

# GUIDELINES FOR RISK ASSESSMENT IN WETLANDS

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**Abstract.** This paper presents some guidelines for risk assessment in wetlands. Ecosystem analysis, i.e., understanding how wetlands function on the landscape, should be at the heart of the process. Another key point is to identify human values that derive from these wetland functions. Knowing the relationship between functions and values will greatly improve the problem identification phase and aid in the selection of appropriate test methods and evaluation endpoints. The result will be more accurate risk identification and more effective risk management. Risk characterization in wetlands should involve a two-step process: (1) utilize a wholistic, ecosystem approach to develop a detailed understanding of how the system functions, and (2) overlay this knowledge base with three tiers of testing, as appropriate; exposure assessment, biological assessment, and ecological assessment. Although this methodology may seem too complex for routine application, integrating ecosystem analysis may actually reduce the overall time and cost by identifying key biological, chemical, and physical parameters that must be evaluated early on in the assessment process.

## 1. Introduction

In the United States, regulations such as the Clean Water Act, CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act), and FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act) make risk assessment an important part of wetland management at the Federal, state, and local levels. Many different approaches have been developed to assess ecological risks (U.S. EPA, 1992; Suter, 1993) but none of these were developed specifically for application to freshwater wetlands. Each has been molded to assure their implementation for risk assessments mandated by law and regulation. For example, some strategies give explicit instructions for evaluating physical stressors that may have impacted a wetland as a consequence of changes in land use practices, but offer no guidance for assessing exposure of biota to chemical stressors. Others fail to address important parameters that are unique to freshwater wetlands. These methods could be improved by integrating ecosystem analysis into the risk assessment process.

It is necessary to use an ecosystem approach in order to identify key linkages between stressors and responses, and develop the most effective risk management strategies. This involves two steps: (1) understanding the principal processes (ecology, hydrology, geomorphology, soils) that determine the structural and functional characteristics of the wetland(s) under evaluation, and (2) using this information to guide the selection and application of assessment methods for identifying where, when, how, and to what extent stressors are, or could be, causing adverse effects.

A major shortcoming of many wetland risk assessments involves step 1. There is often a large *disconnect* between the wetlands research community and the risk assessment community regarding wetland data availability and its interpretation. When factors in risk assessments are dealt with as *uncertainties* sometimes it is simply a lack of awareness that useful data already exists. Failure to bridge this gap by fully exploring and utilizing available information on wetland hydrology, geomorphic setting, and ecology can lead to serious oversights in the risk assessment process.

Three key principles form the conceptual framework for assessing impacts and risks in wetlands. These are: (1) abiotic factors and biotic processes are inseparably linked, and ultimately determine the degree of wetland functions and structure on the landscape, (2) input of chemical, physical, or biological stressors may affect either or both of these components, separately or simultaneously, and (3) the integration of wetland ecosystem functions and human values is an important theme in problem formulation, risk characterization, and risk management. This paper discusses these principles and provides some guidelines for wetland risk assessment.

## 2. Definitions and Terminology

Risk assessment for wetlands may focus on chemical (nutrients, contaminants, etc.), as well as nonchemical issues. In practice, chemical and physical stressors generally impinge on wetlands simultaneously. In evaluating the effects of chemical, physical, and biological stressors, various issues must be resolved during the problem formulation and risk characterization phases of the risk assessment process. For adequate technical support, management and policy input must be clearly positioned prior to the risk analysis activities associated with exposure and ecological effects assessment, including the resolution of questions revolving around two interrelated issues focused on data interpretation (performance-based versus criteria-based practices) and the distinction between risk analysis (characterization), risk assessment, and risk management (Figure 1).

Evaluations of wetlands may incorporate the concepts of performance-based or criteria-based practices to varying degrees, depending on whether the system being assessed is a naturally occurring or a constructed wetlands, and the regulatory context that may be associated with the risk assessment. *Performance-based criteria* are those which specify some design-focused criteria for evaluating wetlands; for example, a naturally occurring or constructed wetland may be considered an effective remediation measure if it decreases heavy metal concentrations in mine tailings runoff by 80%. *Criteria-based evaluation practices* most frequently assess wetland water quality by some numeric value developed as a consequence of a regulatory objective, e.g., water discharged from a remediation wetland must meet the Class 1 Waters (drinking water) standards for heavy metals. Regardless of the

