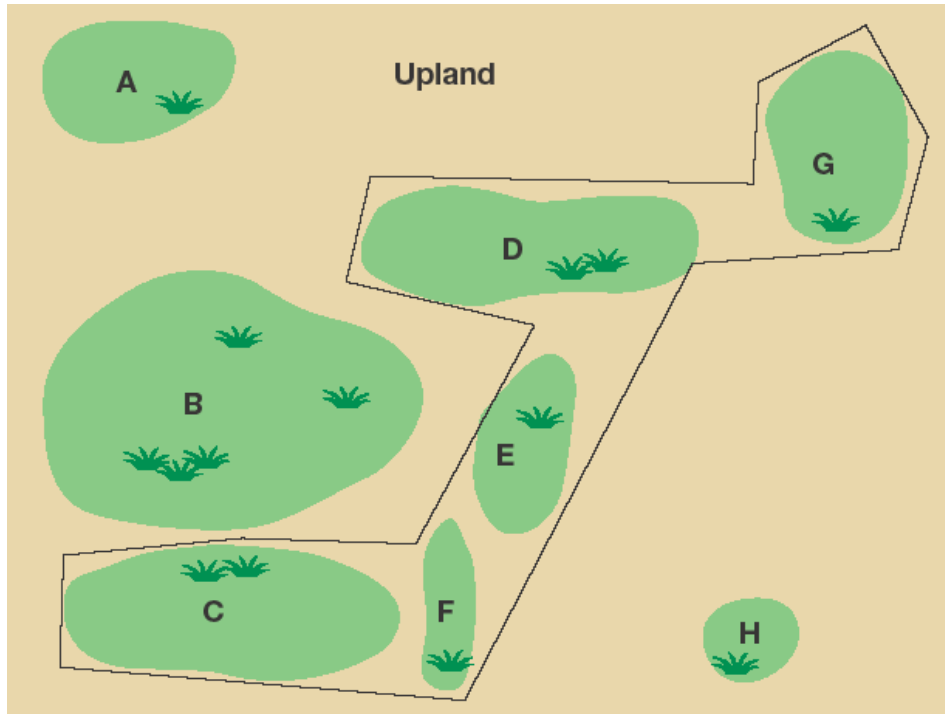
Figure 5. Wetland Mosaic Assessment Area (AA). In this diagram the dark line defines the mosaic. The circles are wetlands and the areas between them are upland. Wetlands C, D, E, F, and G comprise a mosaic because they occupy more than 50% of the total area bounded by the dark line. Wetland B is excluded because it is larger than 1 acre. Wetlands A and H are excluded because each is >100 ft from its closest neighbor.

f. Tidal/Non-Tidal Wetland. If any vegetated part of the AA is tidal (experiences fluctuating water levels as a result of tides) on any day during an average year, that part cannot be accurately assessed with this non-tidal version of WESP.

2.1.6 Estimate the Contributing Area (CA) Boundaries

Estimating the approximate boundary of the wetland's CA is necessary to answer several questions in forms OF and S. Identifying the wetland's contributing area (CA) requires an ability to interpret topographic maps. The CA is the drainage area, catchment area, or contributing upland that feeds the wetland (Figure 6). It includes all areas uphill from the wetland until a ridge or topographic rise is reached, often many miles away, beyond which water would travel in a direction that would not take it to the wetland. The water does not need to travel on the land surface; it may reach the wetland slowly as shallow subsurface seepage[1]. The CA's highest point will be along a ridgeline or topographic mound. The lowest point of a CA is the lowest point in the wetland. Although it is possible that roads, tile drains, and other artificial features that run perpendicular to the slope may interfere with movement of runoff or groundwater into a wetland

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[1] There are often situations where subsurface flow (especially deep groundwater) that potentially feeds a wetland ignores such topographic divides, but due to the limitations imposed by rapid assessment, no attempt should be made to account for that process.

(at least seasonally), it is virtually impossible to determine their relative influence without detailed maps and hydrologic modeling. Therefore, in most cases draw the CA as it would exist *without* existing infrastructure, i.e., based solely on natural topography as depicted in the topographic map. The only exception is where maps, aerial images, or field inspections show artificial ditches or drains that *obviously* intercept and divert a *substantial* part of the runoff before it reaches the wetland, or where a runoff-blocking berm or elevated road adjoins (is contiguous to) a wetland on its uphill side.
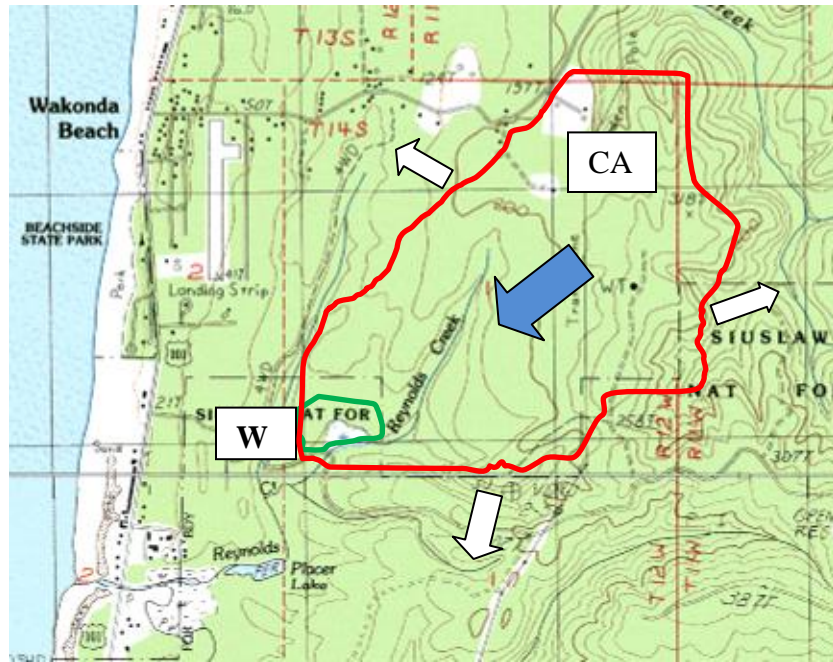
Figure 6. Delimiting a wetland's Contributing Area (CA). Wetland (to the right of the "W") is fed by its Contributing Area (CA) whose boundary is represented by the red line. The dark arrow denotes flow of water downgradient within the CA. The light arrows denote the likely path of water away from the CA and into adjoining drainages, as interpreted from the topography. Note that the CA boundary crosses a stream at only one point, that being the outlet of the wetland.

The CA may include other wetlands and ponds, even those without outlets, if they're at a higher elevation. Normally, the boundary of a CA will *cross a stream at only one point*— at the CA's and AA's outlet, if it has one. Do not include contiguous perennial deep waters at the same elevation (such as a lake, river, or bay) unless so indicated in the question. Especially in urban areas and areas of flat terrain, the CA boundaries can be somewhat subjective and estimation in the field may be preferable. However, for WESP's purposes a high degree of precision is not needed.

2.1.7 Optional Information

Although not required by WESP, you may want to seek and obtain other types of background information on the wetland you're assessing in order to improve the accuracy of your responses to specific WESP questions. This could involve contacting the current or previous landowner, or other knowledgeable people, and local, state, provincial, or federal agencies. As appropriate, ask for information on wetland inlets and outlets, contamination, management practices, plants, and wildlife. Information on past uses of the wetland and nearby areas is also useful for answering WESP questions. A "Google search" on the name of a nearby feature can sometimes be informative.

2.2 Instructions for Field Component

The field component of the assessment involves visiting as much of the AA as possible, filling out the two field forms (F and S), and verifying, as needed, answers on Form OF. Based upon the experience of many persons who tested WESP, this component will generally require less than three hours (large or complex sites may take longer). If circumstances allow, visit the AA during both the wettest and driest times of year. If you cannot, you must rely more on the aerial imagery, maps, other office information, field indicators, and discussions with the landowner and other knowledgeable sources.

2.2.1 Items to Take to the Field

Take the following with you into the field:
- Blank data forms F and S
- Completed data Form OF (to verify answers)
- Aerial images (to verify AA and use as a base map, if no wetland delineation map available)
- Aerial image that includes entire wetland (to answer applicable questions)
- Wetland delineation map (if any, to verify AA and use as a base map)
- Sketch worksheet (if no aerial or delineation map available at appropriate scale or resolution)
- Topographic map with the CA boundary you drew tentatively (to verify)
- Soil maps if available (to determine if your field determinations match)
- Shovel
- Water (for texturing soil)
- Clip board, pencil, rag to clean hands and other items you'd normally take in the field

2.2.2 Conduct the Field Assessment

Step 1. Review the questions on the F and S forms to refresh your memory of what to observe during the field visit. Also review data Form OF to see which questions you may have flagged during the office phase for checking during the field visit.

Step 2. Before answering all questions on the data forms, walk as much of the AA and wetland as possible. Plan your visit beforehand to visit each major vegetation type (these may be evident on the aerial imagery if the AA is large), each different soil map unit, each area with different

topography, the wetland/upland edges and all wetland/water feature edges (e.g., ponds, lakes, streams).

Step 3. Create or revise a base map showing the AA boundary, location of inlets and outlets, open water, and major patches of the different vegetation forms (herbaceous, woody). If the scale and resolution are appropriate, an aerial image and/or wetland delineation map may be used as the base map. If not, use the gridded data form (the "Sketch" worksheet in the WESP spreadsheet) to draw a map less precisely. For larger wetlands, marking of "waypoints" along wetland boundaries using a handheld GPS can expedite mapping and improve precision.

Step 4. Generally note the extent of non-native invasive plant cover within the AA and along its upland edge, as well as any plants you don't often encounter and other indicators described on the field forms.

Step 5. Look for surface water inlets and outlets, even if they contain flow only briefly.

Step 6. Read the instructions at the beginning of Forms F and S and then fill them out, paying attention to all the explanatory notes and definitions in the last column of the data forms. As you answer the questions dealing with "percent of the area" pay particular attention to the spatial context (area) which the question is addressing. For example, in regard to a type of vegetation or land cover, be careful to note if it's asking what percentage is occupied within the:
- open water area, or
- vegetated area *of that type* (e.g., compare only with total wooded area), or
- total vegetated area, or
- upland edge, or
- assessment area (AA), or
- entire wetland, or
- contributing area (CA), or
- circle of specified radius
- circle of specified radius but excluding any water area (e.g., ocean)

Step 7. Examine soil in the currently unflooded part of the AA and within the AA's predominant soil map unit. Record the texture of only the surface layer, i.e., within ~ 2 inches of the surface after any duff is brushed aside. Duff is fresh leaf, needle, twig, moss, dead roots and lichens that have not undergone observable decomposition. The diagnostics flow chart (Figure 7) may help you assess the soil's texture as required by WESP.

Step 8. Look uphill of the wetland to see if any artificial feature that adjoins the wetland *unmistakably* diverts *most* of the surface runoff away from it (e.g., high berm) during normal runoff events. If such is found, redraw the CA to exclude all areas that drain to that feature and not into the wetland.
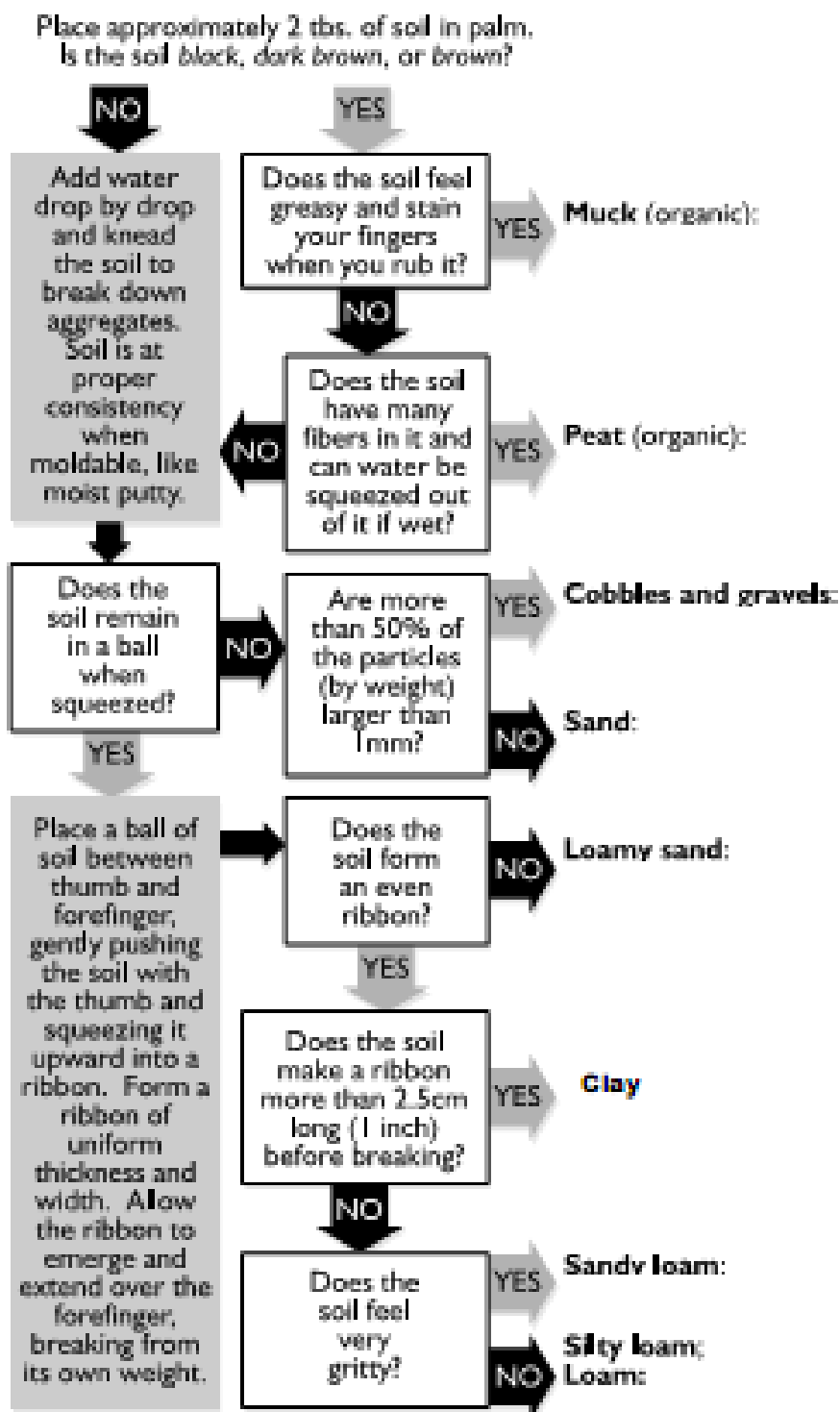
Figure 7. Flow chart for identifying soil texture.

For WESP, you need only determine if the soil is Loam (including Sandy Loam, Silty Loam), Coarse (including Loamy Sand, Sand, Cobbles & Gravels), Fines (Clay), Peat, or other Organic.
source: Washington Dept. of Ecology 2004.

