Chapter 9:

WETLANDS

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9.1 INTRODUCTION

Wetlands have been identified and protected as critical areas by King County in the first Sensitive Areas Regulations in 1987. Since then, wetland regulations have been adjusted to reflect scientific and regulatory information as available. This following wetland chapter is based on an extensive review of the latest wetland Best Available Science (BAS) to provide the background for devising regulations for the update of the Current Critical Areas Ordinance and King County's comprehensive Plan. King County initiates this discussion with a brief overview of wetland definitions, wetland types, and wetland functions and their determinants. Subsequently, the County discusses the foremost impacts to King County jurisdictional lands and their functions. Within this context, the County also singles out mitigation measures and appraises their effectiveness. Finally, the County reviews the BAS regarding the major wetland functions and how human actions may influence these protected functions.

9.2 REVIEW OF LITERATURE

9.2.1 Wetland Definitions and Types

There is no single, formal definition of wetlands among ecologists, managers or government regulators (Dennison 1993; Mitsch and Gosselink 1993). Due to the complex nature of wetlands, ecologists, managers, and government agencies have struggled to identify a formal regulatory definition of wetlands. The State of Washington and King County, as well as most other state and local governments, have accepted the regulatory definition developed by the U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency in administrating dredge and fill permits under Section 404 of the Clean Water Act (33 CFR Section 323.2) and 40 CFR Section 230.3. This definition ascertains that wetlands are those areas that are inundated by surface or ground water with a frequency sufficient to support plants and animals that depend on saturated or seasonally saturated soil conditions for growth and reproduction (Cowardin et al. 1979). Historically, jurisdictional wetlands were identified by only one or two of these attribute (Federal Interagency Committee for Wetland Delineation 1989) rather than all three. From the current jurisdictional perspective, and under normal conditions, wetlands must have all three of these attributes (U.S. Army Corps of Engineers 1987), and King County's wetlands are regulated with this in mind. In atypical and disturbed wetland systems however, less than three characteristics may occur.

The regulatory definitions are often different from the ecological definitions identified in the scientific literature, as there is no universally accepted definition because of the large number of characteristics that describe wetlands and their somewhat arbitrary boundaries. For example, how far do wetlands extend upland or where do they end in deeper water (Mitsch and Gosselink 1993). The National Research Council (NRC 1992) simply identifies wetlands as transitional areas between terrestrial and open water systems, whereas in 1995 the NRC defines them as "an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate "(NRC 1995 p. 50). Other wetland scientists ecologically define a wetland as an ecosystem that "arises when inundation by water produces soils dominated by aerobic processes and forces the biota, particularly rooted plants, to exhibit adaptations to tolerate flooding" (Keddy 2000, p. 3). Regardless, it is clear that wetlands occur in the landscape because of the combination of water, soils, and plants forming unique communities, and that the definitions and delineations reported in the literature are scientifically sound even though they were specifically developed for regulatory purposes (NRC 2002).

There are many kinds of wetlands, from those dominated by open water, to forested areas in which standing water is rarely present at the surface for an extended length of time (Mitsch and Gosselink 1993; Keddy 2000). Common colloquial names for wetlands are ponds, bogs, fens, marshes, wet meadows, shrub swamps, and wooded swamps, each with its own unique set of attributes. For example, sphagnum-dominated peatlands (i.e., specific bog variety) and fens in King County are rare and unique wetland types that were formed in closed depressional systems created by glaciation (Kulzer et al. 2001; Bell 2002). Consequently they are sensitive to hydrological and water quality changes and virtually impossible to restore or to mitigate for detrimental impacts (Trettin et al. 1996).

Because of wetland functions such as flood control, groundwater exchange, water quality enhancement, and their importance to a wide array of plants and wildlife, the colloquial terms describing wetlands were incorporated and formalized by scientists into a standardized, widely accepted scientific terminology with specific ecological, regulatory, and legal usage. Wetlands are also known and classified by specific ecological technical terms depending on their geomorphic, hydrologic, water quality and biologic characteristics.

One common ecologically-based wetland classification system was developed by the U.S. Fish and Wildlife Service (Cowardin et al. 1979) to group wetlands based on dominant vegetation communities (where dominant is defined as 30 percent or greater areal cover). Consequently, this classification system refers to wetlands and their habitats as forested scrub-shrub, emergent, or open water depending on the areal extent of open water and vegetation communities. In addition, wetlands are recognized as either freshwater-dependent (e.g. palustrine, lacustrine) or saltwater-dependent (e.g., estuarine). The majority of the remaining mapped and inventoried wetlands in King County are palustrine wetlands (King County 1991).

More recently, a second popular ecologically based wetland classification method was developed for the U.S. Army Corps of Engineers. It groups wetlands by hydrogeomorphic characteristics, namely by wetlands of similar function because of matching geomorphic settings, water sources and hydrodynamics and consequently named the Hydrogeomorphic Method (i.e., HGM) [Brinson, 1993a #1767]). Therefore, wetlands formed on a river floodplain with unidirectional downstream flow of water are identified as riverine wetlands. Correspondingly, bogs and other wetlands in topographic depressions fed mainly by water from precipitation and runoff from adjacent slopes are classified as depressional wetlands.

Not to be confused with ecologically based classifications describe above, jurisdictions such as the State of Washington and King County also have wetland classification schemes (WSDOE 1993; King County 1990). Although, using ecological criteria for their classifications, these agency arrangements differ significantly from the ecologically based systems in that ecological traits are used to identify attributes and to rank wetlands according to their relative value. Moreover, these ranked classifications are then directly tied to suggested or required wetland protection measures. As a result, ecologically diverse wetland systems are sorted by a limited number of criteria and then categorized for management purposes.

9.2.2 Wetland Functions

Wetlands potentially perform a number of different and often critical environmental and ecological functions benefiting humans (Kusler and Opheim 1996; NRC 1992; 2001). These include flood storage and retention, groundwater discharge/recharge, maintaining and protecting water quality and providing abundant and clean potable water. Some maintain base flow, and may enhance the water quality within streams and lakes with important fish and wildlife species. Correspondingly, some provide habitat for Federally and State threatened and endangered species, as well as for a wide diversity of important invertebrates, amphibians, birds, furbearers and small mammals. In fact, the diversity of birds (Richter and Azous 2001b) and small mammals (Richter and Azous 2001c) in wetlands may exceed that found in upland habitats. Because of the unique mix of water and biodiversity, wetland areas are also used for a broad range of recreational and esthetic activities including hunting, bird watching, and the appreciation of natural beauty and solitude.

Determinants of Function

The capacity of a particular wetland for performing a specific function is dependent on (1) wetland characteristics (e.g. size, morphometry); (2) adjoining environment; (3) watershed characteristics; (4) position of wetland in the watershed; and (5) greater landscape condition (Mitsch and Gosselink 1993; Keddy 2000; Fairbairn and Dinsmore 2001; NRC 1991, 1995, 2001, 2002). Specifically, the flood control function of wetlands is most directly predicted by hydrogeomorphic class, which reflects geomorphic and hydrologic setting (Brinson, 1993a #1767) Shallow riverine wetlands, and to some extent depressional outflow wetlands, do not reduce peak flows to the extent of depressional closed wetlands of the same size, in which the dominant hydrodynamics include the capture and vertical fluctuation of water level. Moreover, deep, steep-sided depressional wetlands with abundant live storage provide maximum flood control (Hruby et al. 1999). Conversely, those of the same size but with gradual slopes and shallow basins exhibit less storage capacity but can more effectively purify runoff by reducing sheet flow velocity, enabling the settling of pollutants including silt and sediments and the uptake or immobilization of toxicants and nutrients (Hruby et al. 1999). Bio-geochemical and other wetland functions change along environmental gradients (Brinson 1993).

The vegetation diversity and wildlife habitat functions of wetlands are also dependent on wetland geomorphology, and adjoining watershed characteristics (Cronk and Fennessy 2001; Richter and Azous 2001b,c,d). Estuarine wetlands have saline or brackish water. Salt marsh plant communities that become established often provide rearing habitat to juvenile Chinook salmon and other fish (Simenstad et al. 1982; Shreffler et al. 1990; Levings et al. 1991; Brennan 2001). Isolated freshwater depressional and semi-permanently flooded wetlands generally provide habitat for different species, some ecologically and legally (i.e., listed species) very important (Galatowitsch and van der Valk 1994; Weller 1999; Kulzer et al. 2001). Riverine wetlands often provide important rearing and refuge areas for specific salmonid life stages (Spence et al. 1996). Regardless of wetland types, wetlands adjoining forests and other natural habitats usually exhibit high diversity of plants and wildlife because of their sheltered condition and joint use by aquatic as well as upland species (Mitsch and Gosselink 1993; Keddy 2000; Azous and Horner 2001). Wetlands within or adjacent to agricultural and residential developments may be isolated from natural habitats and have different functions (NRC 1992; Spaling 1995). Wetlands may have high usage by hikers, birdwatchers, and additional recreationists (NRC 1992; 2002; Richter pers. observation). These human activities can influence biodiversity (Liddle and Scorgie 1980; Kulzer et al. 2001).

Interaction of Wetland Functions

Wetland functions are interdependent and to varying extent, mutually exclusive (flood storage and small mammal habitat for example). Conditions of some functions directly (i.e., 1st order effect) or indirectly (i.e., 2nd , 3rd, and 4th order effects) dictate conditions of other functions (Mitsch and Gosselink 1993). Clearly, hydrology is the single most important determinant of the establishment, characteristics, and maintenance of specific types of wetlands and wetland processes (Mitsch and Gosselink 1993). Consequently, direct impacts to the hydrologic function such as a change in flow from dredging or the partial filling of a wetland has a primary effect on flood storage and secondary effects on water quality enhancement. In turn, changes in both these functions alter vegetation, potentially changing a wetland's value to wildlife. For example, small wetlands with steep slopes that have high flood control function exhibit flashy water level fluctuations, and in these vegetation associations (Azous and Richter 1995; Azous and Cooke 2001) amphibian communities (Azous and Richter 1995) and waterfowl breeding (Euliss and Mushet 1996) may be harmed.