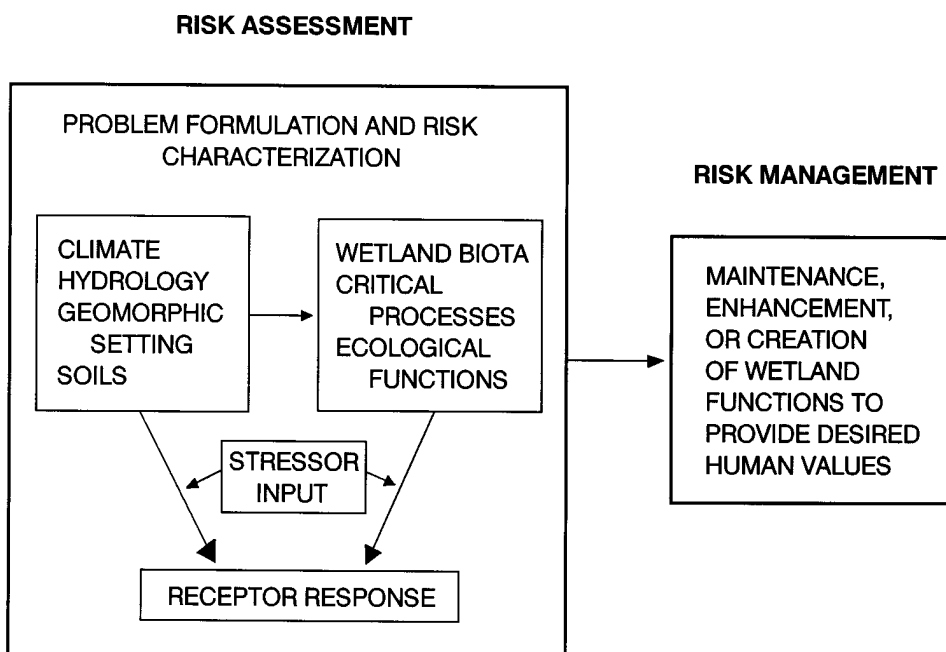


Figure 1. Conceptual framework for risk assessment in wetlands. The integration of wetland ecosystem functions and human values is an important theme in problem formulation, risk characterization, and risk management.

data sources being used in the risk assessment (e.g., historic data or data derived from designed studies), technical data collections must be applied within the data quality objectives that are developed from either performance-based or criteria-based needs.

The relationship of risk analysis, risk assessment, and risk management activities to wetlands may be markedly different, especially as they relate to a technical characterization of wetland *functions* versus a more risk assessment-like consideration of wetland *values*. The role these potential differences play in evaluating *threats* and *impacts* of anthropogenic activities on wetlands depends upon how clearly terms are distinguished and mutually understood by the risk assessor and risk manager.

Wetlands are generally considered to have *functions* centered around hydrologic flux and storage, biological productivity, biogeochemical cycling and storage, decomposition, and community/wildlife habitat (Richardson, 1994). Hydrologic functions are characterized by capacity and input, which may define a wetland as a water source or water sink. Wildlife habitat functions of wetlands may be nested with subsets of biological processes such as decomposition, biological productivity, and biogeochemical cycling; moreover, these are all directly reflected in the biological components of wetland structure. For example, wetland vegetation clearly

is critical and plays a major role in maintaining biodiversity and species-critical functions such as reproduction, feeding, and dispersal. While not without technical disagreement, wetland function is relatively easy to address within risk analysis, but wetland values are better characterized as assessment endpoints wherein societal and policy influences become critical to their definition. Wetland *values* refer to the benefits obtained by society from wetland functions. For example, hydrologic flux and storage is a wetland function. Human values associated with this function include flood control and the economic and recreational benefits derived from hydrologic flux and storage (Table I).

Without question, understanding functions and values is a pivotal part of risk assessment for freshwater wetlands. This function–value relationship provides an important conceptual framework within which the risk assessor and risk manager can formulate operational goals and objectives. The principal truths underlying this relationship are: (1) All wetlands are not of equal function or equal value on the landscape; (2) a restored or newly constructed wetland may or may not be equal to a natural wetland in terms of ecological function or value; (3) wetland ecosystem functions and values are coupled to other systems on the landscape; and (4) wetlands often provide functions and values beyond their boundaries and far from adjacent ecosystems (Richardson, 1994).

The terms from wetland science and related wetland assessment disciplines must be clearly defined and distinguished as assessment endpoints or measurement endpoints if the wetland scientist and risk assessor are going to communicate and become effective resource managers. Similarly, the concepts of threats and impacts to wetlands must be established within an ecological risk setting. Within a risk assessment context, *threats* are anthropogenic activities (planned or unplanned) that have the potential to cause adverse effects, while *impacts* are effects that resource managers typically characterize as *adverse* (U.S. EPA, 1992; Suter, 1993). Risk management objectives must be adequately characterized in order to clearly identify measurement endpoints that will identify (or eliminate from further analysis) differences between wetlands at risk and their reference environments. In order to develop cost-effective risk analysis programs, the concepts of *function* and *value*, as well as *threat* and *impact* must be consistently defined by wetland scientists and those in the risk assessment community.