2.3 Instructions for Entering, Interpreting, and Reporting the Data

2.3.1 Data Entry

Enter data from the data forms (OF, F, S) into the corresponding Excel worksheets. Check to be sure every question on all data forms was answered and entered, except where the form directed you to skip one or more questions. The scores for the functions and other attributes will compute automatically and appear in the Scores worksheet.

2.3.2 Evaluate Results

Before accepting the scores that were computed by *WESP_Calculator* and shown in the Scores worksheet, think carefully about those results. From your knowledge of wetland functions, do they make sense for this wetland and/or AA? If not, review the worksheet for that function or other attribute, as well as Appendix A to see how the score was determined. If you disagree with some of the assumptions that led to that score, write a few sentences explaining your reasoning on the bottom portion of the CoverPg form (add additional sheets if needed). Remember, WESP is just one tool intended to help the decision-making process, and other important tools are your common sense and professional experience with a particular function, wetland type, or species. Review again the caveats given in the Limitations section (Section 1.3).

If you believe some of the scores which WESP generated do not match your understanding of a particular wetland function or other attribute, first examine the summary of your responses that pertain to that by clicking on the worksheet with that attribute's code (e.g., NR for Nitrate Removal). If you want to reconsider one of your responses (perhaps because you weren't able to see part of the AA, or view it during a preferred time of year), change the 0 or 1 you entered on *Form OF*, *F*, or *S*. Then check the Scores worksheet to see what effect that had. If the results still don't match your judgment of that attribute, you may write your reasons in the space provided at the bottom of the CoverPg form.

You may do the same (changing various 0's and 1's) if you'd like to simulate the potential effect of an enhancement or restoration measure on function scores, or the impact on those scores from some controllable or uncontrollable alteration or management activity within the AA or wetland, its contributing area, or surrounding landscape out to within a specified distance. However, understand that WESP is not intended to predict actual changes to an AA – only to estimate the likely direction and relative magnitude of those changes, <u>if</u> they occur, on various functions and other attributes.

3.0 How WESP Was Developed

WESP is a refinement of the first wetland assessment method used widely throughout the U.S. (Wetland Evaluation Technique, WET; Adamus 1983) and a protocol developed and adopted by Oregon Department of State Lands with funding from the USEPA (WESP, Adamus et al. 2009). WESP also incorporates elements of the Hydrogeomorphic (HGM) Approach (Brinson 1993, Smith et al. 1995) and the Millennium Ecosystem Assessment (Finlayson et al. 2005). WESP is

structured around indicators and models. *Indicators* for scoring wetland functions, values, and other attributes were mainly derived from the principal author's experience, but indicators used by other wetland assessment methods were also considered. The particular mathematical-logic formulas used in WESP's scoring *models* were drawn initially from the principal author's understanding of wetlands, with consideration for the usual importance of different indicators and their relative contribution to ecosystem processes that determine specific wetland functions (i.e., whether and when a given indicator is likely to be controlling/ limiting or simply additive/compensatory). Also considered was each indicator's potential interactions with other indicators and its likely repeatability.

Many models in the physical sciences, and less often in ecology, are mechanistic. That is, rates are first estimated or measured for individual processes that comprise a specified function, and then mathematical formulas are prescribed to combine those processes into an actual rate for a function, e.g., grams of phosphorus retained per square meter per year, or number of salmon returning to a watershed per year. However, in the case of wetlands, data appropriate for comparing different wetland types simply do not exist for most variables (indicators) and processes that might be used to structure mechanistic models of function. Use of a collaborative modeling approach, such as Bayesian Belief Network (BBN) modeling (Haas 1991), was considered during the development of WESP but it soon became apparent that asking experts to describe interrelationships among indicator variables and estimate rates of the component processes, as might comprise a BBN approach, would add little to the modeling approach already chosen. That approach can be characterized as heuristic modeling, wherein likely relationships among indicators are identified and thresholds under various conditions are identified or assumed, but resulting process rates are not necessarily specified (e.g., Starfield et al. 1994, Doyle 2006).

4.0 Principles Used to Score Indicators and Structure the Models

4.1 Introduction

Many models in ecology and especially hydrodynamics are mechanistic. That is, rates are first estimated or measured for individual processes that comprise (for example) a river channel function, and then mathematical formulas (e.g., hydraulic or thermodynamic equations) are prescribed to combine variables that determine those processes into an actual rate for a function, e.g., grams of phosphorus retained per square meter per year. However, generally applicable measurements of the processes and the variables that determine them simply do not exist for the types of wetlands occurring in much of the study area. Attempts have been made to build such models on whatever regional data do exist but due to the lack of data involving direct measures of wetland function from a broad array of wetlands, WESP uses a different approach to model the various things that wetlands do naturally. Rather than being deterministic, that approach is at times speculative but logic-based and heuristic. Such approaches are well-regarded as an interim or alternative solution when knowledge of system behaviour is scant (e.g., Haas 1991, Starfield et al. 1994).

4.2 Indicators

For most WESP models, physical or biological *processes* that influence a given function were first identified and then *indicators* of those processes were chosen and grouped accordingly. (The term *indicators* is comparable to the term *metrics* used by some other methods). The indicators then were phrased as questions in the data forms. None of WESP's field-level indicators require *measurement*; they all are based on visual estimates. While the *precision* of measurements is typically greater than for visual estimates, their *accuracy* in predicting functions may or may not be. That is because it is often difficult to obtain sufficient measurements of an indicator, in the span of time typically available to wetland regulators or consultants, to create a full representation of any particular indicator of wetland function, let alone all the indicators that would be needed to assess a common suite of functions.

WESP's indicators were mainly drawn from inferences based on scientific literature and the author's experience throughout North America (e.g., Adamus et al. 1987, Adamus et al. 1992, Adamus 1993). Indicators used by other methods for rapidly assessing functions of wetlands in North America were also considered. To qualify as an indicator, a variable not only had to be correlated with or determining of the named process or function, but it also had to be rapidly observable during a single visit to a typical wetland during the growing season, or information on the indicator's condition had to be obtainable from aerial imagery, existing spatial data, and/or landowner interview.

When developing models of any kind, the factors that contribute to the output can be categorized in three ways: (1) unknown influencers, (2) known influencers that are difficult to measure within a reasonable span of time, and (3) influencers that can be estimated visually during a single visit and/or from existing spatial data. WESP provides an incomplete estimate of wetland functions because it incorporates only #3. Also, some of the indicator variables it uses may be *correlates* of wetland functions rather than actual influencers. For example, changes in water levels are correlated with changes in nutrient cycling, but it is the difficult-to-measure changes in sediment oxygen and pH that induce the changes in nutrient cycling, not the water level changes themselves (which happen to correlate loosely with those changes in oxygen and pH). These types of limitations apply to all rapid assessment methods.

For regulatory and management applications (e.g., wetland functional enhancement), it's often helpful to understand to which of four categories an indicator belongs:
1. *Onsite modifiable*. These indicators are features that may be either natural or human-associated and are relatively practical to manage. Examples are water depth, flood frequency and duration, amount of large woody debris, and presence of invasive species. More important than the simple presence of these are their rates of formation and resupply, but those factors often are more difficult to estimate and control.
2. *Onsite intrinsic*. These are natural features that occur within the wetland and are not easily changed or managed. Examples are soil type and groundwater inflow rates. They are poor candidates for manipulation when the goal is to enhance a particular wetland function.
3. *Offsite modifiable*. These are human or natural features whose ability to be manipulated (in order to benefit a particular wetland function) depends largely on property boundaries, water

rights, local regulations, and cooperation among landowners. Examples are watershed land use, stream flow in wetland tributaries, lake levels, and wetland buffer zone conditions.
4. *Offsite intrinsic*. These are natural features such as a wetland's topographic setting (catchment size, elevation) and regional climate that in most cases cannot be manipulated. Still, they must be included in a wetland assessment method because of their sometimes-pivotal influence on wetland functions.

4.3 Weighting and Scoring

Explicitly or implicitly, WESP assigns relative weights or scores at three junctures:
1. Scoring of the *conditions* of an indicator variable, as they contribute to that indicator's prediction of a given wetland process, function, or other attribute.
2. Scoring of *indicators* (metrics) relative to each other, as they together may predict a given wetland process, function, or other attribute.
3. Scoring of wetland *processes*, as they together may predict a given wetland function or other attribute.

Each of these is now described.

4.3.1 Weighting of Indicator Conditions

As an example of #1, consider the following conditions of the indicator, % of Water That Is Ponded, as it is applied by WESP to estimate the Sediment Retention function:

A	B	C	D	E	F	G
F31	% of Water That Is Ponded (not Flowing)	During most times when surface water is present, the percentage that is ponded (stagnant, or flows so slowly that fine sediment is not held in suspension) is:				0.00
		<5% of the water, or it occupies <100 sq.m cumulatively. Nearly all the surface water is flowing. SKIP to F34.	0	0	0	
		5-30% of the water.	0	1	0	
		30-70% of the water.	0	2	0	
		70-95% of the water.	0	3	0	
		>95% of the water.	0	4	0	

Each row following the first one describes a possible *condition* of this indicator. You must select the one condition that best describes the wetland being assessed by entering a "1" next to that condition in column D. In column E, WESP's author previously assigned relative weights to each of these conditions as they relate to the function. You cannot alter those. In this case, the last condition (>95%) was considered most supportive of that function, other factors being equal, and so had been given a weight of 4. This does not necessarily mean it is 4 times more influential than the condition which has a weight of 1, because this is not a deterministic model. However, available literature seemed to suggest that this condition is distinctly better than the other condition choices, and so it was assigned a weight of 4. When the same indicator is used to score a different function or value, the weight scheme might be reversed or otherwise differ.

In many instances, considerable scientific uncertainty surrounds the exact relationship between various indicator conditions and a function, and thus which weights should be assigned. However, keep in mind that % Ponded Water is just one of 18 indicators used to assign a score to the Sediment Retention function. The use of so many indicators serves to buffer the uncertainty in our knowledge of exact relationships, as well as difficulties of estimating the precise percentage based only on single-visit field observations.

WESP users will also notice that the weighting scale for some indicators ranges from 1 to 8 while for others it ranges only from 0 to 2, or some other range. This does not mean that the first indicator is secretly being weighted 4 times that of the second, because before the indicators are combined, their scores are converted to a 0 to 1.00 scale. The Excel spreadsheet accomplishes that by multiplying the "1" signifying a user's choice (in column D) by the pre-determined condition weight in column E, and placing the product in column F, whereupon a formula (not visible here) in the green cell takes the maximum of the values in column F pertaining to this indicator and divides it by the maximum weight in column E (the condition weight column). The formula in the green cell could just as easily have taken the only non-zero value in the last column and divided it by the maximum weight pre-assigned to the indicator conditions.

Note also that the weight scale for some indicators begins at 0 while for others it begins at 1. Often, "0" was reserved for instances where, if the indicator was the only one being used, that condition of the indicator would suggest a nearly total absence of the function. Because each of the indicator scores is normalized, this difference (0 vs. 1) at the bottom end of the scales for different indicators is probably trivial.

4.3.2 Weighting and Scoring of Indicators of Wetland Functions

In most cases, WESP does not assign weights explicitly (i.e., as multipliers) to the various *indicators* of a function. More often, weights are implicit in the manner in which indicators are combined. For example, if a function model is:

Indicator A + (Average of: Indicator B, Indicator C, Indicator D)

This implies that Indicators B, C, and D individually are likely to contribute less to the function score than Indicator A because they are only contributing to an average rather than standing alone, and as such, a low score for one may compensate somewhat for a high score of another.

If the occurrence of a particular condition of an indicator is so important that it can solely determine whether a function even exists in a wetland, then conditional ("IF") statements are used in WESP models to show that. For example, if a wetland never contains surface water, the Anadromous Fish Habitat function is automatically scored "0". In this case, "access" (presence/absence of surface water) is a controlling indicator. If a few indicators are not individually so controlling but at least one is likely to be strongly limiting in some instances, WESP takes the *maximum* among of the indicators. The *average* is applied to situations where indicators are thought to be compensatory, collinear, or redundant. WESP uses averaging as the default operator unless situations can be identified where there is compelling evidence that an indicator is controlling or strongly limiting.

There also are instances where the condition of one indicator (such as wetland type) is used to determine the relevance of others for predicting a wetland function. For example, the effect of vegetation structure within a wetland on the wetland's ability to slow the downslope movement of water in a watershed can be ignored if the wetland has no outlet channel. In the WESP calculator spreadsheet, the green cell in column G automatically turns blank, meaning that vegetation structure is not a subsequent part of the calculations. All such contingent relationships among indicators that were identified and incorporated into WESP models are documented in the Rationale column.

4.3.3 Weighting and Scoring of Wetland Processes That Influence Functions

For many functions, dozens of hydrologic (e.g., evapotranspiration) and/or ecological (e.g., juvenile dispersal) processes contribute to its ultimate level of performance. Often, too little is know about the relative importance of these processes in determining a wetland function, and for some processes there are no known indicators that can be estimated visually. Nonetheless, we identified processes as an organizing framework for the many indicators WESP employs to score most functions, and created submodels intended to represent them. For most functions, the processes are weighted like indicators and used as a "subscore" when computing the score for a function. For example, for the function Water Storage & Delay, the function model contains processes called Live Storage, Friction, and Subsurface Storage, which together are combined as a weighted average and are then averaged with OutDura (the annual duration of wetland outflow):

$$10*AVERAGE [OutDura, [(4*LiveStore + 2*Friction + Subsurf)/7])]$$

That means that OutDura was given half of the weight, with the other half being the weighted average of Live Storage, Friction, and Subsurface Storage. The three processes are divided by 7 because that is the sum of their weights (4 + 2 + 1) and the resulting function score, for the sake of clear comparisons, is multiplied by 10 in order to convert it to the 0 to 10 scale used by all functions.

5.0 Limitations

WESP is not intended to answer all questions about wetlands. Users should understand the following important limitations:

1. WESP does not change any current procedures for determining wetland jurisdictional status, delineating wetland boundaries, or requirements for monitoring wetland projects. When using WESP for regulatory applications, it is important to be familiar with other regulatory requirements related to wetland assessment. Contact the pertinent agencies as necessary.

2. The intended users are wetland specialists for government agencies, natural resource organizations, and consulting companies, who are skilled in conducting jurisdictional delineations of wetlands. Users should be able to (a) recognize most common wetland plants, (b) determine soil texture, (c) understand wetland hydrology, (d) delineate wetland contributing area boundaries from a topographic map, (e) access and acquire information from the internet, and (f)

enter data in Microsoft Excel® (1997 or later version). For field application of WESP, a multidisciplinary team is encouraged but not required. Training in the use of WESP also is encouraged but not required.

3. The numeric estimates WESP provides of wetland functions, values, and other attributes are not actual direct measures of those attributes, nor are the data combined using mechanistic models of ecosystem processes. Rather, WESP scores are estimates of those attributes arrived at by using standardized criteria (models). The models systematically combine well-accepted indicators in a logically sophisticated manner that attempts to recognize context-specific, functionally contingent relationships among indicators. As is true of all other rapid assessment methods, WESP's scoring models have not been validated in the sense of comparing their outputs with those from long-term direct measurement of wetland processes. That is the case because the time and cost of making the measurements necessary to fully determine model accuracy would be exorbitant. Nonetheless, the lack of validation is not, by itself, sufficient reason to avoid use of any standardized rapid method, because the only practical alternative— relying entirely on non-systematic judgments (best professional judgment)—is not demonstrably better in many cases. When properly applied, WESP's scoring models and their indicators are believed to adequately describe the *relative* effectiveness of a wetland for performing particular functions.