Variation of Functions Over Time

Although wetland functions may remain "relatively" constant over short time frames of five years or so, it is well documented that the capacity of wetlands to perform specific functions can vary greatly over ten or more years and may change completely over longer periods (Middleton 1999). Disturbance can be essential to maintain some functions (NRC 1995; Middleton 1999). In contrast, other processes such as recurrent flooding potentially redirect a wetland's evolution and subsequent functions (Middleton 1999). Similarly, direct and indirect human impacts, which in today's ecosystems are widespread and pervasive, may alter a wetland's ability to maintain existing functions. For example, in even lightly urbanized watersheds, some wetlands assume the role of stormwater ponds by capturing runoff from development (Azous and Horner 2001). Even in relatively pristine areas, such as backcountry wetlands of national parks, airborne pesticides bioaccumulate through aquatic food chains (Colborn and Thayer 2000; Sparling et al. 2001), contributing to amphibian extinction.

Paradoxically, the inherent functional benefits that wetlands provide, if exceeded beyond their natural capacities and thresholds, leads to their deterioration and ultimate losses of their functions (Horner 1995; Horner et al. 2001). Hydrological benefits such as flood control, for example, are functions of a wetland's live-storage. However, if flooding occurs at levels beyond those that are within the normal historical range, sediment loading may increase, plant communities may change and live storage may decrease. Consequently, the impacted wetland may no longer provide the flood control benefits exhibited by the preexisting wetland. Moreover, altered flood regimes may also change water quality enhancement, wildlife benefits, and other functions. Likewise, water quality enhancement can only be maintained as long as wetland vegetation exhibits the density and species to slow current velocity to settle sediments, immobilize pathogens and enable plants to incorporate nutrients and detoxify toxins (Mitsch and Gosselink 1993). Beyond threshold volumes and concentrations, wetlands may no longer carry out water quality improvement functions and may become polluted, and discharge contaminants to streams, lakes, ponds and wetlands, or transfer them to aquifers. Finally, wildlife, agricultural, recreational, and even educational benefits of wetlands also decline with overuse.

Protection of Wetland Functions

Wetland protection means maintaining the ecological integrity of wetlands so their functions remain self-sustaining. Consequently, hydrological processes, groundwater interactions, water quality enhancement, species and habitat support, and other existing functions need to persist in perpetuity, though they may vary somewhat from year to year or decade to decade within a single wetland.

Over the last three decades, several wetland functional assessment methodologies have been developed (e.g., Wetland Evaluation Technique (WET) (Adamus 1983), Hydrogeomorphic Method (HGM), Indicator Value Assessment Method [IVA] Hruby et al. 1995) as tools to measure the extent that wetlands are capable of performing specific functions. These methods do not directly measure ecological function; rather, they rely on structural indicators (e.g., vegetation diversity, dominance, maturity, and degree of interspersion) as surrogates of function. For example, the presence of mature trees (based on diameter), and tree type (conifer vs. deciduous) may be used as an indicator of habitat available for cavity nesting birds (Thomas et al. 1979). These methods are a significant improvement over previous methods that relied primarily on the judgment of the ecologists with limited substantiation from existing literature (World Wildlife Fund 1992). Nevertheless, there is great variation in the sophistication, repeatability, and scientific foundation of these methods (Hruby pers. com.). Most methods require refinement, calibration, and validation to more closely represent wetland functions (Smith et al. 1995; Hruby 1999).

9.2.3 Existing Protection Methods

Buffers

Currently, the most common and widespread method of wetland protection is the application of fixed protective buffers (NRC 2001). The purpose of buffers is to protect wetland functions from detrimental impacts created by adjoining land use, either existing or expected. In general, the scientific literature on buffers is clear and consistent in that there are three primary factors that are critical in determining adequate buffer widths: (1) type of wetland and functions it provides; (2) type of adjacent land use; and (3) characteristics of the buffer (McMillan 2000, per. com.). Consequently, wide ranges of buffer widths are recommended by scientists and engineers for the protection of wetlands and respective functions (Brown et al. 1990; Castelle et al. 1992a; Castelle et al. 1994; McMillan 2000). Somewhat narrower buffers are suggested or required by particular regulatory agencies. In Washington State, the Shoreline Management Act (SMA), the Water Pollution Control Act (WPCA) and the Growth Management Act (GMA) all provide for some degree of protection for wetlands through suggested buffer widths. However, some scientists suspect none of these laws adequately protect all wetland types and functions (McMillan 2000). In Washington, protection varies considerably. The Department of Ecology (DOE) suggests buffers of 50 ft. for Category IV to 300 ft. for Category I wetlands (Washington State Office of Community Development 2002). In King County, current regulatory protection ranges from 25 ft. for Class 3 wetlands to 100-ft widths for Class 1 wetlands. However, the partial removal of vegetation for control of invasive species, development, and other select permitted uses are allowed within these fixed buffers (King County 1990).

Recent literature suggests that buffers alone, although important to help minimize impacts, might be insufficient to fully safeguard all the varied functions (Correll 1997; McMillan 2000; Thom et al. 2001). Buffer effectiveness and benefits also have been found to vary depending on their widths, vegetation, wetland functions, and geographic context (Castelle et al. 1992). Specifically, wetland hydrology, groundwater recharge/discharge and plant and animal habitat functions may not be well protected by buffers alone because these functions are in large part driven by adjoining area and larger watershed conditions (Reinelt et al. 1998; Azous and Cooke 2001; Richter and Azous 2001b). Under some rare circumstances in which buffers have erosive soils and little or no vegetation, buffers may even be detrimental, in that they may provide sediment sources to lakes, ponds, and wetlands as opposed to removing them (Dillaha and Inamdar 1997). Also, not all wetland species benefit from buffers that are wooded. Most shorebirds, for example, shun small wetlands surrounded by trees (Adamus pers. com.) although other species indigenous to the local area would benefit from forested buffers. Many questions remain unanswered regarding the appropriate width, use, and adequacy of buffer zones (Addiscott 1997). The County's summary of buffer literature is provided in the detailed text below and abstracted in summary Tables 1 through 5.

Fixed buffer regulations also assume that buffers are diversely vegetated strips of land surrounding wetlands and therefore appropriate protection is based on this assumption. However, fixed buffers widths may have no current bearing on wetland protection (although it may be argued that eventually they will) because fixed buffers are set distances around wetlands regardless of buffer condition. Consequently, equal width buffers may vary widely in their characteristics and ability to protect wetland functions. For instance, widths could encompass bare soil, grasslands, cleared forests, second growth forests or even old-growth forest, each of which offering a different type and level of protection. Evidence also suggests that in urban locations local residents and other people pose risks to wildlife and other functions by encroaching on buffers or altering buffers and therefore buffers no longer provide the intended buffer benefit to wetland functions (Milligan 1985; Baker and Haemmerle 1990).

Narrow buffers of 300 feet or less and regardless of characteristics, are unable to maintain their existing characteristics because they are vulnerable to climatic influences from adjacent areas. Sometimes there is outright windthrow as edge trees fall from sudden and unaccustomed exposure to wind. Moreover, wind, humidity, temperature and other microclimatic conditions will change within proposed buffers potentially leading to greater levels of drying and hence changes in soil fungi and invertebrates, surface litter and organic condition, and flora, and fauna. Coincidentally, with narrower effective buffers there may be an increase in aggressive native or exotic species that will outcompete indigenous species and therefore the initial buffer protected today may be very different in the future.

There are a large number of studies reporting relationships between buffer widths and water quality improvement (e.g., reduction of sediments, nutrients, pathogens, toxins, water temperatures – Table 1) but only a small number of studies relating buffer widths to hydrologic, groundwater recharge/discharge and various vegetation and wildlife habitat functions. Perhaps one reason for this deficiency is the unclear distinction between administratively defined buffers as opposed to ecologically functional buffers. Strictly speaking, buffers are regulatory constructs, demarcated by policy-determined distances such as 100 or 200 ft. from the water's edge, (Raedeke 1988b). In contrast, ecologically defined riparian areas are lands transitional between terrestrial and aquatic ecosystems that are distinguished by gradients of biophysical conditions, ecological processes and biota through which surface and subsurface hydrology connect waterbodies with their adjoining uplands (NRC 2002). These often extend beyond administrative boundaries.

Fixed-overlay, narrow-width, administrative buffers may not protect wetland integrity in the long-term. Buffer widths based on wetland functions, however, would significantly help in wetland conservation. Most wetland buffers implemented through development regulations assume that a given type of wetland will support a mix of functions. This assumption may result in homogenizing wetlands, making it unlikely individual wetlands will continue to sustain any superior or unique functions over time. Moreover, fixed buffer protection freezes current wetland conditions (or historic conditions) rather than acknowledging that wetlands are dynamic evolving systems in which both short and long-term natural processes combine to create an array of functions that vary over time.

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Currently there are no guarantees of transitional areas between buffers and surrounding land use to minimize "edge effect." Abrupt edges therefore enable predators (of woodland birds such as cowbirds) to access nests etc. Moreover, a fixed buffer may only protect individuals. A landscape approach, however, considers wildlife in context of a mosaic of habitat patches across which organisms move, settle, reproduce, and eventually die (Forman and Godron 1986) and therefore reduces wetland isolation and fragmentation by providing protection of populations through the health and survival of its interacting individuals. Finally, the fixed buffer widths may only partially protect wetland functions regardless of wetland condition and thereby contributing to the incremental declines of already poor functioning wetlands; a trend that may not be supported by existing statutes and regulations.