An ecosystem-based approach gives the risk assessor and risk manager considerable flexibility in how to address the problem at hand. This is necessary given the diversity of wetlands that may be encountered and the multitude of factors or stressors that may be at work in the particular wetland under study. At the same time, however, an ecosystem approach serves to maintain the key concept of interlinkage of the wetland compounds. An additional overarching provision is that collection and evaluation be tiered (or phased) so that resources are focused effectively and there is ample opportunity for the risk assessor and risk manager to discuss the scientific and policy implications as the risk assessment proceeds.

Table I  
 Relationship between ecosystem functions, human values, and assessment endpoints for characterizing risks in freshwater wetlands<sup>a</sup>

Function	Value	Assessment endpoint <sup>b</sup> /Significance
Hydrologic flux and storage	Flood control and protection	Hydrological
	Erosion control	Maintain natural supply of water to wetland/Key to maintaining proper hydroperiod and hydroperiod
Biological productivity	Water supply	Provide sediment control/Reduces turbidity and input of sediment to waterways
	Visual-cultural	Silvicultural
	Timber production	Maintain soil fertility/Provides sustained growth of trees for timber production
	Shrub crops	Control brush/Maximize production of shrub crops
	(cranberry and blueberry)	
	Food production (shrimp, fish, ducks)	
Biogeochemical cycling and storage	Historical and cultural resources	Geomorphological
	Sediment control	Maintain soil stability/Reduces erosion of stream and river banks
	Nutrient removal	Maintain water depth/Stabilizes water treatment capabilities
	Wastewater treatment	
	Water quality	
Decomposition	Medicinal (streptomycin)	Microbiological
	Wastewater treatment	Maintain mineralization rate/Optimize nutrient removal
	Water quality	Maintain aquatic microbial profile/Prevent bacterial contamination of other waterbodies
	Nutrient supply and regulation	
Community/wildlife habitat	Recreation	Ecological
	Hunting and fishing	Maintain level of primary productivity/Supports food web stability
	Preservation of flora and fauna (refuge)	Maintain species diversity/Preserve rare species
	Threatened, rare and endangered species	

<sup>a</sup>Functions and values were adapted from Richardson (1994).

<sup>b</sup>Selected as examples; many more endpoints exist.

### 3. Designing and Conducting the Risk Assessment

#### 3.1. PROBLEM FORMULATION

When beginning a risk assessment it is important to know what information has been developed previously for the wetlands under study. Aerial photographs, historical maps, land use documents, etc., are all useful in learning about the history and current status of the area. Also important is to gain an understanding of the hydrology and geology driving the wetlands under study. Special care must be taken to properly complete a hydrogeomorphic classification of the wetland to assure an accurate understanding of its hydrologic functions on the landscape (Brinson, 1993a).

As noted earlier, wetlands vary greatly in their structure and functions primarily due to hydrological and geological conditions, both of which will influence sources and trigger points for stressors and, thereby, the focus of the risk assessment. For example, lateral surface water is the main source of moisture for fringe wetlands, whereas groundwater is the major source for depressional wetlands. While there are other issues that may be relevant to understand before beginning the risk assessment, a key aspect is to determine the spatial extent of the area under study. For very small wetlands this could amount to only a couple of hectares; for large ones, it may encompass an entire watershed or multi-watershed ecosystem comprised of several thousand hectares or more. In order to develop effective solutions, wetland problems must be formulated within a landscape context. A landscape approach is especially needed when the cumulative effect of wetlands on stream water quality and quantity is at issue (Johnston *et al.*, 1990). Imposing artificial boundaries (political or otherwise) can result in a superficial risk assessment that fails to address some of the important issues.

Once the wetland and its hydrologic linkages are delineated, the problem (stressors) can be described in terms of its source, transport, and potential area of impact. This is the point at which the key stressors and receptors in the wetlands under study should be clearly identified and, if necessary, prioritized in order to guide the risk assessment process that will follow. Problem formulation should be an intensive effort to formulate and validate key questions and issues to be addressed by the risk assessment. Moreover, it should determine those wetland functions and associated human values that are critical to the resolution of the problem. Failure to give adequate attention to this step can undermine the risk assessment and lead to ineffective risk management. Consider the following scenario. A municipally-owned wetland is to be evaluated for possible use in treating domestic wastewater and controlling sediment from nearby farmland. The wetland is currently used for public recreation (visual-cultural, hunting and fishing, preservation of flora and fauna). It would be inappropriate to focus the risk assessment on biogeochemical functions alone even though the primary concern, i.e., new uses (values) for the wetland, may be to remove nutrients and sediments. The recreational values are

supported by several other functions as well, including hydrologic storage and community/wildlife habitat (Table I). Failure to account for the full range of wetland functions that are necessary to support the societal values would constitute an incomplete risk assessment. Resultant decisions of the risk manager would likely not provide a desirable outcome for some of the key wetland values. Although human values may ultimately drive the process, the function–value linkage must be mutually understood and acknowledged as the risk assessment proceeds.