4. WESP may be used to augment the interpretations of a subject professional (e.g., a fisheries biologist, plant ecologist, ornithologist, hydrologist, biogeochemist) when such expertise is available. WESP outputs, like those of other rapid methods, are not necessarily more accurate than judgments of a subject expert, partly because WESP's spreadsheet models lack the intuitiveness and integrative skills of an actual person knowledgeable of a particular function. Also, a model cannot anticipate every situation that may occur in nature. WESP outputs should always be screened by the user to see if they "make sense." Nonetheless, WESP's scoring models provide a degree of standardization, balance, and comprehensiveness that seldom is obtainable from a single expert.

5. WESP's logic-based process for combining indicators has attempted to reflect currently-understood paradigms of wetland hydrology, biogeochemistry, and ecology. Still, the scientific understanding of wetlands is far less than optimal to support, as confidently as some might desire, the models WESP and other rapid methods use to score wetland attributes. To provide transparency about this uncertainty, in the Rationales column of the WESP worksheets for individual functions, some of the more significant alternative or confounding interpretations are noted for indicators used in that function's scoring model.

6. WESP does not assess *all* functions, values, and services that a wetland might support. In particular, WESP does not assess the suitability of a wetland as habitat for any individual wildlife or plant *species*. The 16 functions and 21 values WESP assesses are those most commonly ascribed to wetlands.

7. Factors that potentially affect wetland functions can be categorized in three ways: (1) known influencers that are difficult to measure, (2) influencers that can be estimated visually during a single visit and/or from existing spatial data, and (3) unknown influencers. WESP provides an

incomplete estimate of the functions it attempts to represent because it incorporates only #2. Also, some of the indicator variables it uses may be *correlates* of wetland functions rather than actual influencers. For example, changes in water levels are correlated with changes in nutrient cycling, but it is the difficult-to-measure changes in sediment oxygen and pH that induce the changes in nutrient cycling, not the water level changes themselves (which happen to correlate loosely with those changes in oxygen and pH). These types of limitations apply to all rapid assessment methods.

8. Although each WESP model has a *theoretical* minimum score of 0 and a maximum of 10 (even without scaling), the *actual* range may be narrower because the conditions of some indicators rarely or never occur together in the natural world. Thus, the output scores of all models will not necessarily have the same statistical distribution. That is, scores generated by some models will skew high (e.g., more than half the time they might be above 8 on the 0 to 10 scale) whereas the scores generated by other models might skew low (e.g., more than half the time they may be 0). Because these are scoring models, not deterministic equations, the high or low skew could be due to either (a) one function tending to be inherently less effective than another among wetlands generally, or (b) the relative conservativeness (or lack thereof) of the particular indicators and their criteria as used in a model for a particular function or other attribute -- meaning, for some indicators, very few wetlands happen to satisfy some of the indicator's specified conditions. It is not possible to determine if (a) or (b) is more often the case. One implication is that WESP may be somewhat more reliable in distinguishing differences of levels of a single function *among wetlands*, than in distinguishing differences *among functions* in a single wetland, i.e., ranking correctly the effectiveness or value of those functions relative to each other.

9. If two wetlands have similar effectiveness scores for a function and its value, the larger wetland is usually more likely to provide a greater total level of the associated ecosystem service. However, the relationship between wetland size and the total level of a service delivered is not necessarily linear. For example, if its characteristics make a particular wetland ineffective for storing or purifying water, or for supporting particular plants and animals, then simply increasing its size by adding more wetland having the same characteristics will usually not increase the total amount of water stored or purified, or plants and animals supported. The threshold below which a wetland's characteristics make it completely ineffective is unknown in many cases. Where scientific evidence has suggested that wetland size may benefit a function in a greater-than-linear manner, WESP has included wetland size as an indicator for that function. Those functions are Waterbird Feeding, Waterbird Nesting, Songbirds-Raptors-Mammals, and Pollinators.

10. In some wetlands, the scores that WESP's models generate may not be sufficiently sensitive to detect, in the short term, mild changes in some functions. For example, WESP is not intended to measure small year-to-year changes in a slowly-recovering restored wetland, or minor changes in specific functions, as potentially associated with limited "enhancement" activities such as weed control. Nonetheless, in such situations, WESP can use information about a project to predict the likely *direction* of the change for a wide array of functions. Quantifying the actual change will often require more intensive (not rapid) measurement protocols that are complementary.

11. WESP outputs are not intended to address the important question, "Is a proposed or previous wetland creation or enhancement project in a *geomorphically appropriate* location?" That is, is the wetland in a location where key processes can be expected to adaptively sustain the wetland and the particular functions which those of its type usually support, e.g., its "site potential?" Although WESP uses many landscape-scale indicators to estimate functions and values of a wetland, WESP is less practical for identifying the relative influence of multiple processes that support a single wetland.

12. The impact of potential stressors on a wetland depends partly on their proximity to the wetland, their proportional extent, and spatial arrangement. There are many ways to measure these, and nearly limitless combinations (e.g., Mita et al. 2007). For example, assuming that intensively cropped areas are a potential wetland stressor, that could be expressed as a proportion of the surrounding landscape at any particular distance from the center or edge of a wetland. In addition or instead, that land use could be measured as a percent of the wetland-upland edge (wetland perimeter). The measurement could be limited to just the areas upslope of the wetland being assessed, or include all areas within a specified radius. Alternatively, for some functions the size of the largest patch of a land use within some specified distance may be more important than its distance and the presence of connecting corridors. Some research data suggest land use practices many miles from an isolated wetland can impact its functions (Houlahan & Findlay 2003, DeLuca et al. 2004), but the relationship of function to distance cannot be assumed to always be linear, and there are limits to what can be estimated both accurately and rapidly from aerial imagery and field inspection. The array of potential choices for defining and measuring "landscape" or "connectivity" indicators is befuddling, and for most functions there is no compelling research data from replicate studies that support particular proximities, proportions, and configurations that are especially pivotal (Baker et al. 2006). For adequately assessing stressor effects on wetland functions, field evaluation of stressors is at least as important as interpreting them from aerial imagery (Wardrop et al. 2007).

6.0 How to Calibrate WESP for Your Region, State, or Province

As mentioned in the Limitations section, considerable meaning and utility is added to the raw scores that WESP produces for an individual wetland, and some of their inherent statistical bias is reduced, if those scores can be automatically compared with (calibrated to) the scores from a large series of reference sites spanning the expected range of variation within a region. This section describes how to conduct such a calibration process. The author may be contacted for further explanation and elaboration.

More detailed descriptions of each of these steps follow their general listings below.

6.1 Minimal Approach for Calibration

Skills required: Prior training in WESP and/or familiarity with all WESP materials (calculator, manual).
a1. Manually select at least 50 wetlands which you believe will together span the variety of types, landscape settings, and disturbance gradients within your region.

a2. Visit and assess those using the WESP data forms.
a3. Enter the data in the WESP spreadsheet and calculate their raw scores.
a4. Review the output to identify the regional minimum and maximum for each function and each benefit. Then edit the spreadsheet so it converts each raw score to a normalized score, as described in section 6.3 below.

Elaboration of the Minimal Approach:
a1. "Types" = whatever classification(s) have been previously mapped and/or used. In the U.S. this includes the Cowardin classification (National Wetlands Inventory) and in some places, the Hydrogeomorphic (HGM) classification. "Landscape settings" = encompassing the range of climate, elevation, salinity, soils, proximity to towns, connectivity/proximity to other surface waters, and other factors relevant to estimating functions and benefits. "Disturbance gradients" means the range of human and natural disturbance (least- to most-altered, different post-restoration or post-recovery times) from pollution, hydrologic alteration (dams, irrigation, beaver, etc.), land cover change, fire, grazing, erosion, and others.
a2. Smaller wetlands on public lands and adjacent to roads will be easiest to visit, but this bias should be minimized to whatever extent possible.
a3. Data from *multiple* sites can be entered in the spreadsheet by inserting additional data columns between the WESP calculator spreadsheet's columns D and E (and after F in the form S worksheet), and then progressively copy-pasting the data from each site into column D, and then each time copy-pasting the resulting output from the Scores worksheet into a separate document.
a4. The minimum and maximum scores found among all wetlands you assessed should be placed in columns H-I and K-L of the Scores worksheet, in place of the 0's currently there.

6.2 Preferred Approach for Calibration

Additional skills preferred: Expertise in editing Excel spreadsheets, compilation of spatial data using GIS, use of statistical software.
b1. Identify and obtain all existing *spatial data* that is relevant to assessing wetland functions and benefits.
b2. Intersect, compile, and statistically analyze the spatial data in order to *systematically* select at least 50 wetlands that together span the variety of types, landscape settings, and disturbance gradients within your region.
b3. Identify, obtain, and read *regional literature* on the functions that WESP addresses.
b4. If warranted, refine (edit) the WESP *data forms* to make them more applicable to your region:
      Add or delete particular wetland functions (worksheets).
      Add or delete particular questions (indicators) on the data forms.
b5. Visit and assess wetlands as described for a2-a4 above.
b6. If warranted, refine (edit) the WESP *indicator weights and models* to make them more applicable to your region and/or more aligned with professional judgments of the relative ranks of wetlands visited. (the indicator weights are in column E in the function worksheets, and the models are the cell formulas are in column G at the bottom of each WESP worksheet).
b7. Run the collected data using the refined models.

b8. Test the *repeatability* of the function and benefit scores of the modified WESP, among trained users who simultaneously visit the same wetlands and independently assess each, using the modified WESP.
b9. If you changed any of the WESP models, edit their descriptions in Appendix A of the WESP Manual.

Descriptions for the Preferred Approach:
Additional Skills: Support staff or contractors who have one of more of the listed skills are typically recruited.
b1. At a minimum, spatial data depicting wetlands (as polygons, classified by type if possible) must be available for the entire focal region, even if it suffers from many omissions. In addition, although not all of the following layers are essential, the more that are available with coverage of the entire focal region, the more accurate will be the WESP calibration and analysis:

> topography (DEM, ideally LiDAR), hydrography (streams, lakes, watersheds, heads-of-tide), flood hazard areas, soils, geology, land cover, specially protected areas (due to wildlife, plants, groundwater vulnerability, other factors).

Create a geodatabase (e.g., Excel or dbf format table) consisting of these layers (columns) intersected with the wetland polygons (rows) and automatically assign an identifier number to each wetland polygon. Where multiple classes of some attribute are intersected by one wetland polygon (e.g., several cover types within a single wetland), create a column for each intersected class and fill it with the percentage of the wetland comprised by that class. Do the same compilation for areas within 1 km (or some other buffer radius) of each wetland's centroid.
b2. For selecting calibration sites more objectively, the analysis involves use of a statistical procedure called k-means cluster analysis. Either a statistics package having that option should be used, or the free "R" script for that procedure (available online) should be configured. The data to be analyzed consist of the geodatabase described above. First delete any wetlands (rows) with data missing for any of the above attributes, or if such missing data would be extensive, do not include that spatial layer in the geodatabase. Then specify the number of sites that are feasible to visit and assess (the "k" in the k-means cluster analysis) and run the statistics software on the geodatabase, such that it assigns a cluster ID number to every wetland polygon, e.g., 1 to 100 if you specified that 100 calibration sites is the most that can be visited and assessed before public release of your regionalized WESP. Some of the resulting clusters will contain more wetlands than others. Select one wetland per cluster to visit and assess. That wetland can be selected randomly after first eliminating (filtering) wetlands distant from roads and (if necessary) wetlands on private land. Avoid selecting wetlands that are within a few kilometers of each other.
b3. Regional literature can be identified (and PDF-format versions often obtained) by entering keywords or related phrases in Google Advanced Search, Google Scholar, and subscription-based bibliographic databases such as Web of Science. At a minimum, synonyms such as the following (and their plurals) should be used:

> wetland, swamp, marsh, fen, bog, peatland, pond, vernal pool, wet prairie, bayou, hydrophyte, macrophyte, springs, riparian, off-channel, amphibian, waterfowl, hydric soil

Also, search using various synonyms for the region of interest and some of its geographic features that are likely to have been the focus of past research studies.
b4-b7. In the WESP data forms, you may wish to convert English units to approximate metric equivalents or vice versa. Particular wetland *functions* (worksheets) may be deleted only if you

are very certain that no wetland in the focal region would be capable of performing the functions to any degree. Particular questions (*indicators*) on form OF may need to be deleted if the types of spatial data they specify are not available for the focal region. It is unlikely that additions or deletions of questions on forms F and S will significantly improve accuracy. For a given indicator question, the number of choices of conditions may be expanded or contracted and thresholds may be changed. However, that must be accomplished before calibration sites are visited and assessed so that the collected data do not represent a "moving target." Everywhere a new or adjusted indicator is used in the function worksheets, a large and painstaking effort will be required to adjust cross-referencing cell formulas and their models. Ensure that indicator score cell formulas result in blanks for questions which users were instructed to skip under certain conditions. If no indicators are added to or deleted from the data forms, the current cell formulas for the *submodels and models* can be adjusted fairly easily and those adjustments may be made even after the field calibration has been completed. Modifications of the models may be suggested by interviews with local subject experts, the review of regional literature, and field observations during the calibration site visits.

b8. For the repeatability testing, the number of participants and the number of wetlands assessed should be equal, and the more the better . All testers should first be trained. After data from all testers and sites is entered into the calculator spreadsheet and function scores are generated, determine the mean, standard deviation, and confidence interval of the scores from each site. Also determine those among all sites using the among-tester means. Determine if score variation among sites is greater than variation among users assessing the same site independently (it should be). If user variation is too great, modify the model formulas further or consider requiring more training. In any case, measuring the confidence intervals will be important to future users because it indicates whether a restoration or impact resulting in a change of "x" units in a score can be judged as statistically significant or if it is merely within the average range of variation expected among trained users.

6.3 Normalizing Raw Scores and Converting to Ratings

Normalizing answers the question, "How does this wetland compare with a large set of others in this region?" In that sense, normalized scores are like percentiles. Normalizing also allows for straightforward comparison of any function score with any other function score from the same or a different wetland. The normalizing process, which was applied to the scores for each function, employed this widely-recognized formula:

$$\frac{\text{raw score of \textbf{“wetland x”}} - \textbf{minimum} \text{ score from all calibration wetlands}}{\textbf{maximum} \text{ score of all calibration wetlands} - \textbf{minimum} \text{ score of all calibration wetlands in region}}$$

Unless the number of assessed calibration wetlands is very large (over 1000) it will not be statistically valid to normalize function scores by wetland type, e.g., comparing tidal wetlands only to other tidal wetlands, comparing subalpine depressions only to other subalpine depressions.