Ground water interaction is largely determined by surficial geology and land use setting, although buffer widths may also influence this process (Dunne and Leopold 1978). The hydrology of wetlands in high recharge areas of outwash soil with deep organic matter and vegetative complexity may be sustained by proposed buffer widths. However, in bedrock and till areas with low organic soils and sparse vegetation structure King County's widest buffers (300 ft. plus buffer averaged widths) may not protect the hydrological functions. In these situations, protecting watershed characteristics in the County, especially infiltration areas, organic soils, and diverse vegetation is critical. Reductions in County vegetative cover greater than 35 percent and impervious areas that exceed 10 percent potentially increase water level fluctuations and decrease plant and animal diversity (Schueler 1994; Hicks 1995; Reinelt et al. 1998; NRC 2002). Moreover, runoff from clearing and construction activities and from residential and commercial development would maintain higher winter wetland water levels than with infiltration, therefore decreasing the live storage and flood control capacities. Higher runoff also means less subsurface flows, recharge, and storage. Therefore wetlands may be expected to dry out for greater lengths and more frequently with concomitant hydrological effects on other aquatic areas.

Buffers may filter water prior to entering wetlands depending on slope, vegetation, and width (McMillan 2000). Specifically, sediments and sediment-borne pollution may be expected to be trapped by fixed buffers although the success of buffers will depend on dispersed rather than concentrated flows, steepness of slope, soil permeability, and vegetation cover (Desbonnet et al. 1994). Ideal filtering conditions of gradual slopes, organic soils, and forest and grass-vegetated buffers slow flow velocities (Mitsch and Gosselink 1993). Buffers also control particulate phosphorus associated with sediments. However, dissolved nitrogen and phosphorus, although taken up by vegetation, nevertheless are less effectively controlled by buffers. To enable 80 percent of total sediments and heavy metals to settle out within 100 to 200 ft. respectively (Horner and Mar 1982; Lynch et al. 1985). Herbicides and pesticides require greater distance for attenuation whereas pathogens (fecal coliforms) and estrogens are not as readily filtered out (Table 1). Summaries of the effectiveness of the various vegetated buffers and their effectiveness in pollutant removal as well as in wetland wildlife protection are provided in Desbonnet et al. (1994), Catelle et al. (1992), Castelle and Johnson (2000), McMillan, (2000), NRC (2002) and Fuerstenberg (2003).

Stormwater Management

In response to research findings that stormwater quality and quantity may harm existing wetland functions (Azous and Horner 2001) stormwater management agencies have improved water quality and quantity control standards for stormwater discharge into wetlands (Washington State Department of Ecology (WSDOE) 2001; King County 1991). For example, in addition to meeting minimum treatment and quantity controls, the WSDOE adapted guidelines first published by Azous et al. (2001) to maintain the hydrologic condition, hydrophytic vegetation, and ecologic characteristics necessary to support existing and designated uses of wetland habitats (WSDOE 2001). These guidelines also single out peat systems and other priority wetlands to especially ensure the protection of hydrologically sensitive species. King County's stormwater best management practices include landscape planning, stormwater storage, infiltration, treatment, volume control, and selective runoff bypass methods to protect wetland and other aquatic areas (King County 1998; Whiting 2001).

King County, Washington has translated and implemented these guidelines to protect wetland functions (Horner et al. 2001) through engineering methods and modeling requirements for new development proposals (Boles 2001; Whiting 2001). These procedures provide methods for determining pre-development wetland hydrology and designing surface water systems to maintain critical hydrologic characteristics in the post-development landscape, based on monitoring and hydrologic simulation models incorporating flow and water level fluctuation data. Notably, levels of analysis are customized to watersheds and consider hydrological impact to vegetation

Table 1.Reported Effectiveness of Buffer Zones for Water Quality Protection (NRC 2002; McMillan 2000; Fuerstenberg 2002) [1]

Citation	State	Width (ft./m)	Buffer Type	Reported Reductions'
Young et al., 1980	MN	82/25	Grass	Sediment 92%
Young et al., 1980	MN	89/27	Grass	Nitrogen 84%
Horner and Mar, 1982	WA	200/61	Grass	Sediment 80%
Dillaha et al., 1989	VA	13/4-30/9	Grass	Sediment 84%, phosphorus 79%, nitrogen 73%
Magette et al., 1989	MD	16/5-30/9	Grass	Nutrients <50%
Schwer and Clausen, 1989	VT	85/26	Grass	Concentrations: sediment 45%, phosphorus 78%, Total Kedall N 76%, ammonia 2%
Ghaffarzadeh et al., 1992		30/9	Grass	Sediment 85%
Madison et al., 1992		16/5	Grass	Nitrate and orthophosphorus 90%
Young et.al., 1980		115/35	Grass	Microorganisms <1,000/100 ml.
Grismer 1981		100/30	Grass	Fecal Coliform 60%
Schellinger and Clausen, 1992	VT	75/23	Grass	Fecal coliform 30%
Chaubey, 1994	AR	80/24	Grass	Nitrate 96%, phosphorus 88%, sediment 80%, bacteria 0%
Mickelson et al., 1995	IA	16/5-30/9	Grass	Herbicides 28-72%
Arora, et al. 1996	IA	65/20	Grass	Herbicides 8-100%, sediment 40-100%
Daniels and Gilliam, 1996	NC	20/6-59/18	Grass	Sediment 30-60%, Total Kedall N 35-50%, Ammonia 20-50%, nitrate 50-90%, phosphorus 60%, orthophosphorus 50%
Nichols et al., 1998	AR	59/18	Grass	Estrogen 98%
Lee et al., 1999	IA	10/3-20/6	Grass	Sediment 66-77%, total-N 28-42%, nitrate 25-42%, total-P 37-52%, orthophosphorus 34-43%
Lee et al., 2000	IA	23/7-52/16	Mixed	Sediment 70-90%, total-N 50-80%, nitrate 41-92%, total-P 46-93%, orthophosphorus 28-85%
Lynch et al., 1985		100/30	Forest	Sediment 75-80%
Shisler et al., 1987	MD	62/19	Forest	Nitrogen 89%, phosphorus 80%
Lowrance, 1992	GA	23/7	Forest	Nitrate (groundwater) 100°/a
Doyle et al., 1997		100/30	Forest	Nitrogen 98%
Cooper and Gilliam 1987		52/16	Forest	Phosphorus 50%
Peterjohn & Correll 1984		62/19	Forest	Phosphorus 74%
Peterjohn & Correll 1984		164/50	Forest	Phosphorus 85%

[1.] Reported reductions quantified the experimental reductions and not necessarily values adequate to meet water-quality goals.

and wildlife. Additionally, King County has adopted very stringent nutrient controls and water quality treatment requirements for developments draining to sphagnum bog wetlands.

Wetland Mitigation

In 1988 during his election campaign, then Vice-president George Bush pledged a "no-net loss" of wetland acreage and function. Later as President he endorsed the "no net loss" policy, and in 1990 Congress required that the U.S. Army Corps of Engineers achieve a "no net loss" goal for future water resources projects (Kusler 1983). The "no net loss of wetlands" remained federal policy under the Clinton administration (Dennison and Berry 1993) and represents the national policy on Federal, State, and local levels today. Consequently, when wetlands are filled, channeled, or otherwise destroyed regulations require wetland replacement of both acreage and function. This is difficult and often unsuccessful. The National Research Council estimates that on a national level 85 percent of wetland creation and restorations are judged to be unsuccessful. Their specific findings (NRC 2001, pp. 121-122), were that:

> "1. The performance standards sought in compensatory mitigation have not often been well defined.
>
> 2. Wetland restoration and creation trajectories do not suggest equivalency with reference sites within the commonly used 5-year monitoring period.
>
> 3. The literature and testimony provided to the committee indicate that the national goal of "no net loss" for permitted wetland conversions is not being met.
>
> 4. The gap between what is required and what is realized not precisely known; however, the evidence strongly suggests that the required compensatory mitigation called for by wetland permits to date will not be realized.
>
> 5. Permit follow-up is sparse or too infrequent, and a higher post- monitoring rate will Increase permit compliance rates. Compliance monitoring is commonly known to be nonexistent after 5 years. Better documentation and monitoring will increase compliance rates.
>
> 6. The sparse compliance monitoring is a direct consequence of its designation as a "below-the-line" policy standard. Raising compliance monitoring to "above the line" will greatly enhance mitigation success."

They further recommend that:

> "1. Dependence on subjective best, professional judgment in assessing wetland function be replaced by science-based, rapid assessment procedures incorporating at least the following characteristics;
>
> - Effectively assess goals of wetland litigation projects.
> - Assess all recognized functions.
> - Incorporate effects of position in landscape.
> - Reliably indicate important wetland processes' or at least scientifically established structural surrogates of those processes.
> - Scale assessment results to results from reference sites.
> - Are sensitive to changes in performance over a dynamic range.
> - Are integrative over space and time.
> - Generate parametric and dimensioned units, rather than non- parametric rank.
> - 2. Impact sites should be evaluated using the same functional assessment tools used for the mitigation site."

(NRC 2001, p. 136-137)

In Washington State, Johnson et al. (2000) reviewed permit compliance for each of 45 compensatory wetland mitigation projects for three requirements with the following results

1. Was the compensatory mitigation project implemented? 42 out of 45 (93 percent) were.
2. Was it implemented to plan? 23 of 42 (55 percent) were, and
3. Was it meeting its performance standards (those assessable by the methods of this study)? 12 of 35 (34 percent) were.

Overall, 13 of 45 (29 percent) projects were in full compliance with all three questions.

In a sequel study Johnson et al. (2002) determined the success of wetland mitigation projects from an ecological perspective based on two factors' each with its own criteria: (1) achievement of ecologically relevant measures; and (2) was there adequate compensation for the loss of wetlands? The results indicated that three projects (13 percent) were found to be fully successful; eight projects (33 percent) were moderately successful; eight (33 percent) were minimally successful; and five (21 percent) were not successful.