### 3.2. ESTABLISHING ASSESSMENT AND MEASUREMENT ENDPOINTS

One of the most important steps in risk analysis is establishing clear assessment endpoints because they set the stage for all of the forthcoming effort. In addition, assessment endpoints specific to freshwater wetlands can take on major significance due to the diversity of potential wetland types that may be encountered. In fact, using an ecosystem approach, the assessment endpoint(s) may or may not be biologically or ecologically-based. For example, the hydrology, geomorphology, soils or other aspects of the wetlands may be far more important to focus on than some of the biological resources.

For an illustration of assessment endpoints, assume that a freshwater fen (pH of 7.2, alkalinity of 500  $\mu\text{eq/l}$ ) under study is one that is dependent on a constant supply of high quality groundwater. One assessment endpoint might be to protect the supply of high quality groundwater to the wetlands by preventing exposure to non-chemical stressors. In this example, the focus is on hydrologically-driven endpoints. In other situations ecologically-driven assessment endpoints may be given top priority. For example, in the study of the Clark Fork River Superfund Site in Montana (Pascoe and DalSoglio, 1994; Linder *et al.*, 1994), none of the assessment endpoints for the riparian wetlands or the river itself included protection of the water supply. This does not mean that the risk assessment for this particular wetlands was done incorrectly, but that the primary focus was to protect ecological resources rather than the one key component responsible for the wetlands themselves—water. Another important consideration could be ensuring that the groundwater is meeting a minimum *quality* standard, defined in various ways ranging from a particular range of pH, turbidity, specific conductance, etc., to absence of chemical stressors at some threshold concentrations. The point of these examples is that all of the parameters (hydrological and ecological) that are critical to the long-term sustainability of the wetlands should be considered as possible assessment endpoints during the development phase. A subset of these may be chosen for use in the risk assessment, but it is important to establish the assessment endpoints clearly in the context of what is vital to sustaining or improving the health of the freshwater wetland. Relationships between ecological functions, societal values, and assessment endpoints specific to freshwater wetlands are shown in Table I.

Like assessment endpoints, measurement endpoints may or may not have a biological or ecological basis, but they must be directly relevant to, and linked with, the assessment endpoints. In the examples given above, measurement endpoints could be analytical determinations of contaminant concentrations in the water supplying the wetlands, the specific conductance or suspended solids levels in the water, the flow of water to the wetlands, as well as various biological and ecological measures that are relevant to the assessment endpoints.

Whether qualitative and reliant on published information or quantitative and implemented as part of a designed study, aquatic field surveys and biological tests are the cornerstone for evaluating risks associated with chemical, physical, or biological stressors. Frequently, these tools are used in the measurement or monitoring of wetland populations and communities through structural endpoints such as relative abundance, species richness, community organization (diversity, evenness, similarity, guild structure, and presence or absence of indicator species), and biomass. Functional endpoints, such as cellular metabolism, individual or population growth rates, and rates of material or nutrient transfer (e.g., primary production, organic decomposition, or nutrient cycling) are less commonly measured. Functional measurements are important in interpreting the significance of an observed change in population or community structure as well as ecosystem function. Moreover, functional measures are difficult to interpret in the absence of structural information, are relatively expensive to conduct, have not been standardized, and require considerable understanding of the system and processes involved. However, recent studies have been undertaken to try and develop 'functional metrics' for wetland systems as a way of simplifying, while at the same time preserving the strengths, of this approach to wetland assessment.

One approach that has been developed for examining ecosystem response to stress is the Odum subsidy/stress model (Odum *et al.*, 1979). Primarily, the subsidy/stress model suggests that introduction of a nontoxic limiting element like phosphorus (P) would result in a subsidy effect (not a decrease) in ecosystem responses like productivity, diversity, nutrient storage and cycling, etc., for a P limited ecosystem up to a threshold maximum. At some P 'threshold' concentration or load the ecosystem would reach a maximum response beyond which a decrease in response would become evident. A hypothetical P response curve for the Florida Everglades ecosystem is shown in Figure 2. It should be noted that the threshold is a zone for ecosystems, not one number, and that increases in productivity and diversity, or changes in community structure and species become more evident as the maximum P threshold is reached. The toxic input curve represents the introduction of a xenobiotic compound (e.g., pesticide) and was presented by Odum *et al.* (1979) to demonstrate the severe and immediate effects of toxic compounds on ecosystem processes.