6.4 Converting Raw Scores to Normalized Scores and Ratings

To more readily convey meaning to the scores, the spreadsheet can be scripted to automatically place next to each normalized function and value score a rating (e.g., Lower, Moderate, Higher). For a given function or value, this may be based on natural breaks in the statistical distribution of the normalized scores among all the calibration wetlands. Those natural breaks are best identified using a popular statistical procedure called Jenks Optimization (Jenks 1967). This procedure is relatively objective and uses iterative calculations with gradual adjustments in group membership to minimize variance within groups while maximizing the variance between groups. Because different functions will have different statistical distributions of their calibration wetland scores, the natural breaks for any given function will typically occur at different numeric thresholds than those of other functions.

6.5 Other Considerations

It is not possible to state with certainty for how long the scores of any wetland will remain valid. That will depend on forecasting the likelihood of short and long-term changes in climate, sea level change, beaver activity, natural succession of vegetation, land cover changes in nearby areas, and a host of other factors. A particular wetland's capacity to resist functional change in response to these individual or cumulative factors usually cannot be predicted with confidence. Major changes in any of these factors that are apparent in a wetland or within a few miles, especially along connected streams, could suggest a need to reassess the wetland at future times using the same version of WESP.

Also, note that the indicators and models featured in WESP are intended to represent wetland science as it currently exists. As with all science, continued research in this region and elsewhere could yield new discoveries that might suggest a need to change some of the indicators and assumptions currently embedded in WESP. It is recommended that new spatial data sets and new learnings about wetland science be reviewed at least once every 10 years and their impact on WESP models, scores, and ratings be evaluated. However, any future changes made to the indicators that WESP uses, the wording of its questions, or the weights and combination rules of its models, will require that all of the calibration wetlands be reassessed, or a new calibration series selected and assessed with the changed protocol.

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Appendix A. Narrative Descriptions of the WESP Scoring Models

This appendix attempts to describe, in a narrative manner, the indicator variables (questions in data forms) that WESP uses to assess each function and its value, and how they are combined in scoring models. The indicators mentioned in the descriptions below are shorthand versions of indicators that are defined and explained fully in the WESP data forms (worksheets F, S, and OF). In the *WESP_Calculator* spreadsheet, rationales (and where feasible, citations of supporting literature) for the indicators are provided in column E of the worksheet pertaining to that wetland function. In the "Pts" column of each of the Excel worksheets, understand that a weight of "0" does not necessarily mean the named condition is of no importance at all to the function—it is only a relative measure. For more information on the modeling process, see section 3.0. The narratives below also describe, by function, the relative amount of scientific support for the existance of that function in wetlands generally; for more documentation see Adamus et al. 1992 and Adamus 2001. Finally, under the heading, "Potential for Future Validation," this appendix describes, for each function, some of the types of measurements that might be taken to validate each model if that should be desired in the future.

A.1 WATER STORAGE & DELAY (WS)

Function Definition: The effectiveness of a wetland for storing water or delaying the downslope movement of surface water for long or short periods and in doing so to potentially influence the height, timing, duration, and frequency of inundation in downstream or downslope areas.

Scientific Support for This Function in Wetlands Generally: Moderate to High. Many non-tidal wetlands are capable of slowing the downslope movement of water, regardless of whether they have significant storage capacity, simply because they are *relatively* flat areas in the landscape. When that slowing occurs in multiple wetlands, flood peaks further downstream are muted somewhat. When wetlands are, in addition, capable of storing (not just slowing) runoff, that water is potentially available for recharging aquifers and supporting local food webs. Wetlands intersected by channels and located on steep slopes are least capable. Where this function is performed to some degree, its *benefit* will depend partly on wetland location relative to areas potentially damaged by floods. Also, it is likely that subsurface storage of water in many regions (e.g., in deep peat, alluvium, colluvium) is more substantial than surface water storage. Unfortunately, in most cases subsurface storage cannot be estimated reliably with a rapid assessment method. Typically, it requires measurements of soil depth and texture (at greater depth than is practical to dig during a rapid assessment) and an understanding of subsurface water levels, flow direction, and exchange rate during different seasons.

WS Function Model

```
IF((AllSat1=1), AVERAGE [(OutDura, AVERAGE(Subsurface, Friction)],
ELSE: AVERAGE [OutDura, (4*LiveStore + 2*Friction + Subsurf)/7)) ]
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- If a wetland never contains surface water, half of its score is from its duration of its connection to a stream (no connection or seasonal-only surface water connection scoring

higher) and the other half of its score is based on the average of two factors: *Subsurface Storage* and *Friction*.

- If the wetland has a surface water outlet, half of its score again is based on increasing isolation from other surface waters, but the other half this time is accounted for not only by *Subsurface Storage* (weight of 1) and *Friction* (weight of 2), but also and most significantly by *Live Storage* (weight of 4).

In the above calculations:

- **Subsurface Storage** potential, which is largely associated with increasing infiltration and evapotranspiration, is assumed to be indicated by deep peat soils, lack of evidence of groundwater discharging at the surface (which suggests that subsurface storage areas are nearly full and cannot receive new runoff), small catchment relative to wetland size, and two variables that may indicate less likelihood of a frozen (and thus impervious) surface being present around the time of spring runoff: south-facing aspect and more growing degree-days. These are averaged.

AVERAGE(SoilTex, Groundw, CApct, ETregion, Aspect)

- **Live Storage** is assumed to be indicated by increasing amplitude of water level fluctuation and increasing percent of the wetland's area that floods only seasonally. These are averaged:

IF((AllSat1=1), 0, AVERAGE(Fluctua, SeasPct))

- In wetlands that never have surface water (AllSat=1), **Friction** is the weighted average of decreasing gradient (weight of 3) and the average of increasing ground cover and increasing ground roughness (microtopographic variation). In wetlands that do have surface water, Friction is assumed to be indicated by the average of 5 indicators: flatter internal gradient, mostly ponded condition, a longer flow distance from inlet to outlet, an artificially constricted outlet, and (if intersected by a channel) greater channel meandering within the wetland. These indicators are averaged:

IF((AllSat1=1), (3*Gradient +AVERAGE(Gcover, Girreg))/4, **ELSE**: AVERAGE(Gradient, Constric, ThruFlo, FloDist, IsoDry)

Important Note: The model does not account for the wetland's surface area, and obviously, larger wetlands can store more water. Because the model is estimating relative effectiveness per unit area, some smaller wetlands will have higher scores for this function than larger ones. Thus, wetland size should also be considered in the case of this particular function.

Approach for Future Validation: The volume, duration, and frequency of water storage could be measured in a series of wetlands that encompass the scoring range, and flows could be measured at their outlets if any, and at various points downstream. Measurements should especially be made during major storm or snowmelt events. Procedures that might be used are partly described by Warne & Wakely (2000) and US Army Corps of Engineers (2005).

WS Benefits Model

AVERAGE(FloodBdg, AVERAGE(ShedPos, CAunveg, Transport))

The Benefits score is the average of two factors. One concerns whether buildings or infrastructure within 5 km downriver or downslope from the wetland have been damaged or are in a mapped floodplain. The other is the average of 3 indicators -- the extent of unvegetated

upslope surfaces (more impervious or semi-pervious proportional surface indicates more opportunity for downslope wetlands to influence flood peaks), lower position in a regional watershed, and the potential for runoff to be transported to a wetland as related to steeper slope and decreasing vegetation in its contributing area.

A.2 STREAM FLOW SUPPORT (SFS)

Function Definition: The effectiveness of a wetland for prolonging surface water in headwater streams during seasonally dry periods. This is important for fish passage and overall ecological support.

Scientific Support for This Function in Wetlands Generally: Moderate. Many non-tidal wetlands should be capable of performing this function. If not feeding streams directly themselves, many wetlands at least are discharge sites for groundwater which in turn feeds streams. Higher in a watershed, some wetlands are capable of recharging groundwater, which ultimately discharges to wetlands and then streams lower in the watershed.

SFS Function Model

OutDur * [(2*GroundwaterDisch + ClimateFactors)/ 3]

The model considers three factors: *Groundwater Discharge, Connectivity* (OutDur), and *Storage. Connectivity* is considered the controlling factor, so if the wetland lacks both a surface flow outlet (at any season) and is not immediately upslope from a stream channel, the score is set at 0. Otherwise, the *Connectivity* score is multiplied by the weighted average of *Groundwater Discharge* (weight of 2) and *Storage.* In the above calculations:

- **Connectivity** is considered greater in wetlands with longer-duration surface water outflows. Wetlands without outflows are scored "0" for this function unless they are very near streams, in recognition of the possibility of a subsurface connection.
- **Groundwater Input** is assumed to be more likely if a wetland is of a particular type (e.g., fen) or there are other clues that groundwater may be discharging significantly to the wetland. These 2 indicators are averaged:

AVERAGE(Groundw, Wettype)

- **Storage** is assumed to influence wetland contribution to streamflow, and is represented by northerly aspect, greater water depth, and presence of soils with greater water-holding capacity, e.g., peat. All these indicators are considered to be about equally predictive and so are averaged together:

AVERAGE(Aspect, Depth, Soil)

Important Note: The model does not account for the wetland's surface area, and obviously, larger wetlands could potentially deliver more water to streams if other factors support this function. Because the model for this function is estimating relative effectiveness per unit area, some smaller wetlands will have higher scores than larger ones. Thus, wetland size should also be considered in the case of this particular function.

SFS Benefits Model

> AVERAGE[ShedPos, AVERAGE(InvScore, AnadScore, ResFishScore)]

The Benefit of the Streamflow Support function is assumed greater in wetlands that are either in the headwater of a watershed, or have high scores for supporting habitat of invertebrates, anadromous fish, and/or resident fish. These last 3 indicators are considered to be about equally predictive of the Benefit of this function and so are averaged before their average is combined with the score for watershed position.

A.3 WATER COOLING (WC)

Function Definition: The effectiveness of a wetland for maintaining or reducing the water temperature, primarily in headwater streams.

Scientific Support for This Function in Wetlands Generally: Moderate. Many well-vegetated non-tidal wetlands should be capable of performing this function.

WC Function Model

> IF((AllSat1=1), Gwater, **ELSE**: AVERAGE(Gwater, Shade, OpenPonded, Depth, ISOdry, SatPct)

If a wetland never contains surface water during the summer, then only *Groundwater Input* is considered by the model. In all other wetlands, the score is the average of groundwater input (various features suggest high likelihood of discharging groundwater), increases in percent shade, deeper water, greater proportion of wetland that lacks surface water, smaller proportion of open water, and decrease in the percent of the surface water that is ponded.

Important Note: The model does not account for the wetland's surface area, and obviously, larger wetlands could potentially provide a greater volume of cooled water if other factors support this function. Because the model for this function is estimating relative effectiveness per unit area, some smaller wetlands will have higher scores than larger ones. Thus, wetland size should also be considered in the case of this particular function.

WC Benefits Model

> IF(Fringe=1), 0, OutDur X [AVERAGE(ShadeIn, ShedPos, Aspect, Imperv, Warmth) + AnadFish] /2

If the wetland is a fringe wetland, the Benefits score is set to 0 because it is assumed that the volume of water which the wetland contributes to its adjacent water body will be relatively small. Other wetlands are assumed to be more valuable for this function if (a) accessible to anadromous fish, and/or (b) are at low elevation, surrounded by impervious surfaces, not a fringe wetland, are south-facing, and have an input tributary whose water is predicted to be warmer than that in the wetland itself. The conditions in (b) are all considered to be equally influential so are averaged. That average is considered to be as important as access to anadromous fish (a) so

the two are averaged. Then, that average is multiplied by the duration of the wetland's outlet flow, because longer outflows imply greater opportunity to deliver this function.

A.4 SEDIMENT RETENTION AND STABILIZATION (SR)

<u>Function Definition:</u> The effectiveness of a wetland for intercepting and filtering suspended inorganic sediments thus allowing their deposition, as well as reduce current velocity, resist erosion, and stabilize underlying sediments or soil.

<u>Scientific Support for This Function in Wetlands Generally</u>: High. Being relatively flat areas located low in the landscape, many wetlands are areas of sediment deposition, a process facilitated by wetland vegetation that intercepts suspended sediments and stabilizes (with root networks) much of the sediment that is deposited. Wetlands intersected by channels and located on steep slopes are least capable. An abundance of clearcuts, logging roads, agriculture, and wind-exposed shorelines provides many opportunities for wetlands to trap sediment and/or stabilize underlying soils and sediments.

Potentially, the performance of this function has both positive and negative aspects. Positives include reduction in turbidity in downstream waters, provision of substrate for outward expansion of marsh vegetation into deeper water, and improved detoxification of some contaminants associated with the retained sediment. Sediment serves as a carrier for heavy metals, phosphorus, and some toxic household chemicals, which routinely bind to surfaces of suspended clay particles (Hoffman et al. 2009, Kronvang et al. 2009). Negative aspects potentially include progressive sedimentation of productive wetlands, slowing of natural channel migration, reduction of water storage capacity, and increased exposure of organisms within a wetland to contaminants. The Benefits models address only the opportunity to perform this function, not its potential positive or negative effects which are too difficult to estimate with a rapid method.

SR Function Model

(IF((AllSat1=1), DryIntercept, IF((NoOutlet=1), 1, [2*AVERAGE(Entrain, LiveStore) + AVERAGE(DryIntercept, WetIntercept)]/3

At a coarse level, three types of non-tidal wetlands are analyzed separately as pertains to this function: (1) those that never contain surface water, (2) those that lack outlets, and (3) all others.
- If a wetland never contains surface water, its ability to stabilize underlying soil increases if its *Dry Interception/Erosion Resistance* is great – see below for description.
- If a wetland lacks a surface-flow outlet, i.e., is isolated, then the highest possible score for this function (10.00) is assigned automatically.
- For all other wetland types, the score is the average of a wetland's increased *Hydrologic Entrainment* capacity (weighted 2x), *Storage Space* (weighted 2x), *and* average of Dry and Wet Interception.

In the above calculations:

- **Interception/Erosion Resistance in the Terrestrial** (dry) environment is assumed to increase with decreasing wetland gradient, small catchment relative to wetland area, and the average of increasing ground cover, microtopographic variation, and lack of soil disturbance. It is assumed that wetlands without surface water can only stabilize soil, not trap suspended sediment carried in by surface flow.

AVERAGE[Gradient, WetPctCA, AVERAGE(Girreg, Gcover, SoilDisturb)]

- **Interception/Erosion Resistance in the Aquatic** (wet) environment is ignored in the calculations if none of the vegetation is ever flooded or if the wetland contains no ponded areas. Otherwise it is assumed to increase with increasing width of the vegetated zone, which is given the same weight as the combined average of scores for longer growing season, more meandering of flow paths through the wetland, increased cover of emergent plants, and presence of relatively equal amounts of vegetation and open water arranged in a patchwork:

IF(AllSat1=1),"", IF(NoPonded=1),"", **ELSE**: AVERAGE (Width, AVERAGE(GDD, Thruflo, AqPlantCov, Interspers))

- **Hydrologic Entrainment** capacity is assumed to be indicated by decreased duration of outflow, increased flow path length, greater water depth, greater ponded extent, constricted outlet, and flat shoreline . These are all considered equally predictive and so their scores are averaged:

IF(AllSat1=1),"", AVERAGE(OutDura, FlowDist, Depth, Ponding, Constric, WatEdgeSlope)

- **Live Storage Space** is assumed to be indicated by increasing amplitude of water level fluctuation and increasing percent of the wetland's area that floods only seasonally. These are considered equally predictive and so are averaged:

IF(AllSat1=1),"", AVERAGE(Fluctua, SeasPct)

Important Note: The model does not account for the wetland's surface area, and obviously, larger wetlands could potentially trap and store more sediment if other factors support this function. Because the model for this function is estimating relative effectiveness per unit area, some smaller wetlands will have higher scores than larger ones. Thus, wetland size should also be considered in the case of this particular function.

Approach for Future Validation: The volume of accreted sediments could be measured in a series of wetlands that encompass the scoring range. This might be done with isotopic analysis of past sedimentation rates, or (going forward) with ground-level LiDAR imaging, SET tables (Boumans & Day 1993), or various sediment markers. Suspended sediment could be measured at inlets and outlets if any, with simultaneous measurement of changes in water volume and flow rate (e.g., Detenbeck et al. 1995).

SR Benefits Model

MAX(ToxData, ToxUp, AVERAGE(Inflo, SatPct, AVERAGE(ImpervPctSS, SedIn, CAnatPct, BuffSlope, CApct, TransportSS, MaxFluc)

If water quality data indicates that contamination (within 1 km upstream) has occurred with metals and other substances that readily adsorb to sediment, this counts for half the score.

Otherwise, the Benefits scores increases if a tributary enters the AA, or a large proportion of the wetland contains surface water, or if the average of scores for several indicators is large: increased presence of recent erosive land use activities upslope from the wetland, greater amounts of impervious surface and less natural cover in the wetland's contributing area, steeper slopes surrounding the wetland, large water level fluctuations.

A.5 PHOSPHORUS RETENTION (PR)

Function Definition: The effectiveness for retaining phosphorus for long periods (>1 growing season) as a result of chemical adsorption and complexation, or from translocation by plants to belowground zones or decay-resistant peat such that there is less potential for physically or chemically remobilizing phosphorus into the water column.

Scientific Support for This Function in Wetlands Generally: High. Being relatively flat areas located low in the landscape, many wetlands are areas of sediment deposition, a process facilitated by wetland vegetation that intercepts suspended sediments and stabilizes (with root networks) much of the sediment. Because phosphorus (P) is commonly adsorbed to the suspended solids, it will consequently be deposited. Also, soluble forms of P can be chemically precipitated from the water column if there are sufficient levels of certain elements (iron, aluminum, calcium), the water is aerobic, and the pH is acidic (with iron, aluminum) or basic (calcium). This chemical precipitation of P also results in retention within a wetland. Subsequently, a variable proportion of the P will re-enter the water column (i.e., be desorbed from sediments or leached from organic matter) which makes it vulnerable to being exported from the wetland. This can happen when sediments or the water column become anaerobic or the pH changes. That can result from excessive loads of organic matter, rising temperature, and/or reduced aeration due to slowed water exchange rates, increased water depth, or ice that seals off diffusion of atmospheric oxygen into the water. The wetland's P balance also depends on the physical stability of deposited sediments or soil. Wind can resuspend sediments rich in P making the sediments and their associated P vulnerable to being exported downstream by currents, but wind can also aerate the water column, which helps retain the P in the sediments. Plant roots also can facilitate P retention by aerating the sediment and translocating aboveground P to belowground areas where P-bearing sediments are less likely to be eroded. Phosphorus can potentially accumulate in wetlands more rapidly than nitrogen, and a state can be reached (perhaps after several decades of increased P loading) where sediments become saturated and no more P is retained, at least until some is desorbed and exported.

The **Benefits** model (as opposed to the function model) addresses only the opportunity to perform this function, not its potential positive or negative effects on ecosystems, which are too difficult to estimate with a rapid method. Phosphorus is essential for plant growth but in high concentrations can shift species composition and habitat structure in ways that sometimes are detrimental to rare plants, aquatic food chains, and valued species (Carpenter et al. 1998, Anderson et al. 2002).

PR Function Model

IF((AllSat1=1), AVERAGE(IntercepDry, Adsorb, FreezeDura), IF((NoOut=1), 1, **ELSE**: (3*AVERAGE(Adsorption, Desorption) + 2*Connectivity+ (AVERAGE(InterceptWet, InterceptDry) + FreezeDuration) / 7

At a coarse level, three types of non-tidal wetlands are analyzed separately as pertains to this function: (1) those that never contain surface water, (2) those that lack outlets, and (3) all others.

- If a wetland never contains surface water, its ability to retain phosphorus is assumed to increase with decreased duration of ice cover (FreezeDura) and increased *Dry Interception/Erosion Resistance* and *Adsorption Potential* (see below for description of these terms). These are considered equally predictive so are averaged:
- If a wetland lacks a surface-flow outlet, i.e., is isolated, then the highest possible score (10.00) for this function is assigned automatically, based on an assumption that most phosphorus is associated with suspended sediment. However, some amount of phosphorus is soluble and could still escape in groundwater. That pathway cannot be estimated with a rapid assessment method.
- For all other wetland types, a high score depends on the average of a wetland's increased *Adsorption* and decreased *Desorption* potential (averaged together and weighted 3x), its reduced *Connectivity* (weighted 2x), and the average (unweighted) of shorter *Frozen Duration* (unweighted), greater *Dry Interception/Erosion Resistance*, and greater *Wet Interception.*

In the above calculations:

- **Adsorption potential** is represented by the average of soil texture (greater in clay and peat soils, and lower in coarse-textured soils), presence of calcareous soils (which have higher adsorption potential), and occurrence of either very acidic (pH<5)or very basic (pH >9) conditions.

AVERAGE(SoilTex, Stain, Calcar)

- **Desorption potential** is assumed to be least in wetlands with deep persistent water with stable water levels. Soil respiration, carbon accumulation rate, and subsurface water table fluctuation can be important to phosphorus adsorption and desorption but cannot be assessed accurately with a rapid assessment method.

AVERAGE(SatPct, Persis, DomDepth, Fluctu)

- **Connectivity** is assumed to be less in wetlands that have no outlets, export surface water through a ditch or artificial outlet, have low gradient, and a long flow path. These are considered about equally predictive and so are averaged.

AVERAGE(OutDur, Constric, Gradient, FlowDist, Lake)

- **Interception/Erosion Resistance in the terrestrial** (dry) environment is assumed to increase mainly with a decrease in gradient and lengthening flow path. The remaining 1/3 of the score for this process is based on the average of increased ground cover, microtopographic variation, and wetland size in proportion to catchment size.

AVERAGE[Gradient, FlowDist, AVERAGE(Girreg, Gcover, CApctB)]

- **Interception/Erosion Resistance in the aquatic** (wet) environment is assumed to increase if the wetland is ponded, has greater cover of emergent plants distributed in a patchy manner, and increased meandering of surface water as it travels through the wetland. These are considered equally predictive and so are averaged, and that average is then averaged with wetland width. This factor and its indicators are ignored in the calculations if none of the vegetation is ever flooded.