The results of the Phase 2 study also indicate that "created wetlands are more successful than previous studies have shown, since 60 percent of them were at least moderately successful, and only one project (10 percent) was not successful. However, only 65 percent of the total acreage of wetlands lost were replaced by creating or restoring new wetland area, thereby resulting in a net loss of 24.18 acres of wetland area.

Locally, in King County restoration was not as successful. Twenty-three of 29 (79 percent) wetland/stream restoration sites associated with residential and commercial developments were judged to be unsuccessful (Mockler et al. 1998).

The level of mitigation success also may vary with type of mitigation activity. Specifically (Johnson et al. 2002) found that of three fully successful mitigation projects, two were predominantly created wetlands, while one was a restored wetland. Interestingly, none of the enhancement projects were successful. Out of five projects that were unsuccessful, four were enhancement projects, while one was a creation project. Although, small in sample size, enhancement projects were statistically less successful than wetland creation projects. These results indicate that creation is more successful than previous studies have shown.

Failure of wetland mitigation generally occurs during both in the creation and restoration of wetland acreage and in the replacement of lost functions (NRC 2001; Johnson et al. 2000; 2002; Mockler et al. 1998). Consequently, agencies are developing and implementing policies and recommendations to address this concern. For example, recognizing the fact that mitigation is not 100 percent reliable in replacing wetland acreage and function, " mitigation replacement ratios" are commonly used. These ratios are used to address risk of failure, temporal loss (due to the length of time it takes even "successful" sites to be fully functioning), and the frequent tradeoffs in wetland functions that occurs in mitigation. Numerical ratios, and the mitigation process in general, are based on requiring 'no net loss' of acreage, are ill-suited tools to addressing technical shortcomings of mitigation design, which include lack of suitable water regimes, inadequate soil or plant conditions, poor design and inadequate follow-up by regulatory agencies (NRC 2001; Johnson et al. 2000, 2002). Though higher ratios attempt to attain the policy goal of no net loss of acreage, the goal of no net loss of wetland function cannot be addressed by this policy alone. For one, wetland enhancement results in a net loss of wetland acreage because no new wetland acreage is created to compensate for the wetland area lost as a result of the permitted action.

There are other policies (such as advanced compensatory mitigation or mitigation banking) that create substantial financial incentives for successful design, but these policies are appropriate only where wetland impact is unavoidable, and should not be perceived as a sole solution to the mitigation dilemma.

The problem is complex, and the solution must reflect that complexity. Mitigation success can be attained through a combination of factors, not the least of which is enforcement, compliance, and monitoring of existing regulations. That, in combination with improved performance standards and additional guidance or regulatory requirements related to pre-project monitoring (such as that requiring additional hydrologic data) is needed. Monitoring must occur pre-, during, and post-construction to identify and correct design problems. Regardless of mitigation ratios, what is needed is to increase restoration, creation, and enhancement success.

Functional assessments are designed to provide additional technical information that can be used in mitigation design to replace assessed functions (rather than just acreage, towards which mitigation replacement ratio targets are focused). Functional assessments also can be used to develop performance standards for mitigation wetlands, and to monitor the attainment of those. Wetlands, however, provide function and values (services) in context of their landscapes; therefore replacement has been required and encouraged first on site, then within local sub-basins and watersheds rather than being transferred elsewhere (NRC 2001).

Ways to reduce risks of failure in wetland restoration projects have been identified by the NRC (1992 p. 309) and are listed below:

- Adherence to goal of no net loss in wetland acreage and function
- More detailed assessment of function prior to wetland damage or destruction
- More detailed plans
- Higher standards for success
- More expertise
- Larger buffers
- More detailed and longer-term surveillance and monitoring
- Greater midcourse correction capability
- Longer-term and greater maintenance Responsibilities
- More detailed reports with broader distribution
- Larger bonds
- Complete restoration or creation before allowing damages (in mitigation projects)
- Require 3:1, 5:1, or 10:1 habitat replacement ratios, depending on functional value of habitat loss (when projects are part of compensatory mitigation)

Watershed and Landscape Protection

Recognizing the limitation of protecting wetland functions by buffers alone, other less common but more comprehensive and better effective methods of wetland protection have been developed and implemented. Foremost among these are policies that govern landscape and watershed-level activities, such as those recently institutionalized by certain state and county governments through their resource management plans. In Maryland (Maryland Department of Natural Resources 2001) and in San Diego, California (San Diego County 1998), wetlands, and other resource lands were incorporated into comprehensive regional planning efforts. The greater Portland Metropolitan Area also is protecting wetlands and other resources using a comprehensive watershed and broader landscape approach (METRO 2002).

Innovative, comprehensive, and beneficial wetland protection methods are also found in King County. In the Bear Creek Plan (King County Surface Water Management Division et al. 1990) regionally Significant Resource Areas (RSRAs) were identified with an emphasis on protecting watershed functions, including aquatic functions of both streams and wetlands, and important salmonid functions. In the East Lake Sammamish Basin Plan (King County Surface Water Management Division 1994), the County established Wetland Management Areas (WMAs) to protect important wetland systems on the Sammamish plateau. More recently adopted basin plans, such as the Cedar River Basin Plan, also attempt to take a more comprehensive method of protecting wetland (and stream) hydrological function, by restricting clearing (i.e., vegetation removal) to no less than 35 percent where subdivisions are permitted. Bear Creek and Issaquah Creek Basin Plans reflect this policy as well (King County Surface Water Management Division et al. 1996). To date, data on implementation of these policies is not available. However, such policies are clearly supported by the literature related to hydrologic functions. Although RSRAs and WMAs provide protection to specific infiltration and wetland recharge areas, maintaining the 35 percent clearing restriction standard to overall watershed basin vegetation clearly provides a larger measure of hydrology and water quality protection to wetlands and also may provide significant habitat for wetland wildlife if retained areas are accessible (i.e., not isolated by habitat fragmentation).

Ecosystem Level Management Based on Functional Criteria

Clearly, the value of wetlands lies in the functions they perform. Consequently, protection actions should target methods that maintain the ecological and hydrological integrity of wetlands. Best Available Science (BAS) emphasizes that wetlands are complex, dynamic, and highly variable (Mitsch and Gosselink 1993; Keddy 2000; Middleton 1999), and clearly suggests that buffer policy and aquatic habitat protection can and should be based not solely on the wetland and its immediate 'buffer' but additionally on ecosystem-level management strategies linked to specific ecosystem functional criteria (Dickson and Schaeffer 1997; NRC 1992; NRC 2001). Furthermore, review of the literature indicates that wetlands and their respective functions are determined at three landscape scales: (1) the wetland; (2) the adjoining environment; and (3) the greater watershed. Therefore, protecting ecological integrity of functions must occur at the appropriate and relevant scales. Wetlands exhibit inherent geology, soils, morphometry, vegetation, and other characteristics, that combine to determine their ecological function. These characteristics can be directly altered by dredging, filling, channelization and other actions, thereby affecting flood control and other hydrologic functions, water quality enhancement, food chain support, vegetation and wildlife habitat functions. The wetland itself is also the area where most wetland-dependent animals such as amphibians breed, waterbirds, such as marsh wren, and waterfowl nest, and where the food chain support function for most wetland wildlife originates.

Wetlands have immediately adjoining areas (e.g., local areas) that may protect, augment, or harm inherent wetland functions. Undisturbed, these adjacent areas provide pollutant and nutrient abatement services as well as critical habitat for obligate and associated wetland wildlife. They vary in width depending on geophysical characteristics (e.g., geology, soils, and slope), and vegetative cover. In general, adjoining areas offer water quality benefits but may provide little hydrological benefit because of their limited infiltration capacity compared to that of their watershed. These adjoining areas protect wetland wildlife (e.g., amphibians, waterfowl, swallows, muskrat) from disturbance through visual isolation, noise attenuation, and encroachment by predators and humans. This nearby zone also provides habitat where other wildlife breed, nest, or calf, and from which they move into the wetland to drink and feed. Finally, these areas also provide habitat for early successional plant and animal species because of repeated disturbances such as flooding. Wetlands additionally occur in diverse watersheds and landscapes, each exhibiting repeatable pattern of habitats, physical features, and human influences (Forman and Godron 1986). Watersheds include characteristics such as forests, cleared and impervious areas, additional wildlife habitat, and corridors to other wetlands.

The advantage of using multiple spatial scales is that wetland functions are determined in part by dynamic landscape conditions that influence wetland hydrology, groundwater recharge/discharge and wildlife populations. Consequently, there is a need to manage the impact of land use change on a landscape scale such that "the boundaries of an assessment unit encompasses an area that is, to the extent possible, ecologically closed to the water and nutrient flows so that forces external to the basin can be minimized and large enough to satisfy the home range and habitat requirements of the farthest ranging animal species of interest" (Gosselink et al. 1990 in Pearsell and Mulamoottil 1996, p. 142). For hydrology, the relevant landscape scale may include the basin subbasin or larger watershed. For groundwater interactions, the appropriate area of influence may include recharge areas beyond the watershed or other drainage systems. For wildlife the appropriate management scale may be considered to encompass wildlife home ranges - habitat used by a species, together with the other organisms with which it coexists, and the landscape and climate units that affect it; the place where an animal or a plant normally lives and reproduces. This scale may be large and quite variable depending on wetland species. However, without consideration of the species' minimum requirement for contiguous habitat, some sensitive species will decline.