There are numerous techniques for assessing effects of stressors on biological processes. Field and laboratory methods are available for evaluating aquatic habitats, sediments, and soils within wetlands. Sources of information on tests that

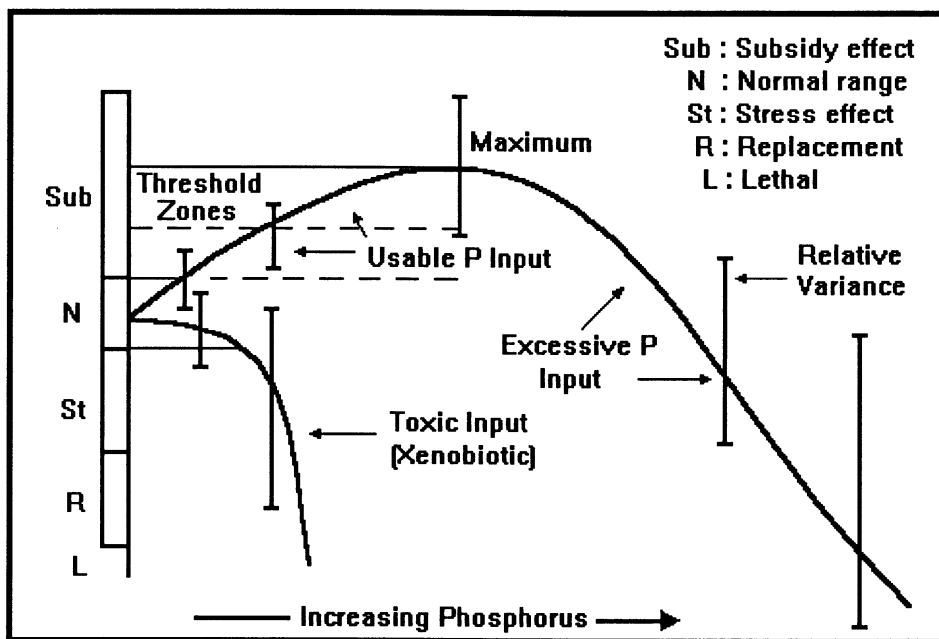


Figure 2. Hypothetical phosphorus response curve for the Everglades ecosystem. The curves simulate the output response (as measured by appropriate systems functions like diversity or productivity, etc.) to increasing phosphorus (P) additions (modified from Odum *et al.*, 1979).

measure biological responses to stressors are listed in Table II. The response variables used in these tests are the measurement endpoints that can be used to predict likely impacts and, ultimately, the risk that wetland functions will be impaired. Multiple lines of evidence gathered using tools such as biomarkers, chemical residues, and bioassays are critical to the risk assessment process. These tools are used to develop a preponderance of evidence upon which a credible risk management decision can be reached.

### 3.3. EXPOSURE ASSESSMENT

Exposure assessment refers to the identification of major pathways and media through which wetland receptors come in contact with the stressor. The extent, frequency and magnitude of the exposure will strongly influence the potential for negative impacts and, thereby, affect risk. Inputs of chemical and non-chemical stresses to freshwater wetlands occur through geological, biological, and hydrological pathways typical of other ecosystems (Mitsch and Gosselink, 1993). Geological input from weathering of parent rock can be an important source of exposure in some wetlands (Presser, 1994; Presser *et al.*, 1994). Biological inputs include photosynthetic uptake of carbon, nitrogen fixation, and biotic transport of materials by animals. Except for gaseous exchanges such as carbon and nitrogen fixation or

Table II

Representative technical references for sampling and test methods that may be useful for evaluating risks in wetland habitats

Habitat	Biota	Reference
Freshwater	Vascular plants	Ratsch (1983) Gorsuch <i>et al.</i> , (1992)
Freshwater/marine/ estuarine	Algae and vascular plants	Gorsuch <i>et al.</i> (1992) Wetzel and Likens (1995)
Freshwater	Birds	Adamus (1993a, b)
Freshwater	Aquatic vertebrates and invertebrates	Nielsen and Johnson (1983) Rand and Petrocelli (1985) U.S. EPA (1990, 1991) ASTM (1995) Wetzel and Likens (1995)
Marine	Marine/estuarine invertebrates and vertebrates	Nielsen and Johnson (1983) U.S. EPA (1989, 1991) ASTM (1995) Wetzel and Likens (1995)
Freshwater sediments	Epifauna, infauna, and vertebrates	U.S. EPA (1989, 1991) ASTM (1995) Wetzel and Likens (1995)
Marine/estuarine sediments	Epifauna, infauna, and vertebrates	U.S. EPA (1989, 1991) ASTM (1995)
Transitional/upland	Vertebrates and invertebrates	Linder <i>et al.</i> (1994)
	Vascular plants	Linder <i>et al.</i> (1993)

aerial deposition, however, inputs to wetlands are generally dominated by hydrology. Hydrologic transport to freshwater wetlands may occur through precipitation, surface and/or ground water flow. The hydrologic exposure pathways of freshwater wetlands are determined by their flooding regime or by the balance between precipitation and evapotranspiration.