```
IF(AllSat1=1),"", IF(NoPonded=1),"", AVERAGE (Width, MAX(Thruflo, AqPlantCov, Interspers))
```

Frozen Duration is assumed to decrease with longer growing season.

Important Note: The model does not account for the wetland's surface area, and obviously, larger wetlands could potentially retain more phosphorus if other factors support this function. Because the model for this function is estimating relative effectiveness per unit area, some smaller wetlands will have higher scores than larger ones. Thus, wetland size should also be considered in the case of this particular function.

Approach for Future Validation: Among a series of wetlands spanning the scoring range, total phosphorus could be measured simultaneously at wetland inlet and outlet, if any, and adjusted for any dilution occurring from groundwater or runoff (or concentration effect from evapotranspiration) over the intervening distance. Measurements should be made at least once monthly and more often during major runoff events (e.g., Detenbeck et al. 1995). A particular focus should be on the relative roles of soil vs. vegetation characteristics, as they affect adsorption vs. uptake processes.

PR Benefits Model

```
[MAX(Pload, PsampUp, PsampDown, AVERAGE((Inflo, AVERAGE(BuffSlope,CApct, Transport, Groundw, ImpervCA, NatCApct))
```

This function is considered most valuable if a wetland has greater opportunity to perform it. The score is calculated by taking the larger of four indicators: a score for phosphorus load, known presence of a nutrient problem above or below the wetland, presence of a tributary, and the group average for several indicators of increased phosphorus delivery to the wetland, such as buffer slope, upland erodibility, lack of undisturbed upland cover.

A.6 NITRATE REMOVAL AND RETENTION (NR)

Function Definition: The effectiveness for retaining particulate nitrate and converting soluble nitrate and ammonia to nitrogen gas, primarily through the microbial process of denitrification, *while generating little or no nitrous oxide* (a potent "greenhouse gas"). Note that most published definitions of Nitrate Removal do not include the important restriction on N_2O emission.

Scientific Support for This Function in Wetlands Generally: High. The Benefits models address only the opportunity to perform this function, not its potential positive or negative effects, which are too difficult to estimate with a rapid method. Nitrate is essential for plant growth but in chronically high concentrations, such as from urban and agricultural runoff, can be a significant "nonpoint source" that shifts species composition and habitat structure in ways that sometimes

are detrimental to rare plants, aquatic food chains, and valued species (Carpenter et al. 1998, Anderson et al. 2002). High concentrations of nitrate in well water also are a human health hazard, and some levels of ammonia impair aquatic life. When excessive algal growths are triggered by abnormally high levels of nutrients in the tidal or marine water column, they block light needed by eelgrass (Williams & Ruckelshaus 1993), a submersed plant very important to fish and wildlife. Nitrate concentrations as low as 1 mg/L can change the structure of freshwater algae communities of streams (Pan et al. 2004) and contribute to blooms of toxic algae in lakes and wetlands.

NR Function Model

IF((NoOutlet=1), 1, IF((AllSat1=1), (2*Connec + Intercep + FrozDur + Organic + Redox)/6, **ELSE**: (3*Redox + 2*Connec + FrozDur + Organic + Intercep)/ 8)))

At a coarse level, three types of non-tidal wetlands are analyzed separately as pertains to this function: (1) those that never contain surface water, (2) those that lack outlets, (3) all others.
- If a wetland lacks a surface-flow outlet, i.e., is isolated, then the highest possible score (10.00) for this function is assigned automatically.
- If a wetland never contains surface water, its ability to remove N is assumed to be greater if it has limited connection to downslope water bodies (*Connectivity*, weight of 2), is likely to capture sediment that enters it (*Interception*), and has a relatively warm microclimate (*FrozDura* or *Warmth)*, highly organic substrate (*Organic*), and strong potential for spatially and temporally alternating reducing conditions *(Redox).* The weighted average of these terms is calculated. Their indicators are described below.
- For all other wetlands, the same model is used but in calculating the weighted average, *Redox* is weighted more heavily (3x).

In the above calculations:
- Decreased **connectivity** is defined by shorter duration of surface outflow, flatter wetland gradient, and lack of any artificial drainage. These 3 indicators are considered equally predictive so are averaged:

AVERAGE(OutDur, Gradient, Constric)

- **Warmth** is assumed to increase with closeness to tidal waters, south-facing aspect, lack of tree canopy, and strong evidence of groundwater input. These are considered equally predictive and so are averaged.

AVERAGE[(AVERAGE(WoodyTyp, TreeCanop, Groundw), AVERAGE(Warmth, Aspect)]

- **Interception** is assumed to increase mainly with increasing flow path length, extent of ponding, vegetated width, ground cover density, interspersion of open water and vegetation, headwater position, and size of wetland relative to size of its catchment. These are considered equally predictive and so are averaged:

AVERAGE(PondPct, Width, FloDist, Gcover, Thruflo, Interspers, Elev, WetPctCA)

- **Organic** content is assumed greater in peatlands, older wetlands, and wetlands with extensive plant cover and with little or no history of soil disturbance.

AVERAGE(Acid, SoilTex, WetType, NewWetland, AqPlantCov, SoilDisturb)

- **Redox** conditions favourable to denitrification are assumed likeliest to occur where a large portion of the wetland is inundated only seasonally. Considered equally important is the average of 4 indicators: presence of many upland inclusions, large ratio of upland edge to wetland area, greater water level fluctuation, and extensive microtopography.

(AVERAGE(SatPct, Persis, SeasPct) + AVERAGE(Fluctu, UpEdgeShape, Inclusions, Girreg))/2

Important Note: The model does not account for the wetland's surface area, and obviously, larger wetlands could potentially remove more nitrate if other factors support this function. Because the model for this function is estimating relative effectiveness per unit area, some smaller wetlands will have higher scores than larger ones. Thus, wetland size should also be considered in the case of this particular function.

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), nitrate and ammonia could be measured simultaneously at wetland inlet and outlet, if any, and adjusted for any dilution occurring from groundwater or runoff (or concentration effects from evapotranspiration) over the intervening distance. Measurements should be made at least once monthly and more often during major runoff events (e.g., Detenbeck et al. 1995). Monitoring should also measure denitrification rates (at least potential), the nitrogen fixing rates of particular wetland plants, and nitrous oxide emissions.

NR Benefits Model

MAX[Aquifer, GWsens, Inflo, MAX(NSource, NsampUp, NsampDown, Nfix), AVERAGE(Imperv, RdDist, PopDist), AVERAGE(CAnatPct, BuffSlope, BuffCovTyp, Transport)]

Greater benefit is assigned based on the average of three factors: (a) either domestic wells are present within 1000 feet downslope from the wetland, (b) a tributary is present, (c) potential sources of N are present; this includes N-fixing plants, septic systems and various other human activities, closeness to populated areas, extent of impervious surface near the wetland, lack of an upland buffer around the wetland, and wetland contributing areas with limited extent of natural cover.

A.7 CARBON SEQUESTRATION (CS)

Function Definition: The effectiveness of a wetland both for retaining incoming particulate and dissolved carbon and converting carbon dioxide gas to organic matter (particulate or dissolved) through the photosynthetic process. And to then retain that organic matter on a net annual basis for long periods *while emitting little or no methane* (a potent "greenhouse gas"). Note that most published definitions of Carbon Sequestration do not include the important limitation on methane emission.

<u>Scientific Support for This Function in Wetlands Generally</u>: Although wetlands with high rates of primary productivity would seem to sequester (store) more carbon more rapidly, at northern latitudes it is likely that the amount of carbon that remains in storage will depend more on how slowly what has initially been sequestered will be decomposed. Artificial disturbances or extreme events, such as increased frequency of drought (e.g., from global warming, artificial drainage) and perhaps flood (e.g., from sea level rise) can quickly reverse gains in the amount of carbon sequestered in a wetland. Moreover, some of the most productive non-tidal wetlands also tend to be among the most significant emitters of methane, a potent greenhouse gas.

CS Function Model

(2*MAX(HistAccum, PhysAccum) + Productiv +3*MethLimit) /6

A wetland is scored higher if its existing ("legacy") carbon stores (*Historical Accumulation*) are large, *Decomposition* of that carbon is likely to occur slowly, the wetland has a great ability to physically retain organic matter it produces or receives from upgradient sources (*Physical Accumulation*), and it lacks factors that suggest it has substantial methane emissions (*Methane Limitation*). In the final model, *Methane Limitation* is weighted equally with the average of *Historical Accumulation, Decomposition*, and *Physical Accumulation*.

In the above calculations:
- **Historical Accumulation** (existing carbon store) considers first if this is a new wetland. If so, Historical Accumulation is based only on its estimated age. If not (i.e., wetland is older than 100 years), this factor is calculated as the average of greater extent of moss cover, peat soils, and lack of soil disturbance or recent burn. To a lesser degree, the score for this factor increases with increasing percent cover of conifers, growing season length, and wetland vegetated width:

AVERAGE(SoilDisturb, MossCov, Wettype, Burn, SoilTex, AVERAGE(Warmth, DecidPct, DecidTree, Width, NewWetland))

- **Decomposition** is assumed to be slower (thus facilitating carbon sequestration) when indicated by shorter growing season, wetland type is peatland, and moss cover is extensive. These are considered equally predictive so are averaged and then are averaged with the rating for wetland water depth, wherein intermediate water depths (if surface water is present at all) are hypothesized to support an optimal combination of elevated productivity and slowed decomposition.

AVERAGE(Depth, AVERAGE(Freeze, Warmth, MossCov, WetType)

- **Physical Accumulation** is assumed to increase with flatter wetland gradient, less persistent outflow, and an artificial (presumably more constricted) outlet if an outlet is present at all. These are considered equally predictive and so are averaged.

AVERAGE (OutDura, Constric,AqPlantCov, Gradient, IsoWet)

- **Methane emissions** are considered to be least when moss cover is extensive, the wetland is not a sedge fen, water level fluctuations and groundwater inputs are probably minimal, tree cover (if any) is coniferous, and the wetland is not persistently flooded condition. These are considered equally predictive of Methane Limitation and so are averaged.