Wetland Functions and Their Protection at Four Spatial Scales

Wetland types and their respective functions are determined at four spatial scales: (1) wetland; (2) adjoining environment; (3) watershed; and (4) landscape. The jurisdictional wetland is determined by King County's implemented US Army Corpse of Engineers wetland delineation method (USACE 1987). The County identifies adjoining area according to the definition of riparian area presented by the National Research Council (2002). Adjoining areas are therefore defined as transitional between terrestrial and wetland ecosystems that are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect waterbodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with wetland ecosystems (i.e., zone of influence). Adjoining areas are adjacent to all wetland types. The important feature of this definition is the notion that adjoining areas have gradients in environmental conditions and in functions between uplands and wetlands. Consequently, an adjoining area does not have a fixed boundary, such as the jurisdictional wetland edge or it is pre-determined fixed-buffer, which may or may not encompass the adjoining area. Rather, it is more expansive and based on fundamental ecological functions of: (a) hydrology and sediment dynamics; (b) biogeochemistry and nutrient cycling; and (c) habitat and food web maintenance. Although on strictly theoretical grounds the adjoining area could encompass the entire watershed, the County limit the width to the adjoining wetland transition zones in which overlapping wetland-upland interactions occur including shallow groundwater aquifers, meteorological (microclimatic) influences, and reproductive (e.g., breeding, nesting, calving) wetland-associated wildlife needs.

These areas are also delineated in Figure 1. Functional boundaries A and F are also wetland jurisdictional boundaries. Functional boundaries A and F also provide required flooded conditions for wetland-breeding amphibians. Functional boundaries B and C are adjoining areas buffer wetlands and fulfill select requirements of several species of wetland wildlife. Boundary B may provide upland feeding habitat of amphibians and breeding habitat of some small mammal species whereas boundary C may provide additional foraging habitat as well as hibernation (surviving winter cold by minimizing activity) and aestivation (minimizing activities when conditions are hot and dry) habitat for species. Boundary D, the sub-basin, basin or watershed boundary represent the source area for most of the water entering the wetland. Simultaneously, boundary D provides additional habitat requirements for wetland-associated species not available within B and C. Boundary E and F are in the greater landscape beyond the watershed. Area E in the greater landscape circumscribes an aquifer recharge area that drains into the wetland and contributes to groundwater interchange functions. Boundary F, also beyond the drainage area, circumscribes second wetland, which is of critical importance to retaining healthy and viable wildlife populations found in the original wetland. Clearly, meaningful wetland protection must include management scenarios for identifying adequate protection at all four scales.

Flood control, water quality enhancement, and wetland biota functions of wetlands are primarily determined by wetland hydrology. Hydroperiod is the pattern of fluctuating water levels resulting from the balance between surface inflows and outflows, wetland topography, subsurface soil, and groundwater conditions (Mitsch and Gosselink 1993). Inflows and outflows may differ in the following respects, each of which controls processes and influences wetland structure and biodiversity. Flow magnitude is the amount of water moving past a given location per unit time. It can influence rates of solute, suspended sediment, and bedload sediment transport. Flow frequency refers to how often a flow of a given magnitude is equaled or exceeded over some time interval. Flow frequency, in combination with flow magnitude, indicates the amount of energy moving through a wetland. Flow duration represents the period of time associated with a specific flow magnitude. From the perspective of wetland plant communities, flow duration represents the length of time that a wetland remains flooded or soils remain saturated. Therefore it is a crucial variable for many riparian plants that have adapted their physiology to accommodate extended periods of high moisture levels. Flow timing generally refers to the seasonality of a given flow. For example, snowmelt runoff to many wetlands and rivers in King County occurs from March through early June. Fish and other organisms have adapted their life history strategies to the timing of these flows. Flow timing also determines the relative wetness or dryness of adjoining riparian areas and therefore is a crucial structuring process (NRC 2002).

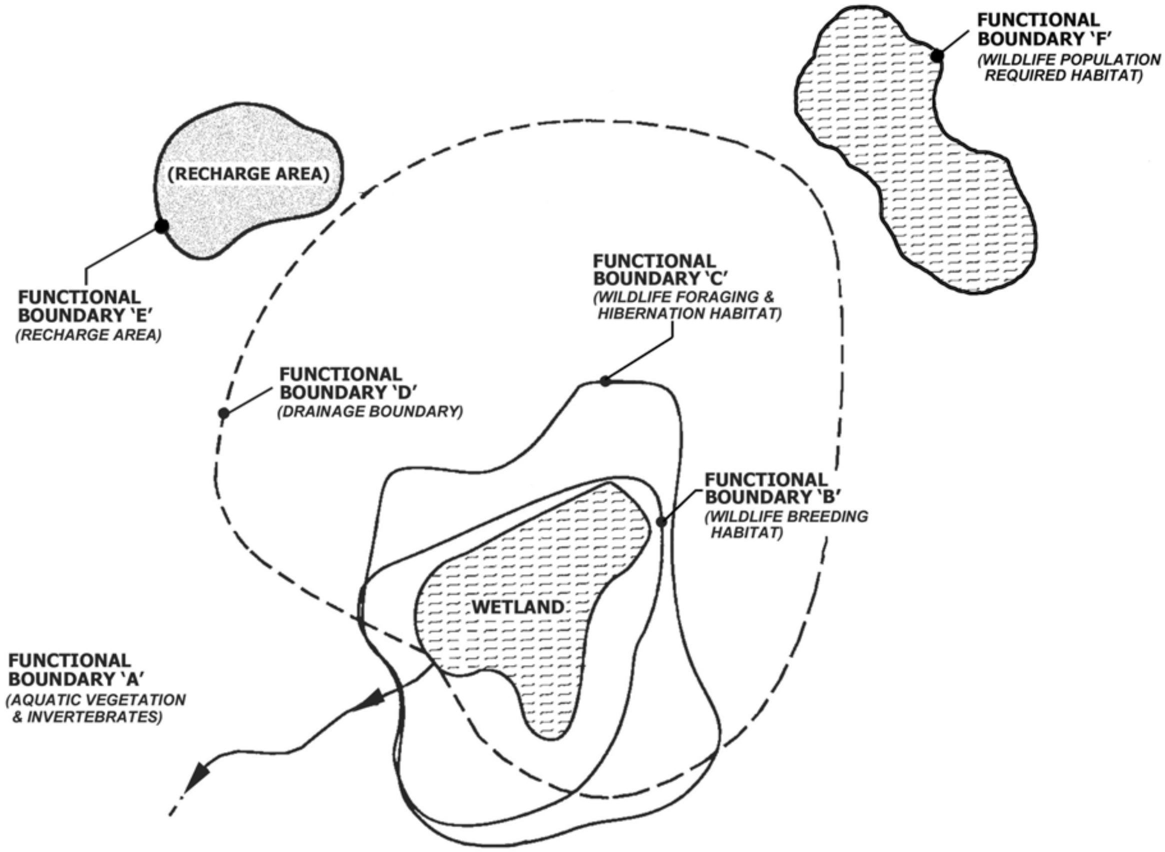

Figure 1. Wetland functional boundaries (adapted from Pearsell and Mulamoottil 1996).

Wetland Hydrology (Flood Control)

The departure from normal and the rate of change of these processes are also critical to wetland functions. Current velocity and water level fluctuations represent how quickly a flow changes from one magnitude to another. Therefore, riverine wetlands that derive their runoff from urbanization and associated impervious areas exhibit increased velocities, whereas depressional wetlands generally become “flashier” than those that drain vegetated watersheds do. Rate of change in current velocity and water levels can influence wetland sediment transport and biotic communities (NRC 2002). Specifically, many organisms are rheotropic; that is, they respond to the stimulus of a current gradient, and may not remain within a wetland, or are displaced to suboptimal locations (Wellnitz et al. 2001). Seedlings of deciduous woody species, aquatic invertebrates, and wetland-amphibians may need a relatively low current velocity for successful establishment, breeding, and survival (Middleton 1999; Mitsch and Gosselink 1993; NRC 2002; Richter and Roughgarden unpublished manuscript).

Although characterized by different hydroperiods, the less frequently flooded or saturated portions of wetlands are no less functionally active than wetter portions; the functions are simply different and efforts to classify wetlands according to their hydroperiod do little to reveal their fundamental properties (Brinson 1993b).

- **Wetland**. Dredging, filling, and channelization alter a wetland's storage capacity and flood control functions. Moreover, roads, culverts and other outlet barriers and constrictions also regulate flow rate thereby altering not just flood control, but other hydrologically dependent functions (Taylor 1993; Taylor et al. 1995). Specifically, altered flows can either improve or impair water quality enhancement, food chain support, and vegetation and wildlife habitat functions. Filling destroys the capacity of a wetland to capture sediments and treat pollutants as well as removes or reduces habitat for fish, amphibian, waterbird, muskrat, beaver, and other wetland-dependent animals. Altered flow leading to unnatural flooding or drying may also alter algae, invertebrates and overall food chain support functions on which fish and wildlife depend.
- **Adjoining Area.** The adjoining area to a wetland may be the extension of its riparian area, "a zone of influence" between aquatic and terrestrial areas (NRC 2002) or be entirely terrestrial. Adjoining areas may significantly influence wetland hydrology depending on the geology, topography, soil porosity, and vegetation cover. Gradual slopes, gravely and porous soils, and diverse vegetation can slow velocities and increase infiltration. Elevated water tables forming a hyporheic zone or deeper horizontal aquifers may move water towards the wetland augmenting its hydrology and adding to base flows (Lowrance et al. 1985). Adjoining areas of riverine wetlands may be extensions of the flood plain or comprise raised terraces. These areas are often underlain by alluvial aquifers that are longitudinally and vertically closely linked to and controlled by the river (NRC 2002).
- **Watershed.** The flood control function of a wetland is partly dependent on wetland-watershed ratio, size, depth, and live storage (Reinelt et al. 1998). Equally important, however, is the role of land cover and human use of watersheds as a determinant of a wetland's inherent ongoing ability to maintain its flood control function. Historically extensive clearcutting and associated silvicultural practices have influenced runoff and wetland hydrology (Brandt 1988; Kostadinov 1994). Currently, watershed development, and associated increased imperviousness, alter all aspects of wetland hydrology by intercepting precipitation, reducing the water that infiltrates into the soil and causing higher runoff volumes and more frequent peaks to either enter or bypass wetlands (Arnold and Gibbons 1996; Booth 2000). Increased volumes, higher peaks and greater "flashiness" of peak discharges result in greater physical (erosion) and water quality damage (e.g., sedimentation) sedimentation to wetlands reducing their flood control functions.
- **Greater Landscape.** Certain wetlands under select conditions of hydrology, may be influenced by recharge areas beyond the watershed and within an adjacent basin. These external areas may discharge water to aquifers that lead to wetlands in a different basin through subterranean drainage (Dunne and Leopold 1978). Consequently, if they are altered or destroyed they hydrology of the wetland in the adjacent basin would be altered.