Hydrodynamics will affect exposure levels in both the aquatic and soil/sediment compartment of a wetland because it will to a large extent determine the soil/sediment chemistry by producing anaerobic or aerobic conditions, importing and removing organic matter, and replenishing nutrients. Exposure can occur in transition zones between the wetland and surrounding upland areas. It is important to consider this area as well when examining potential exposure scenarios.

Ideally, exposure in the wetland ecosystem is assessed based on representative monitoring data. In the absence of measurement data, exposure can be predicted in the context of a wetland-specific hydrogeomorphic, biogeochemical and ecological setting. In case of a chemical exposure assessment, information on the inherent properties of substance(s) should be used in combination with the wetland charac-

Table III

Important parameters for assessing exposure to chemical and non-chemical stressors in freshwater wetlands

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Hydrogeomorphic information
Type of water input (capillary, precipitation, etc.)
Type of water flow (surface, subsurface, etc.)
Type of water outputs (percolation, evaporation)
Suspended sediment load and characterization
Sedimentation or peat accretion rate
Biogeochemical information
Soil/sediment origin and characterization
Microbial activity
Oxidation/reduction conditions
Organic matter content of sediments
Decomposition rate
Ecological information
Plant communities
Aquatic and benthic community structure
Wildlife survey
Structural/functional assessment (e.g., diversity, evenness)
Compound-specific information (chemical stressor)
Volatility
Hydrophobicity
Water solubility
Octanol/water partition coefficient
Hydrolysis
Photolysis
Biodegradation

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teristics in order to derive exposure concentrations or levels. Describing the level and distribution of a stressor in the wetland environment, or organisms, and its changes with time (in concentration and chemical form) is a complex process and needs to include a rigorous evaluation of what drives exposure. In order to ensure that predicted aquatic and sediment exposures are realistic, all available knowledge of the wetland ecosystem should be integrated in the exposure evaluation of a chemical stressor. Some parameters and measurements that can be important when evaluating and predicting exposure to chemical and/or non-chemical stressors in freshwater wetlands are listed in Table III.

Compound-specific information on chemicals and biogeochemical processes affecting exposure in the different compartments are usually derived and extrapolated from standard laboratory tests or literature data. Applicability of literature

data and data from standard tests to freshwater wetland ecosystems does require review and, ideally, field verification. Little of this work has been done for wetland ecosystems.

#### 3.4. BIOLOGICAL ASSESSMENT

Biological assessment is the determination of potential adverse effects to biota and the linkage of exposure to the stressor. The associated level of exposure and resulting response (concentration – response) determination is also part of this assessment. Toxic or other harmful effects may be observed at the species level (as from acute or chronic aquatic toxicity tests for example) but may also occur at higher levels of organization (population, community). Biological assessments are primarily toxicological tests which can be used in either a field or laboratory setting. While there are many issues related to the conduct and application of ecotoxicological tests, they represent one of the main sources of effects information available to the risk assessor.

In order for the assessment to be on target and provide useful data, the key stressors and receptors in the wetlands under study must be clearly identified. Adequate attention to the problem formulation step should provide this information. Generally, assessments of biological effects in wetlands should consider toxicity to animals and plants in the overlying water as well as in the sediments, provided the stressor is likely to enter and persist in the sediments. In addition, the assessment may not be limited to wetland or aquatic systems but may need to extend to the surrounding transitional zones. Some stressors will impact the terrestrial environment adjacent to the wetlands and this area too should be evaluated if there are potential pathways for exposure of receptors in the wetlands.

Biological assessments in the aquatic environment should include representative and, ideally, sensitive species of: (1) primary producers, (2) primary consumers, (3) microbial community, (4) saprophages/detrivores, and (5) carnivores. Potential tests for the primary producers could include tests with algae and vascular plants, both submerged and emergent forms. Effects on primary consumers could be evaluated by testing representative species of protozoa, invertebrates, insects, and amphibians. Inhibition of microbial activity could be evaluated by studying the effect on aerobic and/or anaerobic respiration. Toxicity tests with crustacea and insects can be used to assess effects on the saprophage/detrivore community. Finally, standard acute and chronic tests are available to assess the effect on fish (Table II).

Biological assessment of the benthic communities should take into account pathways of exposure. In addition, it needs to be realized that observed effects will be strongly influenced by sediment/soil biogeochemical conditions such as organic carbon content, particle size distribution, sulfide content, redox potential and time period allowed for equilibration to occur between dissolved and sorbed fractions of chemical stressors. Available test methods concern detrivores or mixed

detrivores/herbivores/carnivores and include insect, annelida, and crustacea species with both acute and chronic endpoints (Table II).

Guidelines and tests should be developed within a *framework* of taxonomic groups rather than for single species. This should make it possible to test representatives from the different wetland compartments and facilitate extrapolation of obtained test results to the wetland of interest. Furthermore, the guidelines and tests should include both acute and subchronic/chronic toxicity endpoints.