```
AVERAGE(MossCov, Sedge, SeasPct, Fluctu, Groundw, TreeForm, PermWpct)
```

Important Note: The model does not account for the wetland's surface area, and obviously, larger wetlands could potentially retain more carbon if other factors support this function. Because the model for this function is estimating relative effectiveness per unit area, some smaller wetlands will have higher scores than larger ones. Thus, wetland size should also be considered in the case of this particular function.

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), particulate and dissolved organic carbon would need to be measured regularly at wetland inlet and outlet, if any, along with measurements of changes in water volume. Equally important, emissions of methane and carbon dioxide would need to be measured regularly throughout the year and throughout the day/night cycle. Plant productivity rates (especially belowground), decomposition rates, hydrology, and net carbon accumulation in sediments or soils would require measurement as well.

A.8 ORGANIC NUTRIENT EXPORT (OE)

Function Definition: The effectiveness of a wetland for producing, rapidly cycling, and subsequently exporting organic matter, either particulate (detritus) or dissolved, and including net export of nutrients (C, N, P, Si, Fe) comprising that matter. It does not include exports of carbon in gaseous form (methane and carbon dioxide) or as animal matter (e.g., emerging aquatic insects, fish).

Scientific Support for This Function in Wetlands Generally: Moderate-High. Wetlands which have outlets are potentially major exporters of organic matter to downstream or marine waters. That is partly because many wetlands support exceptionally high rates of primary productivity (i.e., carbon fixation, which provides more carbon that is available for export) or have large legacy reserves of undecomposed carbon. Numerous studies have shown that watersheds with a larger proportion of wetlands tend to export more dissolved and/or particulate carbon, as well as iron and other substances important to downstream and estuarine food webs (Bjorkvald et al. 2008). Value of the exported matter to food webs depends partly on the quality and timing of the export, but those factors cannot be estimated with a rapid assessment method.

OE Function Model