Table 2 provides a brief outline of the variables of flow and how and a select summary of the BAS for the conservation of wetland hydrology.

Table 2. Summary of Best Available Science for the Conservation of Wetland Hydrology.

Function	Depressional Wetland & Potentially in Some Others (e.g. Riverine)					
	WITHIN WETLAND		ADJOINING AREA (984 FT., 300 M)		WATERSHED AND GREATER LANDSCAPE	
Hydrology	**Factors of Influence**	**Protection**	**Factors of Influence**	**Protection**	**Factors of Influence**	**Protection**
All flow characteristics including: Magnitude Rate of change Velocity Frequency Duration Timing	Primarily a function of wetland geology, soils, morphometry, vegetation	Prohibit dredging and filling	Characteristics of geology, topography, soils, organic litter and vegetation primary determinant of flows	Complex structure of grasses, herbs, shrubs and trees best reduce flows	Watershed geology, topography, soils and vegetation primary determinant of flows	Minimize watershed clearing and impervious surfaces. Disturbance thresholds at 3% and 12 % imperviousness lead to dramatic increases in water level fluctuations (Taylor 1993), Reinelt et al. 1998). Generalized aquatic area (i.e., stream) impacts suggests degradation 1st occurs at 10% and becomes severe at 30% (Arnold and Gibbons 1996).

Groundwater Recharge/Discharge

- **Wetland**. Wetlands play an important role in groundwater interactions (Hensel 1991) Wetlands in the Puget Sound lowlands function as both recharge and discharge areas for groundwater (Reinelt and Horner 1993). In the Pacific Northwest, groundwater generally discharges into wetlands during the winter. Some wetlands then recharge groundwater during the summer. All other things being equal (i.e., adjoining area and watershed conditions), the recharge and discharge abilities are directly related to wetland substrate, size, morphometry and vegetation, all factors that are influenced by wetland filling or alteration. In some watersheds, headwater wetlands play an important role in ground and surface water recharge.
- **Adjoining Area**. The role of adjoining areas in groundwater interaction functions of wetlands depends on geology, slope, soil porosity, vegetation density and species, and size of the area. Trees and other vegetation intercept, store and return moisture to the air via evapotranspiration thus modifying the delivery of water to the ground (NRC 2002), reducing soil moisture and subsurface storage. The adjoining area, because of its relatively small area when compared to a larger watershed, presumably plays a more-limited part in precipitation and snowmelt infiltration, and groundwater recharge. However, with alluvial gravelly soil aquifers may extend from the wetlands far into adjoining areas.
- **Watershed**. Characteristics of the watershed, including geology, topography, soil porosity, and vegetation determine the rate at which precipitation and snowmelt is intercepted, temporarily stored, infiltrated and finds its way to wetlands (Dunne and Leopold 1978). Because watersheds are so much larger than most adjoining buffer areas they intercept and store greater total amounts of total water and provide more area for infiltration than do narrower zones adjoining wetlands (although on a per unit area basis this may not be the case).
- **Greater Landscape.** In some areas, the topographic limit of the watershed may not coincide with the boundary between subsurface drainage systems (Dunne and Leopold 1978). In these landscapes the groundwater interchange function of a wetland may be highly influenced by subterranean drainage from another basin as well as from traditional runoff and infiltration characteristics within the watershed. Presumably, in these situations land use practices in one basin and more directly over such a recharge area would influence the groundwater interaction function of a wetland in another watershed. Consequently, adjoining areas, the watershed and potentially the greater landscape may all play important roles in groundwater dynamics.

Table 3 provides a brief outline of the variables of flow and how and a select summary of the BAS for the conservation of wetland groundwater interchange. .

Water Quality Enhancement

- **Wetland.** Wetlands can be sources, sinks, or transformers of water quality factors (NRC 1995). Wetland water quality benefits include filtering of nutrients, heavy metals, microbes, and viruses. Low current velocity flows through wetland vegetation enables nutrients

Table 3. Summary of Best Available Science for the Conservation of Wetland Groundwater

Function	Depressional Wetland & Potentially in Some Others (e.g. Riverine)					
	WITHIN WETLAND		ADJOINING AREA (984 FT., 300 M)		WATERSHED AND GREATER LANDSCAPE	
Groundwater	**Factors of Influence**	**Protection**	**Factors of Influence**	**Protection**	**Factors of Influence**	**Protection**
Groundwater interactions; wetland recharge/discharge	All flow characteristics including: Magnitude Rate of change Velocity Frequency Duration Timing	Prohibit dredging and filling Buffers ineffective in removing dissolved contaminants from groundwater in tile-drained agricultural watersheds (NRC 2002)	Characteristics of geology, topography, soils, organic litter, and vegetation primary determinant of flows Groundwater extraction	Complex vegetation structure of grasses, herbs, shrubs and trees with organic layers Groundwater/aquifer "mining".	Watershed geology, topography, soils and vegetation primary determinant of flows	Minimize watershed clearing and impervious surfaces. Disturbance thresholds at 3% and 12 % imperviousness lead to dramatic increases in water level fluctuations (Taylor 1993), Reinelt et al. 1998). Generalized aquatic area (i.e., stream) impacts suggests degradation 1st occurs at 10% and becomes severe at 30% (Arnold and Gibbons 1996).

(Phipps and Crumpton 1994) and suspended sediment and chemicals to adhere to particles to settle out (Adamus et al. 1991; Livingston 1995). Additionally, toxicants, nutrients, and other mobile chemicals in solution are absorbed by vegetation and in some cases converted to benign forms (Vymazal 1995). The nutrient uptake of water quality enhancement is further influenced by floating vegetation, retention of nutrients in wood and litter, and by the adsorption of pollutants on clay and organic peat in the sediment (Mitsch and Gosselink 1993). These wetland conditions have been simulated in the construction of wastewater and other treatment wetlands solely for the purpose of water purification (Hammer 1989). Clearly, direct filling wetlands will destroy live storage and vegetation. Sediments in runoff also reduce the storage capacity and associated functions. Deepening of wetlands, changing side-slopes and other alterations to topography will alter hydroperiod and thereby indirectly shift vegetation communities. Collectively, all these changes alter the water quality enhancement function of a wetland.

- **Adjoining Area.** Characteristics of adjoining areas can significantly buffer a wetland from being overwhelmed by water-borne pollutants. The efficacy of adjoining areas in removing pollutants from surface water is highly dependent on geology; topography, soils, and vegetation cover (see agricultural buffer section). Moreover, for effective removal of particulates, dissolved nutrients, and toxic materials, surface flows must occur slowly or as sheet flow rather than rapidly or in highly focused flows (Correll 1997). Discussions within the agricultural section describe these interacting factors and the adjoining area protection measures necessary for pollutant removal.
- **Watershed.** The water budget of a wetland is to a large degree controlled by adjoining and watershed and landscape characteristics (Reinelt and Horner 1993). Sedimentation, nitrogen, phosphorus, and other pollutant concentrations increase as watersheds are cleared (Gosselink and Lee 1989; Jones et al. 1976). Pollutants from drainage may be especially damaging from developments with large impervious areas. Loss of tree cover leads to greater water temperature fluctuations, making the water warmer in summer and colder in winter (Galli 1991) and thereby directly influencing the immediate environment of aquatic vegetation, invertebrates, and vertebrates. Other urban pollutants such as heavy metals (e.g., lead, zinc, copper) from street runoff may also enter wetlands through channelized sources from watersheds (Ebbert et al. 2000). Significant agriculture and grazing activities in the watershed can potentially also lead to water quality deterioration.

  The ability to provide water quality function and extent of enhancement is also attributable to a wetland's position in the watershed (NRC 2001; Meyers and others 2003). Consequently, wetlands occupying a relatively lower watershed elevation such as riparian, floodplain wetlands and depressional wetlands provide better water quality functions than those at higher elevations in that they capture pollutants from a greater drainage area. Similarly, wetlands at the head of streams and rivers also provide good enhancement because of their location and area of drainage.
- **Greater Landscape.** It has become increasingly apparent that the water quality conditions in wetlands and other aquatic areas are influenced by environmental conditions often far beyond the watershed. Most of these impacts are airborne pollutants, and have included acid precipitation (Haines 1981); UV radiation (Blaustein et al. 2003), and more recently agricultural chemicals (Sparling 2001; Dickerson et al. 2003). Furthermore, these pollutants may independently, or in combination, influence potential biological functions (Davidson et al. 2002). Acid rain, for example, may be particularly detrimental to wetland biota including vegetation (USEPA 2003); fish (USEPA 2003); invertebrates (Borgeraas and

Hessen 2002) and amphibians (Pough 1976; Freda 1986). Correspondingly, UV-B radiation has been implicated in harming vegetation (Rattenborg et al. 1999); fish (Armstrong et al. 2002) and amphibians (Blaustein et al. 1994).

Table 4 provides a brief outline of the variables of flow and how and a select summary of the BAS for the conservation of wetland water quality.