Most of the impacts on freshwater wetlands will occur in the aquatic environment in association with the sediment and overlying water. Effects may be restricted to animals and plants that live in the water or they can include animals that only use the wetland for feeding or drinking. Early indicators of problems may be noticed in the sediment and food-web, for example, bioaccumulation of a contaminant. Detecting these early responses in sediments and food-chain organisms will allow the potential for impacts on higher trophic levels to be evaluated more accurately. Impacts may ultimately involve many species of fish and wildlife, some of which may not continually occupy the study area (for example, migratory waterfowl). The potential for seasonal usage by some species makes it essential to integrate exposure assessment into the evaluation of biological effects.

The terrestrial environment surrounding or transitional to the freshwater wetland may also be at risk depending on the type of stressor and the exposure. Species that are dependent on the wetland structure and function, including insects, amphibians, reptiles, small mammals, birds and transition zone plants, trees, and shrubs, should be given consideration when evaluating potential effects. Standardized toxicity tests are currently available for many insects, some amphibians, and numerous small mammals and birds but few have been adapted for the species most often associated with freshwater wetlands. Acute and chronic bioassays with rodents and lagomorphs have been used for many years to determine the toxicity of chemicals and other materials that may also pose a risk to humans. Similarly, standard acute and chronic tests with species of waterfowl and upland birds have been widely used in the field of environmental toxicology.

There are, however, few tests that have been developed for non-food plants although the tests currently used in regulatory programs for pesticides and herbicides may be useful. Tests for root elongation and shoot development, seed germination and other methods are known (Table II) and may be useful in evaluating toxicity of soils in the transition zone. Other soil tests, some using earthworms, might be useful in this context (Table II). Keep in mind that the primary focus of the assessment is the wetland itself and it is there that the effort should begin.

Toxicity to plants from soil or sediment associated contaminants should be distinguished from, and evaluated independently of, toxicity to animals. There may be substantial effects on sediment microorganisms with little concomitant impact on plants, or vice versa. Moreover, contaminants may accumulate in soils or sediments, have little effect there, but be passed through the food chain and impact fish and wildlife. Depending on the focus of the risk assessment, the most

important component could be soil organisms, plants, sediment microfauna, or higher levels in the food chain. All should be given adequate consideration to identify their role in the risk assessment. For example, soils and sediments may not be a concern if they bind contaminants and render them biologically unavailable. The emphasis should be on the effects and the risk assessment needs to consider all of the facets that may contribute to them.

Unfortunately, there are few tests which lend themselves easily to determining the potential toxic effects on trees and shrubs that may inhabit the transition zones. In those situations it may be more plausible to determine impacts in situ on those trees and shrubs located adjacent to the wetlands of concern. Methods developed by plant scientists to analyze and interpret vegetation in transitional or upland zones can be utilized for this (Table II).

Using standardized toxicity tests brings up several important considerations. One of these concerns data interpretation and is driven primarily by the fact that most easily maintained species used in testing are not the same species generally found in freshwater wetlands. Thus, the uncertainty of extrapolating from one species to another within the same genus could be as large as extrapolating from rodents to humans. Therefore, it is important to understand the limitations of surrogate species testing and its application to risk assessment. Other uncertainties arise when extrapolating from acute exposure test data to chronic exposure situations, high concentration response studies to low-concentration exposures, and many other potential situations.

As mentioned above, selection of biological tests for wetland toxicity evaluation should be driven by the exposure assessments framed by the hydrogeomorphic and biogeochemical characteristics of the wetland of interest.

### 3.5. ECOLOGICAL ASSESSMENT

Ecological assessment is the determination of harmful impacts at the population, community or ecosystem level and may entail field studies, laboratory studies, or both. In general, standardized tests do not lend themselves to this type of assessment and few provide useful ecosystem-level information. In addition, there are significant temporal and spatial issues that come into play. Measuring or accurately predicting a significant change in an ecosystem may require years or decades of study, yet the risk assessor and risk manager are faced with much more compressed time lines. Just as important, it is difficult to isolate easily studied areas of the wetlands from the surrounding ecosystem that supports it, which may require the risk assessor to include caveats and large uncertainties in the risk assessment.

Given this situation, most ecological assessments have focused on measuring structural components of the ecosystem, including the size and make up of the habitat, and standing crop of important plants and animals, the abundance and diversity of plants and animals, and other measures. There are, however, functional measurements that are useful for understanding the ecological health and sustainability of

wetlands. These include hydrologic flux and storage, biological productivity, biogeochemical cycling and storage, decomposition, and wildlife habitat (Richardson, 1994). A functional assessment is based on the concept that variables (functions) which integrate key ecosystem-level wetland processes can be used as a metric to compare impacts and quantify functional loss when compared to reference wetlands of the same hydrogeomorphic classification (Brinson, 1993b; Richardson, 1994). Measured disturbances to wetland functions are scaled to a reference wetland (reference system = 100%), thus creating a comparative *ecosystem response surface*. The final step is to develop a threshold of acceptability for the wetlands under investigation and compare the altered functions to that threshold. Practical methods for analyzing wetland functions in the field are developing concurrently with the conceptual framework for this assessment technique (Richardson, 1994).