```
IF((NoOutlet6=1),0, ELSE: (3*ExportPotential+ 2*CurrentProductivity + HistoricalAccumulation) /6
```

If no surface flow ever exits a wetland, its OE function is automatically scored 0. For all other wetlands, the score is the weighted average of greater *Historical Accumulation, Export Potential* (weight of 3), and current *Productivity* (weight of 2). In these calculations:
- **Historical Accumulation** (existing carbon store) is the average of the scores for soil texture, with peat soils considered most important, and NewWet (new wetlands considered to have less carbon in storage).

> AVERAGE(SoilTex, NewWet)

- **Export Potential** is predicted by 4 items which are averaged: flow path length within the wetland, duration of surface water outflow, wetland gradient, and a group average based on less outlet constriction, less ponding, narrower vegetated width, lower elevation in a watershed, and greater interspersion of vegetation and open water.

> AVERAGE [OutDura, Gradient, FloDist, AVERAGE(Constric, ThruFlo, Interspers, Width, PondedPct)]

- Current **Productivity** is comprised of three factors that are averaged: *Frozen Duration, Nutrient Availability*, and *Plant Cover*. These are described as follows:
  - *Frozen Duration* is assumed to decrease with longer growing season and presence of discharging groundwater. These are considered equally predictive and so are averaged:

> AVERAGE(Warmth, Groundw)

  - *Plant* input available for rapid export is assumed to be greater with more extensive cover of emergent and deciduous woody vegetation, decreasing bare ground extent, and shallower water depth. These are averaged:

> AVERAGE (AqPlantCov, Decid, DecidTree, Gcover, Depth)

  - Greater *Nutrient Availability* is reflected by wetland type (fen> marsh > swamp > bog), presence of calcareous soils, moderately fluctuating water levels, increased cover of nitrogen fixing plants, greater proportion of the wetland that is inundated only seasonally. These are considered equally predictive of Nutrient Availability and so are averaged:

> AVERAGE(Wettype, SeasWpct, Fluctu, Nfix, Karst)]

Important Note: The model does not account for the wetland's surface area, and obviously, larger wetlands could potentially export more carbon if other factors support this function. Because the model for this function is estimating relative effectiveness per unit area, some smaller wetlands will have higher scores than larger ones. Thus, wetland size should also be considered in the case of this particular function. Also, this model is limited inasmuch as it does not attempt to estimate the immediate availability of the exported carbon to food chains. Some "more labile" forms of carbon are known to transform and then be taken up beneficially by aquatic organisms more quickly than other forms.

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), particulate and dissolved organic carbon would need to be measured regularly at wetland inlet and outlet, if any, along with measurements of changes in water volume and flow rate.

A.9 ANADROMOUS FISH HABITAT (FA)

Function Definition: The capacity to support an abundance of native anadromous fish for functions other than spawning. The model described below will not predict habitat suitability accurately for every species, nor is it intended to assess the potential to restore fish access to a currently inaccessible wetland.

Scientific Support for This Function in Wetlands Generally: Moderate-high, depending mainly on accessibility of a wetland to anadromous fish. Many accessible wetlands provide rich feeding opportunities, shelter from predators, and a beneficial thermal environment.

FA Function Model

IF((Access=0),0, IF((AllSat1=0),0, **ELSE:**
(AVERAGE(Access, OutDura)) X (AVERAGE(HydroRegime, Structure, Productivity, LScape, Stress))

Wetlands are scored 0 if no information suggests they are accessible to anadromous fish or if no surface water is ever present. In all other wetlands, the score increases with increasing fish *access* to the wetland and persistence of the wetland's *outflow*. The scores for these two factors are averaged and then multiplied by the average of increased wetland *Productivity, Structure, Hydrologic Regime, Landscape Condition,* and a lack of human-related *Stressors.* The model assumes these factors are moot if access is lacking and/or are less important if outflow persistence is less. In these calculations:

- **Productivity** is assumed to be greater where the wetland contains or is adjoined by alder, is situated in areas with limestone bedrock, is at low elevation, is a fen/marsh, and/or there is evidence of significant groundwater input. These indicators are considered equally predictive and so are averaged.

AVERAGE(GroundW, TidalProx, Elev, Wettype, Karst, Nfix)

- **Structure** beneficial to anadromous fish is represented by the average of beaver presence (considered a positive indicator) and a group average for moderately increased shade and cover of aquatic plants, large instream wood, presence of both ponded and flowing water, and more favourable wetland type (Marsh > Fen > Swamp > Bog).

AVERAGE[Beaver, AVERAGE(Wettype, WoodAbove, AqPlantCov, Shade, IsoWet)]

- **Hydrologic Regime** is considered optimal when all or nearly all of the wetland has surface water at least seasonally and water depths are moderate. The remaining one-third of the score for this factor is based on the average of increasing interspersion of patches of vegetation and open water, wetland adjacency to a lake, wetland intersected by channels that wind indirectly and intersect flooded trees, and either a moderate proportion of habitat that remains persistently inundated or is inundated only seasonally.

AVERAGE(Depth, SatPct, MAX(SeasWPct, PermWPct), Lake, Interspers, ThruFlo)

- **Landscape** condition is assumed to be better when land cover in the contributing area and area closest to the wetland is mostly natural.

AVERAGE(NatVegPctCU, BuffLU, ImpervCA)

- **Stressors** (lack of) is represented by absence of known or suspected contaminants, absence of turbid water input, lack of other sediment inputs in excessive concentrations, and lack of altered flows. Whichever of these indicators has the most potentially harmful condition in the assessed wetland is the one that is used in calculations.

MIN(Acid, ToxicIn, SedIn, AltTime, ToxData)

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), the number of anadromous fish and their duration of use would need to be measured regularly throughout the times when usually expected to be present, and weight gain during the period of wetland habitation should be measured when applicable.

FA Benefits Model

AVERAGE(WbirdFeed, Fishing, Core, PopCtr, DistRd)

A wetland with the potential to support anadromous fish is assumed to be more valuable if it has a high habitat score for Feeding Waterbird Habitat, if there is evidence of fishing, near a road or population center, or is otherwise believed to be frequently visited.

A.10 RESIDENT FISH HABITAT (FR)

Function Definition: The capacity to support an abundance and diversity of *native* non-anadromous fish. The model described below will not predict habitat suitability accurately for every species, nor is it intended to assess the ability to restore fish access to a currently inaccessible wetland.

Scientific Support for This Function in Wetlands Generally: High. Many accessible wetlands provide rich feeding opportunities, shelter from predators, and thermal refuge (especially if groundwater is a significant water source).

FR Function Model

IF((Fish Access=0),0, IF((AllSat=1),0, **ELSE**: AVERAGE(HydroRegime, Structure, Productivity, AnoxiaRisk, Stress)

A wetland automatically scores a 0 if there is no fish access and it is not known to contain resident fish, or if it never contains surface water. For all other wetlands, the score increases with increased wetland *Productivity, Hydrologic Regime*, and habitat *Structure,* and decreased *Stressors* and risk of winterkill from *Anoxia*. These 5 factors are considered equally predictive of resident fish habitat suitability and so are averaged.

In the above calculations:
- **Productivity** is assumed to be greater where the wetland contains both an inlet and outlet, contains or is adjoined by extensive alder, is situated in an area of limestone bedrock or water has moderately high connectivity, is not a new wetland, has evidence of significant groundwater input, and is a lake or (in order of decreasing productivity) is Marsh > Fen > Swamp > Bog. These indicators are considered equally predictive and so are averaged:

AVERAGE(InletOutlet, GroundW, NewWetland, Wettype, Conduc, Karst, Nfix, Lake)

- **Structure** beneficial to resident fish is represented by the average of beaver presence (considered a positive indicator) and a group average that includes wetland type (see ranking

above) as well as increased shade, an intermediate proportion of open water, and extent of aquatic cover.

> AVERAGE[Beaver, AVERAGE(Wettype, Shade, WoodAbove, ABpct, AqCov)]

- **Hydrologic Regime** is assumed most favourable for resident fish when surface water is present persistently or at least seasonally, both ponded and flowing water are present, interspersion of patches of vegetation and open water is good, there are complex internal channel networks that intersect woody vegetation, and a variety of water depths is present in fairly equal proportions. These indicators are considered equally predictive and so are averaged:

> AVERAGE(SatPct, Depth, DepthEven, PermWPct, Interspers, ThruFlo)

- **Stressors** are represented by the average of scores for **lack** of contaminants, highly acidic water, artificially altered flow timing, and narrow upland buffers.

> AVERAGE(SedExcess, Acid, AltTime, ToxData, NatVegCUpct)

- **Anoxia Risk** is assumed to increase with shallower water depth, less outflow persistence, and shorter growing season. These are considered equally predictive of resident fish winterkill and so are averaged.

> AVERAGE (OutDura, Depth, Warmth)

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), the number of resident fish and their onsite productivity and diversity would need to be measured regularly. For transient species, the duration of use and weight gain throughout the times when usually expected to be present should be determined.

FR Benefits Model

> AVERAGE(Feeding Waterbird Habitat score, Fishing, PopDist, DistRd, Core)

This function is presumably valued to a greater degree if its score for Feeding Waterbird Habitat is high, there is evidence of fishing, distance to a population center is minimal, distance to a road is small, and accessibility of the wetland to people is great. The scores of these are averaged.

A.11 AQUATIC INVERTEBRATE HABITAT (INV)

Function Definition: The capacity to support an abundance and diversity of invertebrate animals which spend all or part of their life cycle underwater, on the water surface, or in moist soil. Includes dragonflies, aquatic flies, clams, snails, crustaceans, aquatic beetles, aquatic worms, aquatic bugs, and others, including semi-aquatic species. The model described below will not predict habitat suitability accurately for every species, nor the importance of any species or functional group in the diet of important fish or birds.

Scientific Support for This Function in Wetlands Generally: High. All wetlands support invertebrates, and many wetlands support aquatic invertebrate species not typically found in

streams or lakes, thus diversifying the local fauna. Densities of aquatic invertebrates can be exceptionally high in some wetlands, partly due to high primary productivity and warmer water temperatures, and partly because submerged, floating, and emergent vegetation provide additional structure (vertical habitat space).

INV Function Model

AVERAGE [Struc, Productivity, AVERAGE(Hydropd, Connec, Stressors, LScape)]

In all types of non-tidal wetlands, the score is the weighted average of six factors: *Structure*, *Hydroperiod*, *Productivity (Food), Connectivity, Landscape, and Stressors.* The first two each account for one-third of the score and the average of the remaining ones accounts for one-third.

- **Structure** is comprised half by the score for percent of the wetland that is open water (30-70% being best), and half by the average of scores for more ground cover, microtopographic variation, herbaceous plant diversity, downed wood, in-water large wood, interspersion of tall and short vegetation, and intermediate amounts of ponding.

AVERAGE [ABpct, AVERAGE(AqCov, WoodHerbMix, HerbDiv, Gcover, WoodDown, Girreg)]

- **Hydroperiod** is assumed most favourable when water levels fluctuate moderately and seasonally, there is evidence of groundwater discharging to the wetland, and there is an intermediate proportional extent of persistent water. The scores for these are averaged:

AVERAGE [PermWpct, SatPct, SeasPct, Fluctu,GroundW)]

- **Productivity** score is based half on wetland type and half on a group average of several indicators: greater hardwood cover (especially alder), downed wood, situated in area of limestone bedrock, shallower water depth, and closer to tidal waters.

AVERAGE [WetType, AVERAGE(Depth, DecidTree, Hardwood, WoodDown, Nfixers, Conduc, Karst, TidalProx)]

- **Connectivity** is reflected by a balanced mix of ponded and flowing water, greater patchiness of open water, greater interspersion of patches of vegetation and open water, and more sinuous internal channels that intersect woody vegetation. These indicators are considered equally predictive and so are averaged:

AVERAGE(Interspers, ThruFlo, IsoWet)

- **Landscape** condition is assumed better for invertebrates when land cover in the contributing area and wetland buffer is mostly natural, as represented by the average of 3 indicators which reflect that, and when wetland is adjoined by other wetlands of a different type.

AVERAGE(Imperv, NatVegPctCU, CUbuffLUtype, Subtypes)

- **Stressors** are represented partly by the average of (the lack of) increased soil disturbance, excessive sediment inputs, and altered timing of the water regime.

AVERAGE(AltTime, SedCA, SoilDisturb)

Approach for Future Validation: The aquatic invertebrate richness, density, and (ideally) productivity would need to be measured regularly throughout the year among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity).

INV Benefits Model

AVERAGE(AnadFish, ResFish, Amphib, WbirdF, WbirdNest, SongbMam)

The benefits score for Invertebrate Habitat is the average for several other functions which invertebrates support: Amphibians, Anadromous Fish, Resident Fish, Feeding Waterbirds, Nesting Waterbirds, and Songbirds & Mammals.

A.12 AMPHIBIAN & REPTILE HABITAT (AM)

Function Definition: The capacity of a wetland to support an abundance and diversity of native amphibians (frogs, toads, salamanders) as well as turtles. The model described below will not predict habitat suitability accurately for **every** species.

Scientific Support for This Function in Wetlands Generally: High. Many amphibian and turtle species occur almost exclusively in wetlands. Densities can be noticeably higher in some wetlands, partly due to high productivity of algae and invertebrates, and partly because submerged vegetation provides shelter and sites for egg-laying and larval rearing.

AM Function Model

AVERAGE [(Wettype, Hydro, AVERAGE(AqStruc, TerrStruc, Produc, Lscape, Waterscape, Stress)]

The function score is the average of three indicators. One is the wetland type, with types ranked for amphibian suitability as follows: Marsh > Fen or Swamp > Bog. The second is the wetland's *Hydrologic Regime*, and the third is the average of *Aquatic Structure*, *Terrestrial Structure*, wetland *Productivity*, *Landscape*, *Waterscape,* and *Stressors*.

In the above calculations:
- **Hydrologic Regime** is assumed more suitable in ponded wetlands with at least 20% of their water persisting throughout the growing season and water level fluctuations that are relatively small:

AVERAGE(Fluctu, SatPct, PermWpct, ISOwet)

- **Aquatic Structure** that is more suitable for amphibians is represented by a wide zone of bordering vegetation, some large woody debris, and considerable interspersion of vegetation and open water. These indicators are considered equally predictive and so are averaged:

AVERAGE(ABpct, WoodAbove, Interspers, Vwidth)

- **Terrestrial Structure** is considered to be best for amphibians in wetlands with moderate ground cover and cover of shrubs, extensive microtopographic variation, some upland inclusions, much downed wood, and which are adjoined by wetlands of a different type. These indicators are considered equally predictive and so are averaged:

AVERAGE(WoodHerbMix, WoodDown, ShrubSun, Gcover, Girreg, Inclus, WetTypeDiv)

- **Productivity** is assumed to be highest in flat-gradient, south-facing wetlands in areas with longer growing season, strong evidence of groundwater inputs, larger-diameter trees, and/or

which are in regions of limestone bedrock. All these indicators of productivity are considered equally predictive so their scores are averaged together:

AVERAGE(Aspect, GDD, Karst, TreeVar, GroundW)

- **Waterscape** is represented by increasing proximity to the nearest other ponded wetland.
- **Landscape** conditions are considered better for amphibians when natural cover comprises a large and proximate part of the upland cover. Seven indicators of this are averaged, with absence of roads that interfere with dispersal being considered the most important and thus accounting for half the Landscape score:

AVERAGE[RoadCirc, AVERAGE(NatVegPct, BuffLU, NatVegProx, NatCov2mi, ScapeLU, NatVegSize)]

- **Stressors** of potential detriment to amphibians are considered to include increasing proximity to nearest road, documented toxicity from contaminants, frequent human visitation, and lack of fences and other measures that otherwise limit trampling of soil and vegetation. These indicators are averaged and the average considered equally with actual or potential presence of fish, which can be a powerful stressor in many situations.

AVERAGE(FishAcc, AVERAGE(RdDis, Toxic, Core1, Core2, BMP))

Note that some assessment methods, as an indicator of biodiversity, include "number of wetland types" or "number of hydroperiod types" present within a single wetland AA. WESP does not use those explicitly because the boundaries between such types are seldom clearly distinguishable either in the field or from aerial imagery. WESP addresses habitat heterogeneity (both within and surrounding an AA) using other indicators.

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), amphibian density and (ideally) productivity and survival would need to be measured during multiple years and seasons by comprehensively surveying (as applicable) the eggs, tadpoles, and adults.

AM Benefits Model

IF((RareHerp=1),1, **ELSE**: AVERAGE[WBFscore, MAX(HerbUniq, WoodyUniq,DistPond), SBMscore]

If a regionally rare amphibian or turtle has been documented from the wetland, the Benefits score is automatically a 10. Otherwise, the score is the average of two factors. One is a score indicating that either herbaceous or woody vegetation comprises less than 10 percent of the surrounding (100 m, 1 km, 5 km) landscape yet is significantly present in the wetland or the wetland is distant from other ponded water. The second is the average of scores for Feeding Waterbird Habitat and Songbird-Raptor-Mammal habitat, because amphibians are important foods for some species in those groups.

A.13 WATERBIRD HABITAT - FEEDING (WBF)

Function Definition: The capacity to support an abundance and diversity of feeding waterbirds, primarily the migratory species present outside of the usual nesting season. The model described below will not predict habitat suitability accurately for every species in this group.

Scientific Support for This Function in Wetlands Generally: High. Dozens of waterbird species occur almost exclusively in wetlands during migration and winter. Densities can be exceptionally high in some wetlands, partly due to high productivity of vegetation and invertebrates, and partly because wetland vegetation provides shelter in close proximity to preferred foods.

WBF Function Model

IF((AllSat1=1),0, IF((TooSmall=1),0, IF((TooSteep=1), 0, **ELSE:**
[3*MAX(Mudflat, AVERAGE(Hydro, Struc) + AVERAGE(Lscape,Stressors, Produc)] /4

Wetlands are scored 0 if they are very small (<0.01 ha), or on very steep (>10%) slope, or if no water is ever present. In all other wetlands, the score is the weighted average of two groups. One (accounting for 3/4 of the score) is the greater of two indicators: extent of shorebird habitat (mudflats, shallow water), and average of *Hydrologic Regime* and *Structure*. The other group is the average of scores for *Landscape, Stressors*, and wetland *Productivity*.

In the above calculations:
- **Hydrologic Regime** is assumed to be more suitable if surface water is present at least seasonally, is ponded, its depth is mostly shallow (<1 m), its level fluctuates mildly, and a variety of depth classes is present in relatively equal proportions. These indicators are considered equally predictive and so are averaged.

AVERAGE(ISOwet, SatPct, MAX(SeasWpct, PermWpct), Depth, DepthEven)

- Habitat **Structure** is scored higher if interspersion of emergent vegetation with open water is great, and the average of the scores for extent of ponded open water and percent cover of emergent vegetation is large -- intermediate conditions of both being considered most favourable.

AVERAGE[Interspers, AVERAGE(OWpct, EmPct), AreaTotal]

- **Landscape** context is included only if the wetland is a marsh or fen. In those cases, an average is taken of the scores of indicators that reflect closer proximity to ponds and especially lakes, presence of beaver, and presence of different wetland types nearby:

IF((_Fen+Marsh=0), blank, **ELSE**: AVERAGE(WetTypeDiv, Beaver, PondProx, BigPondProx)

- **Stressors** of significant concern to feeding waterbirds include harmful concentrations of metals and other contaminants, and frequent visitation of nearly the entire wetland by people. Scores indicating the absence of these are averaged:

AVERAGE(CoreA, CoreB, BMP, _Tox)

- **Productivity** for feeding waterbirds is assumed to include wetlands with extensive duckweed or algae, fish, flatter gradients, larger area, adjoining lakes, longer growing season, closer to tidal areas, and/or belonging to wetland types favoured by waterbirds in this order: Marsh > Fen > Bog ~ Swamp. These indicators are considered equally predictive of aquatic productivity and so are averaged.

AVERAGE(Wettype, Warmth, Fringe, Lake, Fish, Algae, TidalProx, Gradient)

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), feeding waterbird species richness and density would need to be determined monthly and more often during migration (see USEPA 2001 for methods). Ideally, daily duration of use and seasonal weight gain should be measured.

WBF Benefits Model

IF((Rare=1),1, IF((IBirdv=1),1, MAX[HerbUniq, DistPond, AVERAGE(DuckHunt, PopCtr, Visib)]