Generalized Wetland Vegetation, Habitat, Fish and Wildlife Function

- **Wetland**. Riparian areas in general provide more biologically important functions than do uplands in proportion to their area within a watershed (NRC 2002). A large number of plants are endemic to wetlands and even to specific wetland types (Adamus 2003). Additionally, large number of fish and wildlife are obligate wetland, or wetland dependent, species and heavily dependent on wetland habitat for their resources for life's needs (Brown 1985a, b). Specifically, Zeigler (2003) states that "approximately 85 percent of Washington's terrestrial vertebrate species use riparian habitat for essential life activities and the density of wildlife in riparian areas is comparatively high. Forested riparian habitat has an abundance of snags that are critical to cavity-nesting birds and mammals and to many insectivorous birds. Downed logs are common and provide cover and resting habitat for amphibians, reptiles', and small mammals. Intact riparian habitat as well-developed vegetation, usually with multiple canopy layers. Each layer consisting of unique habitat niches that together supports a diversity of bird and mammal species. Riparian habitat also form natural corridors that are important travel routes between foraging areas, ahead and seasonal ranges, and provides protected dispersal routes for young. Protected access to water is also an essential attribute of intact riparian habitat.
- Riparian habitat is limited geographically, however and is vulnerable to loss through human activities and land uses. Since the arrival of settlers in the early 1800s, at least 50 percent and as much as 90 percent of riparian habitat in Washington has been lost or extensively modified. Protecting riparian habitat may yield the greatest gains for fish and wildlife across the landscape awhile involving the least amount of area." Clearly, wetlands provide required habitat for aquatic-breeding wildlife such as invertebrates, amphibians, and waterfowl. Moreover, wetlands provide essential habitat for rearing or for the adult life stages of numerous species of fish, amphibians, turtles and some mammals. For many terrestrial species wetlands provide water for drinking and vegetation for food and cover. Wetland emergent plants including rushes, sedges and grasses and their attached algae are highly sought as food by invertebrates, fish, frog and toad tadpoles, herbivorous small mammals (e.g., voles) and large mammals including ungulates (deer and elk). Wetlands and associated vegetation, similar to other aquatic ecosystems, also ameliorates local weather conditions (e.g., evaporative cooling, winter warming) providing unique microclimates sought out by many invertebrate and wildlife species.
- **Adjoining Area.** Conservation should include adequate adjoining areas to protect the wetlands' unique conditions. In many cases in the Puget Sound such conditions include natural vegetation of shrubs and trees providing habitat for a unique community of amphibians, birds, and mammals. Occasionally, adjoining areas may be comprised of open areas of exposed rock, soil, and grasses providing habitat for a different assemblage of wildlife. Adjoining areas also often juxtapose early successional stage communities (because of periodic disturbance regimes) and late successional stages (because of historically

Table 4. Summary of Best Available Science for the Conservation of Wetland Water Quality

Function	Depressional Wetland & Potentially in Some Others (e.g. Riverrine)					
	WITHIN WETLAND		ADJOINING AREA (984 FT., 300 M)		WATERSHED AND GREATER LANDSCAPE	
Water Quality	**Factors of Influence**	**Protection**	**Factors of Influence**	**Protection**	**Factors of Influence**	**Protection**
Temperature	Groundwater discharge	Prohibit dredging, filling of wetland	Adjoining area geology, slope, soils litter and forest vegetation cover	36-151 ft (11-46 m) (May 2000, (Knutson & Neaf 1997) assumes 100% attenuation. 82 ft for 100% attenuation.	Watershed geology, soils and vegetation primary determinant of flows	Minimize watershed clearing and impervious surfaces. Disturbance thresholds at 3% and 12 % imperviousness leads dramatic increases in water level fluctuations (Taylor 1993, Reinelt et al. 1998, Booth 2000 and Booth et al. 2002) Generalized aquatic area (i.e., stream) impacts suggests degradation 1st occurs at 10% and becomes severe at 30% (Arnold and Gibbons 1996).
Sediment	Organic decomposition, water warmer temperatures, nutrient input,	Dumping of materials. Eutrophication builds up organic sediment. Maintain bank stability	Adjoining area geology, slope, soils vegetation structure and cover	200ft grass for 80% removal (Horner & Mar 1982)	Most sediment originates in watershed.	Stormwater detention ponds and biofiltration swales may capture road runoff

Table 4, continued

Function	Depressional Wetland & Potentially in Some Others (e.g. Riverrine)					
	WITHIN WETLAND		ADJOINING AREA (984 FT., 300 M)		WATERSHED AND GREATER LANDSCAPE	
Water Quality	**Factors of Influence**	**Protection**	**Factors of Influence**	**Protection**	**Factors of Influence**	**Protection**
Metals Adhered to sediments Dissolved, in solution	Particle size (bind tightly to clay) Bioavailability low Bioavailability high	Maintain depth and wetland vegetation for filtration and settling Maintain depth and wetland vegetation for plant uptake	Cation Exchange. Primarily bound to sediments. Watershed geology, slope, soils, litter and vegetation structure and cover are primary determinants of flows	Presumably same as for sediment *i.e.*, 200ft grass for 80% removal (Horner & Mar 1982).	Most metals originate in watershed.	Stormwater detention ponds & biofiltration swales may capture road runoff
PAH & phthalate esters			Watershed geology, slope, soils, lope and vegetation structure and cover are primary determinants of flows			
Nutrients Nitrogen Phosphorus	Wetland vegetation	Eutrophication releases and builds up nutrients	Watershed geology, slope, soils, slope, litter and vegetation structure and cover are primary determinants of flows	62-100 ft forest for removal of 89-98 % nitrogen (Shisler et al. 1987; Doyle et al. 1997) 52- 164 ft. forest for removal 50-85 % phosphorus (Cooper & Gilliam 1987; Peterjohn & Correll 1984)	Watershed geology, soils and vegetation primary determinant of flows	
Herbicides /		Source Control	Watershed geology, soils, litter and vegetation are primary determinant of flows	16ft grass for removal 28 % and 30 ft. for removal of 72% (Mickelson et al. 1995. 65 ft. grass for removal of 8-100% (Arora 1996).		
Pathogens	Little data	Source Control				
Estrogens	Little data	Source Control				

- undisturbed vegetation), both of which benefit different species as well as mutually similar species. Similar to wetland ecosystems, adjoining areas affect the microclimate in wetlands. They ameliorate wind currents that can penetrate a distance 10 times the height of vegetation. Thus a wetland within a forest of 20 m tall trees may require a 200 m wide buffer zone to protect it from wind, and concomitant desiccation, temperature influence and other wind-related meteorological edge effects (Saunders et al. 1991 in Simberloff 1993). In the Pacific Northwest meteorological changes are generally considered to extend up to two tree-lengths (i.e., 525 ft. [160 m]) inside a forest patch (Harris 1984; Franklin and Forman 1987), suggesting a narrower-width adjoining zone may not sufficiently protect wetlands from microclimatic effects. Regardless, for wetlands where ecologically appropriate, adjoining buffer zones should exceed 115-ft. (35 m) to avoid windthrow (Pollock and Kennard 1998 in McMillan 2000) although the downed trees and wood may provide unique habitat previously unavailable in the adjoining area. Ideally, buffers should be wide enough to prevent threats from edge effects (e.g., microclimates, unnatural successional changes) and external effects (effects that originate outside of wetlands and/or that do not recognize boundary lines including pollutants, diseases, exotic species and fires).

  To protect fish-bearing streams, the Pacific Northwest Forest Plan identified an interim 91-m (300-ft.) buffer (actually a riparian reserve capable of being logged) that can be increased or decreased based on the needs of both aquatic and terrestrial species (Forest Ecosystem Management Assessment Team 1993). In other locations, to protect wildlife a 322 to 732 ft. zone was recommended for adjoining forested wetlands in Florida (Brown et al. 1990), and 322 ft. were recommended for adjoining emergent wetlands in Maryland (Maryland Department of Natural Resources; 2001a; Maryland Department of Natural Resources; 2002b; Maryland Department of Natural Resources; 2002a).

  Protected wetlands and their administrative buffers are frequently too small, fragmented, and isolated to support wildlife populations in which natural migration rates balance local extinctions (NRC 2001; Semlitsch 2003; Dodd and Smith 2003). Small, isolated wildlife populations, go extinct from detrimental systematic processes including isolation and habitat fragmentation and from stochastic processes including environmental “catastrophes” and population fluctuations with a concomitant loss of genetic diversity (Haila et al 1993; Gulve 1994; Sjörgen 1991;Hinsley et al. 1995; Brook et al. 2000; Lehmkuhl et al. 2001). Consequently, ecologists argue for the protection of more than one population center such as wetland complexes to avoid loosing an entire population to a single influence (Semlitsch and Bodie 1998; Fairbairn and Dinsmore 2001; Lehmkuhl et al. 2001; Marzluff and Ewing 2001) to offset such developments. Moreover, small populations, low population densities, populations with high rather than low variability in numbers, and species which require landscape complementation, in which patches of one type are used for one activity (breeding sites of birds), while patches of a second type are used for another essential activity (roosting areas for birds) are especially vulnerable to local population declines and extinctions (Lehmkuhl et al. 2001). Often narrow zones only provide breeding habitats for individuals, with larger watershed areas extending beyond jurisdictional buffers, required by juvenile and adult populations for feeding, maturation, overwintering and other aspects of species survival (Brown 1985a,b). In spring, deer and elk for example, give birth to their young and forage with them in the riparian areas of wetlands where herbs, forbs, and cover are abundant. In winter these ungulates return to riparian areas for feeding and protection. Often these ungulates also carry on daily and seasonal migrations between wetlands and higher elevation terrestrial range.