Functional assessment can be a powerful tool for evaluating ecosystem-level impacts and risks within a timeframe necessary for risk assessment. One of the main strengths of this approach is that it causes the risk assessor and risk manager to identify and resolve problems in the context of what a wetland does on the landscape. Even though human values may ultimately drive the risk assessment, the inseparable linkage of values to ecological functions, particularly for constructed wetlands, becomes evident as this approach is planned and implemented. Moreover, it provides the risk manager with information on what functions must be maintained or restored in order to provide the desired outcome (values) of the wetland (Figure 1).

In cases where sufficient supporting data already exist, it may be possible to evaluate chemical stressors by developing contaminant-specific assessment protocols that can be applied at an ecosystem level. For example, using published information on toxicity, bioaccumulation, and environmental cycling, Lemly (1995) developed a protocol for aquatic hazard assessment of selenium. This protocol integrates data for abiotic (water, sediments) and biotic (plankton, macroinvertebrates, fish, aquatic birds) components and yields information that can be directly applied to risk assessment. This technique can save time and money in the assessment process by targeting data collection toward specific parameters and utilizing existing toxicity information in the evaluation phase. It also has the advantage of being applicable regardless of wetland type, size, or location and can be used to evaluate the success of risk management activities. Thus, in certain situations, ecological assessment in the risk analysis context can be simplified to a linkage of contaminant monitoring data with existing toxicity and hazard profiles.

#### 4. Conclusions

Risk assessment for wetlands can be improved by integrating ecosystem analysis into the risk assessment process. However, there is a clear need to establish and implement a consistent operational framework in order to make full use of this

approach. Several concerns are evident. The effect of multiple stressors (chemical, physical, biological; of antropogenic or natural origin) must be an integral component of the assessment process. Development of reliable acute, subchronic and chronic tests specific to actual wetland biota rather than *standard* or *surrogate* test species is necessary. Alternative exposure/effects scenarios must be evaluated. Understanding fate and transport of chemicals and their interaction with physical, chemical and biological toxicity modifying factors is critical. The parameters that must be measured on-site to determine potential pathways and fate of toxins need to be better quantified.

The levels of uncertainty resulting from presently used *standardized* toxicity tests have not been carefully scrutinized in the context of freshwater wetland ecosystems. For example, plant toxicity data are generally based on one green alga (*Selenastrum capricornutum*, *Scenedesmus* sp. or *Chlorella* sp.) and one vascular aquatic plant (duckweed species, *Lemna minor* or *Lemna gibba*), but there may be a need to represent different groups of photosynthetic and non-photosynthetic wetland organisms. Using a species battery approach could lessen the potential errors associated with interspecies extrapolation and strengthen the multiple lines of evidence necessary for an environmentally sound risk assessment. This is also true for micro- and macroinvertebrates, fish, and aquatic birds. Laboratory to field extrapolations of single species tests may therefore be improved by using ecologically relevant species batteries with subsequent field validation.

There are also specific information needs for organismic, population and community, and ecosystem levels of organization. As with inter-species comparisons, errors and uncertainty associated with *inter-organizational* extrapolation need to be evaluated. This would include scaling issues associated with transitions between different levels of biological organization.

The ecosystem approach presented here uses hydrogeomorphic characterization together with wetland functions as the criteria for establishing transport, fate, and effects of both chemical and non-chemical stressors. Coupled with toxicity assessments at three organizational levels – organismic, population and community, and ecosystem – this approach may be used to describe exposure and effects of stressors in freshwater wetlands both as a predictive tool and to describe existing conditions. Practical application of the approach will provide a better understanding of how physical, chemical and biological factors modify the intensity of the stressors. Tools for integrating and analyzing these complex ecosystem interactions need to be refined or, in some cases, are yet to be developed. Approaches for evaluating the influence of seasonal and spatial variability are especially needed.

Toxicity assessments involve tests of varying complexity (single-species, mesocosm, ecosystem assessments, etc.). As a rule of thumb, costs escalate with increasing complexity; single species laboratory bioassays being the least expensive. From a cost–benefit perspective the least complex test that can adequately predict ecosystem effects should be the method of choice providing proper validation has been carried out. An ecosystem approach may reduce the overall cost of risk assess-

ment by identifying key biological, chemical, and physical parameters that must be evaluated early on in the assessment process.

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