If the wetland is known to host a rare migratory waterbird species or if has been officially designated an IBA (Important Bird Area), the Benefits score is automatically a 10. Otherwise it is the maximum of three indicators: greater distance to open water; greater scarcity of herbaceous cover (if it is an herbaceous wetland) within 100 m, 1 km, and/or 5 km; and a third group that averages the scores for documented use by hunters, greater proximity to a population center, and/or most of wetland is visible from public land or a road. This third group is meant to reflect the potential for more frequent enjoyment of birds by people.

A.14 WATERBIRD HABITAT - NESTING (WBN)

Function Definition: The capacity to support an abundance and diversity of nesting waterbirds. The model described below will not predict habitat suitability accurately for every species in this group.

WBN Function Model

IF((AllSat=1), 0, IF((TooSteep=1),0, IF((TooSmall=1),0, **ELSE**:
[3*AVERAGE(OWpct, SizeHerbac, Wettype,Wscape) +2*AVERAGE(HydroRegime, Structure) + AVERAGE(Productivity, Stressors, Landscape)] / 6

The model first eliminates (assigns a score of 0) wetlands that never contain surface water, wetlands on slopes of greater than 10 percent, and very small (<0.01 ha) wetlands. For all remaining types of wetlands, the weighted average is taken of three groups. One group (with weight of 3) is the average of increased area of emergent vegetation, aquatic plant cover percentage (intermediate being best), preferred wetland type, and *Waterscape* indicators (described below). A second group (weight of 2) is the average of *Hydrologic Regime* and *Structure* (described below). The third group (unweighted) is the average of *Productivity, Stressors*, and *Landscape* indicators. These are determined as follows:
- **Waterscape** is represented by increasing proximity to ponds and especially lakes, and actual or potential presence of beaver. These are assumed to be equally predictive so are averaged. The Waterscape group is included in the calculations only if the wetland is a marsh or fen.

IF((Fen + Marsh=0), blank, **ELSE**: AVERAGE(Lake, LakeProx, Fringe, PondProx)

- **HydroRegime** is assumed to be more suitable in moderately shallow ponded wetlands with a large proportion of vegetation that is inundated at least seasonally, with only mild annual water level fluctuation, and with a variety of depth classes in relatively equal proportions. These indicators are considered equally predictive and so are averaged:

AVERAGE(ISOwet, SatPct, Fluctu, MAX(SeasWpct, PermWpct), Depth, DepthEven)

- **Structure** is assumed to be more suitable in herbaceous ponded wetlands that have intermediate amounts of open water interspersed well with aquatic plants. This counts for half the *Structure* score, with the other half based on the group average of several indicators: increasing vegetated width, snags suitable for cavity-nesting ducks, and intermediate percent cover of emergent vegetation:

AVERAGE[(Interspers, AVERAGE(EmPct, OWpct), AVERAGE(EmRobust, Size, Vwidth, Beaver, Snags)]

- **Productivity** is assumed to be greater in non-acidic, fish-accessible wetlands with flat gradients and mostly flat shorelines, that contain an island and/or are a more productive wetland type (in descending order, this is believed to be: Marsh > Fen > Bog > Swamp). These indicators are assumed to be equally predictive so are averaged:

AVERAGE(Wettype, Gradient, Acidity, ShoreSlope, Fish, Island, Beaver)

- **Stressors** are represented by increased proportion of the wetland visited often by people on foot, lack of measures to reduce human disturbance of nesting waterbirds, and evidence of toxic contaminants. Scores reflecting the absence of these are averaged:

AVERAGE(Core1, Core2, BMP, Toxics)

- **Landscape** factors beneficial to nesting waterbirds are assumed to include increased wetland distance from roads, and extensive natural cover contiguous with the wetland and/or in its upland buffer. These are averaged:

AVERAGE(BuffLUtype, BuffNatPct, RdDis)

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), nesting waterbird species richness and density would need to be determined during the usual breeding period -- approximately May through July (see USEPA 2001 for methods). Ideally, nest success and juvenile survival rates should be measured.

WBN Benefits Model

IF((Rare=1),1, IF((IBirdv=1),1, **ELSE**: MAX(DistPond, HerbUniq))

If the wetland has been officially designated an IBA (Important Bird Area) or is known to host a rare breeding waterbird species, it automatically scores a 10. Otherwise, its Benefits score increases with increasing distance from a different pond or wetland and scarcity of other herbaceous wetlands within 100 m, 1 km, and/or 5 km.

A.15 SONGBIRD, RAPTOR, AND MAMMAL HABITAT (SBM)

Function Definition: The capacity to support, at multiple spatial scales, an abundance and diversity of songbirds, raptors, and mammals, especially species that are most dependent on wetlands or water. The model described below will not predict habitat suitability accurately for every species in this group.

Scientific Support for This Function in Wetlands Generally: High. Several large mammals, such as moose and bear, as well as several species of songbirds and raptors, depend on wetlands. Densities can be exceptionally high in some wetlands, due partly to high productivity of vegetation and invertebrates, and partly because wetland vegetation provides breeding or wintering sites in close proximity to preferred foods.

SBM Function Model

IF((AllWater=1),0, **ELSE**: AVERAGE[PermWpct, AVERAGE(Produc, StrucA, StrucB, Lscape, Wscape, Stress)]

In the unlikely event that the entire assessment area is always >99% water-covered, the model assigns the lowest score (0). For all other wetland types, half of the score is based on the wetland having relatively little surface water (thus more habitat space and structure for songbirds and most mammals), and the other half on the average of 6 metrics: *Productivity, StructureA, StructureB, Landscape, Waterscape*, and *Stressors*. The metrics are described as follows:

- **Productivity** is assumed to be greatest in wetlands with an extensive or wide zone of vegetation, especially herbaceous vegetation. After averaging the scores for these two indicators, that average is multiplied by the average of scores for 4 indicators: greater cover of nitrogen-fixing plants, high edge-to-area ratio, presence of numerous upland inclusions, and predominance of hardwood cover (if the wetland is wooded). These are all considered to be equally predictive of SBM habitat.

AVERAGE(SizeHerbac, Vwidth) x (AVERAGE(Nfix, Inclus, UpEdge, Hardwd)

- **StructureA** is a group of indicators that together represent some beneficial components of SBM habitat. This includes cliffs, snags, downed wood, increased ground cover, and varied microtopography. These indicators are assumed to be equally predictive so are averaged:

AVERAGE (Gcover, Girreg, Cliffs, SnagsD, WoodDown)

- **StructureB** is another group of indicators that together reflect beneficial components of SBM habitat. This includes increased amounts of tree and shrub cover in and around the wetland, more mature trees, some small forest gaps, and a diversity of shrubs. These indicators are assumed to be equally predictive so are averaged:

AVERAGE (WoodyHtDiv, ShrubDiv, WoodPatt, TreeTypes)

- **Landscape** condition is assumed better for SBM if the wetland is near and connected with a large tract of natural vegetation, has a naturally vegetated buffer, and is adjoined by a different wetland type. These indicators are assumed to be equally predictive so are averaged:

AVERAGE (WetTypeDiv, CUbuffNatPct, CUtypeLU, NatVegProx, NatVegPctScape, ScapeLU, NatVegSize)

- **Waterscape** condition is assumed better for SBM where a large proportion of the wetland lacks surface water (thus providing more habitable space for songbirds), is near a pond, has vegetation that is well-interspersed with patches of open water, and is actually or potentially used by beaver. These indicators are assumed to be equally predictive so are averaged:

AVERAGE (SatPct, PermWpct, PondProx, Beaver, Interspers)

- **Stressors** which could affect SBM use of a wetland include frequent human visitation, proximity to population centers, lack of a vegetated buffer around most of the wetland perimeter, close proximity to a road, and road blockage of wildlife access to other wetlands.

Scores indicating a lack of these indicators are averaged because they are assumed to be equally predictive:

> AVERAGE (CoreA, CoreB, BuffPerim, PopCtr, RdBox, DisRd)

Note that some assessment methods, as an indicator of biodiversity, include "number of wetland types" or "number of hydroperiod types" present within a single wetland AA. WESP does not use those because the lines between such types are seldom clearly distinguishable either in the field or from aerial imagery. WESP addresses habitat heterogeneity (both within and surrounding an AA) using other indicators.

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), species richness and density of songbirds, raptors, and mammals would need to be determined monthly and more often during migration or seasonal movements (see USEPA 2001 for methods). Ideally, daily duration of use and seasonal weight gain of key species should be measured.

SBM Benefits Model

> IF((Rare=1),1, IF((IBA=1),1, **ELSE**: MAX(HerbUniq, WoodyUniq, DistPond))

If the wetland has been officially designated an IBA (Important Bird Area) or is known to host a rare breeding waterbird species, it automatically scores a 10. Otherwise, its Benefits score increases if it is distant from other wetlands or is nearly the only herbaceous wetland or only wooded wetland within 100 m, 1 km, and/or 5 km.

A.15 NATIVE PLANT HABITAT (PH)

Function Definition: The capacity to support, at multiple spatial scales, a diversity of native vascular and non-vascular (e.g., bryophytes, lichens) species and functional groups, especially those that are most dependent on wetlands or water.

Scientific Support for This Function in Wetlands Generally: High. Many plant species grow only in wetlands and thus diversify the local flora, with consequent benefits to food webs, energy flow, and human consumers.

PH Function Model

> IF((InvasDom=1), 0, **ELSE**: (4*SppArea + 3*CompetPD + 2*AqFertilPD + 2*TerrFertilPD + LscapePD + StressPD)/13)

If invasive species comprise more than half the vegetated cover, the score is set to 0. Otherwise, the score is the weighted average of 7 factors: *Species-Area* (weighted 4x), *Competition/Light* (weighted 3x), *Aquatic Fertility* (weighted 2x), *Terrestrial Fertility* (weighted 2x), and unweighted: *Landscape* and *Stressors*. These are calculated as follows:

- **Species-Area** score increases with increased vegetated wetland size, vegetated width, connectivity to large tracts of natural land cover, and proportion of the wetland that is inundated only seasonally. The scores these are averaged:

  AVERAGE (Width, Size, SizeVegConn, SatPct)

- **Competition/ Light** encompasses several indicators. A scarcity of invasive plant species counts for half the score. The other half is the average of: lack of strongly dominant species in the shrub and herbaceous layers, relatively even mix of scattered patches of herbaceous and woody plants, predominance of hardwood cover (if forested), varied microtopography, and not recently burned.

  AVERAGE[Invas, AVERAGE(DecidCov, WoodyHtDiv, WoodHerbMix, HerbDom, Burn, Girreg)]

- **Aquatic Fertility** is assumed to be greater if the wetland is a calcareous fen. If not, the score is greater if the wetland has a tributary, there is evidence of groundwater input and/or circumneutral pH, shallow water depth, well-interspersed vegetation and open water, seasonal-only flooding, and moderate water level fluctuation. These indicators are assumed to be equally predictive so are averaged:

  AVERAGE [MAX(Conduc, Acidic), Inflow, AVERAGE (Interspers, Fluc, SeasWpct, Groundw, Depth)]

- **Terrestrial Fertility** is assumed to increase with increased cover of nitrogen-fixers, limestone bedrock, presence of finer-textured and moderately organic soils, and longer growing season. These indicators are all assumed to be equally predictive so are averaged:

  AVERAGE (Nfix, SoilTex, Karst, GDD)

- **Landscape** condition is assumed better for native plants where the proximate upland land cover is mostly natural, ponded areas are numerous and nearby, and actual or potential use by beaver has been noted. These indicators are assumed to be equally predictive and so are averaged:

  AVERAGE (Beaver, NatVegCA, BuffLUpd, PondScape, PondProx)

- **Stressors** are represented by increased wetland visitation by humans without measures to minimize soil disturbance; extensive cover of invasive plants along the wetland's upland edge; proximity to roads and population centers; more-altered timing of runoff reaching the wetland; and increased soil disturbance. These indicators are assumed to be equally predictive and so the scores which indicate their absence are averaged:

  [AVERAGE (Core1, Core2, BMPsoils, WeedSource) + AVERAGE(PopCtr, DistRd) + AVERAGE(AltTime, Salt, SedDep, SedDisturb)]/3

Note that some assessment methods, as an indicator of biodiversity, include "number of wetland types" or "number of hydroperiod types" present within a single wetland AA. WESP does not use those because the boundaries separating such types are not often clearly distinguishable either in the field or from aerial imagery. WESP addresses habitat heterogeneity (both within and surrounding an AA) using other indicators.

Approach for Future Validation: Among a series of wetlands spanning the function scoring range and a range of wetland condition (integrity), all plant species would be surveyed and percent-cover determined at their appropriate flowering times during the growing season.

PH Benefits Model

IF((RarePlant=1),1, **ELSE**: AVERAGE(SBMscore, MAX(HerbUniq, WoodyUniq), ScorePOL)

The Benefits score is automatically set to 10 if a rare plant species is present in or near the wetland. Otherwise, the score is the average of three metrics: score for Pollinator Habitat, socre for Songbird-Raptor-Mammal Habitat, and a score indicating either <10 percent of the surrounding 100 m, 1 km, or 5 km contains herbaceous vegetation (but much of the wetland does), or a score indicating <10 percent of the surrounding 100 m, 1 km, or 5 km contains woody vegetation (but much of the wetland does).

A.16 POLLINATOR HABITAT (POL)

<u>Function Definition:</u> The capacity to support pollinating insects, such as bees, wasps, butterflies, moths, flies, and beetles, and also pollinating birds (hummingbirds and perhaps others). No model is provided here for tidal wetlands due to their presumed limited capacity to support pollinating insects and birds, and due to lack of knowledge of features that would be predictive.

<u>Scientific Support for This Function in Wetlands Generally</u>: Moderate. Many wetlands may be important to pollinators because they host different plant species than those in surrounding uplands, which implies they may flower at different times than those in the uplands, and may do so over a prolonged season due to greater water availability in wetlands. Also, in many landscapes wetlands contain the last remaining patches of unaltered vegetative cover.

POL Function Model

IF(AllWet=1), 0, AVERAGE(PollenOnsite, NestSites, Stress)

The model is comprised of three metrics: *Pollen Onsite, Nest Sites,* and *Stress*. These indicators are assumed to be equally predictive so are averaged. They are calculated as follows:
- **Pollen Onsite** is calculated as the average of two groups. One represents either high forb cover or a predominance of low woody shrubs, both of which are favoured by pollinators. The other is a group average based on lack of strongly dominant herbaceous species and presence of diverse size classes of both hardwood and conifer trees.

AVERAGE[MAX(WoodyHtForm, Forbs), AVERAGE(herbsens, herbdiv, ShrubDiv)]

- **Nest Sites** available for pollinating insects are assumed to increase with increased snags, large-diameter trees, downed wood, microtopographic variation, cliffs, and intermediate extent of vegetative ground cover. Together, these account for half the NestSites score and the other half is determined by the percentage of the wetland that is not persistently flooded.

AVERAGE[persist, AVERAGE(woodydbh, snags, downwood, girreg, cliff, gcover)]

- **Stressors** (lack of) are represented by toxic sources, isolation from natural vegetation, and lesser extent of wetland perimeter adjoined by natural vegetation. Scores indicating a lack of these indicators are averaged because they are assumed to be equally predictive:

AVERAGE(Toxic, CovPctScape, DistNat, BuffPerim, BuffLUtype)

POL Benefits Model

MAX(RareHerb, HerbUniq, WoodyUniq)

Pollination is presumably valued to a greater degree if a wetland contains a rare plant (although not all plants are insect-pollinated), or if the wetland contains some of the only herbaceous or woody vegetation within 5 km, 1 km, or 100 m.

A.17 PUBLIC USE & RECOGNITION (PU)

Definition: The potential and actual capacity of a wetland to sustain low-intensity human uses such as hiking, nature photography, education, and research. The model assumes that more human use of a wetland means that the particular wetland is more valued by the public. However, it is recognized that some individuals would benefit more those wetlands that receive less human use, because heavy use compromises the solitude sought and valued by some.

The score for Public Use Benefit of a wetland is assumed to increase with an increase in scores for 3 metrics: *Convenience*, *Investment*, and *Recreation Potential.* These are considered equally predictive so are averaged. They are comprised of the following indicators:

- **Convenience**: score is greater where most of wetland is physically accessible, publicly owned (especially as a conservation area), visible from roads, near marine waters and/or near a population center. Scores for these are averaged:

AVERAGE(Ownership, Visibility, RdDist, Core1PU, Core2PU, ElevPU, PopCtrDisPU, TidalProxPU)

- **Investment**: This is intended to reflect positively any past expenditure of public funds for the wetland's conservation, as well as designation as a mitigation site or regular use for scientific research or non-regulatory monitoring. The metric's score is based on the maximum of these indicator scores.

MAX(MitigaSite, ConsInvest, ConsDesig, SciUse)

- **Recreation Potential**: score is greater if wetland is on a lake, contains some walkable area, and is near a visitor center or has similar educational or recreational enhancements while also featuring best management practices to reduce ecological impacts of overuse. Scores for these are averaged:

AVERAGE(RecreaPoten, BMPsoils, BMPwildlife, LakePU)

A.18 WETLAND SENSITIVITY (Sens)

Definition: the lack of intrinsic resistance and resilience of the wetland to human and natural stressors (Niemi et al. 1990), including but not limited to changes in water chemistry, shade, frequency and duration of inundation or soil saturation, water depth, biological invasion, habitat fragmentation, and others as described in the USEPA report by Adamus et al. (2001).

The model assumes that wetland sensitivity, especially to human activities, can be represented by the unweighted average of the following 6 metrics, all considered equally predictive:

- **Abiotic Resistance and Climate Sensitivity** is assumed to be less (i.e., wetland more sensitive) in wetlands with no outlets, relatively small contributing areas, with a large portion that lacks surface water, and located in an area with a cold and dry climate. The scores of these are averaged:

AVERAGE [OutDura X AVERAGE(SatPct, CUratio, IsoDry, Depth, Constric), AVERAGE(BuffSlope, SoilTex, Beaver), AVERAGE(GDD, ETregion)]

- **Biotic Resistance** is assumed to be less (i.e., wetland more sensitive) in wetlands that are small; have a narrow vegetated width; are already dominated by native plant species; also support rare amphibians, waterbirds, songbirds, mammals, or plants; and (less predictably) have limited ground cover, convoluted upland edge, and few shrub species. Indicators in this last group are averaged, and their average is then combined with the average of the preceding more-predictive indicators:

AVERAGE [AVERAGE[VwidthAbs, WetSize, (AVERAGE(EmSens, ShrubPattS, WoodySens2, Gcover, UpEdge)), RareSpp]

- **Site Fertility** is assumed to speed recovery time from disturbance, which is a component of Wetland Sensitivity. It is predicted to be greater in wetlands that have more cover of nitrogen-fixing plants, are in an area with a shorter growing season, have poorly-buffered water chemistry (low conductivity), and are a new wetland or a type of wetland that typically has less nutrient availability. The assumed order of *increasing* nutrient availability is: Bog> Swamp > Fen > Marsh.

AVERAGE[ETregion, GDD, AVERAGE(Wettype, Nfix, NewWet, Acidic, Conductiv)]

- **Availability of Colonizers** also affects the recovery rate. Recovery times in wetlands might be greater if surrounding lands are dominated by natural land cover, the wetland is near other wetlands or lakes, the wetland is not located in the headwaters of a watershed, and no herbaceous species is strongly dominant.

AVERAGE(HerbDom, Elev, NatVegProx, NatVegSize, NatVegCUpct, PondProx, LakeProx)

- **Growth Rates** of wetland vegetation, and thus the time to full recovery, also depend on the plant species. Trees grow the slowest and live the longest, so if a wetland contains much tree cover, especially of large-diameter trees, and that is removed, full recovery takes longer. Thus, such wetlands could be considered less resilient and more sensitive.

AVERAGE(TreeDBHs, TreeCover)

A.19 WETLAND ECOLOGICAL CONDITION (EC)

Definition: The integrity or health of the wetland as defined primarily by its vegetation composition (because that is the only meaningful indicator that can be estimated rapidly). More broadly, ecological condition is defined by the structure, composition, and functions of a wetland as compared to relatively intact reference wetlands of the same type, operating within the bounds of natural or historic disturbance regimes.

Non-tidal wetlands in excellent ecological condition often have no invasive plants, little bare ground, and at least one species of conservation concern. Equally, they have no strongly dominant herbaceous or shrub species, varied microtopography, and no extensive algal blooms.

However, many wetlands perceived to be in excellent condition do not have any of these characteristics. The model is structured as follows:

(AVERAGE(RareAll, EmSens, BareGpct) + AVERAGE(HerbDom, GirregCQ, OverRich))/ 2

A.20 WETLAND STRESS (STR)

Definition: The degree to which the wetland is or has recently been altered by, or exposed to risk from, human-related factors that degrade its ecological condition and/or reduce its capacity to perform one or more of the functions listed in this document.

Structure: Stressors were organized in four groups: Hydrologic Stress, Water Quality Stress, Fragmentation Stress, and general Disturbance Stress. The maximum score among these is added to their average score and divided by 2:

[MAX(HydroStress, WQstress, FragStress, DisturbStress)) + AVERAGE(HydroStress, WQstress, FragStress, DisturbStress)] /2

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