- **Watershed and Greater Landscape**. Without consideration of the larger watershed, efforts concentrating solely on wetlands and immediately adjoining area will fail to protect many wetland wildlife functions for vagile species (e.g., free to move around, wide-ranging herbivores and carnivores including elk, deer, mink, otter). For these the home range often extends beyond the wetland and its adjoining environment and it is only the watershed and larger landscape that have enough resources and habitat necessary for populations to thrive. Computer modeling of the amount of breeding habitat and fragmentation of breeding habitat of hypothetical organisms suggests that the effects of habitat loss far outweighs the effects of habitat fragmentation implying that protecting large habitat blocks may be preferable to maintaining smaller blocks with corridors (Fahrig 1997). Fragmentation thresholds, the point at which fragmentation effects become more dominant than area effects, however do occur when habitat area represents less than 20 percent of total habitat (Fahrig 1997). Consequently, modeling suggests that in watersheds exceeding 20 percent habitat, large areas should be selected for conservation, whereas in watersheds with less than 20 percent remaining habitat, management emphases should maximize connectivity between habitats. However, the scientists caution that applying the simulation results to real species requires the identification of the species' habitat.

  Gibbs (1993) modeled wetland-associated amphibian, turtle, small bird, and small mammal distribution and identified the extinction rates of these taxa associated with the removal (e.g., alteration, destruction) of small wetlands in the landscape. By increasing the distance between wetlands from eliminating small (less than 4.05 ha) wetlands, he found an exponential increase in the interpond distance and the chance of extinction in turtles, small birds, and small mammals. Interestingly, no change in metapopulation extinction risk was evident for salamanders or frogs, largely because high rates of population increase buffered these taxa against extinction.

  Nevertheless, one of the more consistently supported findings in conservation biology is that wildlife diversity is positively affected by the ability to move along corridors and other landscape connections (Dawson 1994; Beier and Noss 1998). Corridors, however, need to be wide enough to facilitate wildlife use and bridge essential home range requirements of breeding populations. They should enable rescue effects and offset inbreeding depression (i.e., the loss of genetic variation and increases in deleterious alleles through increased matings with relatives). Unfortunately, current information is inadequate to predict the distance and direction of dispersal of many species and consequently the location and length of corridors for management purposes remains uncertain, although they should link critical habitat. Corridors may also be less important to species with short or very long movement distances relative to the landscape, low mortality rates or in areas where habitat is naturally ephemeral. Corridors should not be considered fixed structures but rather as functioning parts of a landscape that change according to season, species, and landscape disturbance. Perhaps most importantly, corridor width should also be considered from an ecosystem perspective (e.g., forest with interior abiotic conditions) rather than just traditional species-specific perspectives (Maryland Department of Natural Resources 2001) because corridors themselves must be self-sustaining ecosystems or they will deteriorate and lose their intended functions.

Wetland Vegetation: Specific Findings

- **Wetland.** The depth, duration, and frequency of flooding strongly influence wetland plant communities (Adamus 2003). Most, submerged, truly aquatic species cannot withstand periods of drying out, particularly during summer. Emergent species, although tolerant of water level fluctuations, may be sensitive to submergence during spring (Azous and Richter 1995; Azous and Cooke 2000; Ewing 1996). For other species, exposure of the substrate is essential for germination (Maitland and Morgan 1997). Bog adapted vegetation is especially sensitive to water level fluctuations because when water level drops, available oxygen increases the rate of decomposition, especially of sphagnum peatlands, destroying their integrity (Kulzer et al. 2001). One recurring observation is that human changes to natural water regimes enable exotic species to colonize wetlands and some native species to become aggressive resulting in monocultures (Houck 1996). These may not provide historic wetland abiotic functions or be suitable habitat for amphibians (Brown and Blossey 2002) and other wetland biota (Galatowitsch et al. 1999).

Wetland hydrology has selected for plants with unique growth forms, thereby providing a variety of spawning, rearing, cover, basking, display and other habitat needs for invertebrates, fish and wildlife. For example, it is in the emergent zone that the diversity and density of macroinvertebrates is often highest and in which most wetland-breeding amphibians oviposit (Hruby et al. 1999). Floating-leaved plants, either rooted in the sediment, or free floating on the surface, have leaves both above as well as below the surface (often with two different forms) and thereby provide shade, cover from predators and resting areas for invertebrates, amphibians and some birds. Floating plants are often the only vegetation remaining for wildlife as water depths along shorelines recede, excluding aquatic habitat once available in the shallower emergent zone. Finally, deeper wetlands may exhibit a variety of totally submersed plants, algae, and mosses. Many of these, although individually small or microscopic, are often found in extensive mats along the bottom sediments, or attached to plants, logs, rocks, and other substrates. The detritus and aquatic invertebrates found among submersed plants provide the foundation of aquatic food webs.

Wetland hydrology alone however may not account for vegetation associations. Specifically, in King County, species richness, evenness, and growth form (number of annuals) were not well predicted by differences in the magnitude and fluctuation of water flooding among six freshwater wetlands (Emers 1990). Moreover, as above ground biomass of reedcanarygrass (*Phalaris arundinacea*) and cattail (*Typha latifolia*) increased, species richness in survey plots decreased, suggesting that these two species are the primary influencing factor in plant association patterns. Consequently, depth duration and frequency of flooding must be assessed in the context of a wetland's historical factors including disturbance, seed bank characteristics, adjoining vegetation, and life history traits of individual species, in order to understand vegetation associations and patterns (Emers 1990).

Water quality also strongly influences vegetation. Primary production and biomass can be limited by the availability of nutrients (NRC 1995). Often low-nutrient wetlands support plant species that cannot compete with those found in high-nutrient wetlands (Keddy 1990; Kulzer et al. 2001). In contrast, excessive nutrients leads to eutrophication that leads to plant die-backs and anoxic conditions that have major impacts on aquatic invertebrates, fish and other taxa (Keddy 2000).

- **Adjoining Area.** Any activity within adjoining areas that alters drainage to wetlands exhibits the ability to alter wetland vegetation and habitat functions. It has also become clear that in many small, isolated wetlands, plant and animal populations are dependent on complimentary habitats found in the surrounding landscape (Pearson 1994). Moreover, the clearing of adjoining areas, and access by fisherman and other recreationists may unknowingly facilitate the dispersal of invasive species both aquatic (e.g.., Eurasian milfoil) and terrestrial (e.g., Tansy ragwort) plants (Desbonnet et al. 1994).

- **Watershed and Greater Landscape**. Clearing and impervious areas within watersheds alter the surface and groundwater supply to wetlands that, in turn, alters vegetation and habitat within wetlands (Konrad and Booth 2002). Furthermore, watershed activities altering subsurface flow and the water table may result in different vegetation and successional patterns within wetlands and along the shoreline.

Wetland Fauna and Habitat: Aquatic Invertebrates

- **Wetland**. Extensive information is available on wetland invertebrate habitat usage and needs with respect to hydrology, water quality, species composition, predator-prey interactions, and other factors (Merritt and Cummins 1996; Cummins et al. 1989; McCafferty and Provonsha 1981). Hydrology, for example, directly affects aquatic invertebrates because they are morphologically, physiologically, and behaviorally adapted to specific hydroperiods and current velocities (Wiggins et al. 1980; Rosenberg and Danks 1987; Rosenberg and Resh 1996). Permanently flooded wetlands have different communities than seasonally flooded wetlands (Wiggins et al. 1980; Richter 2001a). Flooding generally amplifies invertebrate richness and densities although these increases may decrease after one year (Murkin 1991). On an annual basis, wetlands with a semi-permanent hydroperiod exhibit the greatest biomass and production although greater densities can be found in wetlands with temporary and permanent annual hydroperiod (Adamus et al. 2001). Riverine wetlands with seasonally higher current velocities than depressional wetlands exhibit greater diversity and numbers of stoneflies, mayflies, and caddisflies (McCafferty and Provonsha 1981).

  Water quality is also critical in structuring aquatic invertebrate communities with pH, salinity, nutrients, toxicants, and physical factors, including silt and sediments and thermal alteration, playing critical roles. Nutrient inputs can lead to increases as well as decreases in invertebrate richness depending on concentration and associated declines in dissolved oxygen. Toxicity from heavy metals, pesticides, oils and other contaminants can individually kill invertebrates outright or act synergistically through their combined effects. Moreover, pollutants can exhibit sub-lethal effects that detrimentally influence physiology and behavior. Together, these pollutants structure wetland invertebrate communities (see water quality review by Adamus et al. 2001). Recently, nutrient and pesticide pollutants have been implicated in population declines, mutations, and sub-lethal effects on amphibians (Sparling et al. 2001; Steeger and Tietge 2003).

  Vegetation is also a major determiner of aquatic invertebrates (Murkin et al. 1992; Voigts 1976) as vegetation provides food and cover. Artificial removal of vegetation, such as mowing 50 percent of the cover for example, resulted in higher numbers of adult water boatmen, hydrophilid beetles and possibly amphipods, and reduced the number of mosquito larvae in a seasonal California wetland (Batzer and Resh 1992). Vegetation also ameliorates water temperature and dissolved oxygen, and many other physical and chemical characteristics of water quality that are known to affect aquatic invertebrates.

- **Adjoining Area.** Overall there is little information regarding the extent to which adjoining areas of wetlands influence the distribution and abundance of aquatic invertebrates. In streams with buffer strips wider than 30 meters macroinvertebrate diversity was not noticeably affected; in streams without buffer strips, or with strips narrower than 30 m (100 ft.), decreases in diversity were regularly detected (Erman et al. 1977). Clearly, buffers adjoining small wetlands play a proportionately greater ecological role in shade and water temperature control and productivity through litter and nutrient enhancement than those adjacent to larger wetlands.

Roads are known to pose a functional barrier to small-bodied ground-dwelling animals such as snails, and butterflies (Bennett 1991) and would be assumed to similarly effect aquatic invertebrates and their dispersal adjacent to wetlands. Links between aquatic and terrestrial insects and other invertebrates are described in Gregory et al. (1991).

- **Watershed and Greater Landscape.** Invertebrate communities are influenced by watershed conditions through runoff that may be harmful or beneficial. Watershed clearing, urbanization, and impervious areas influence wetland hydrology and indirectly invertebrate communities. Thresholds of imperviousness from Hick's (1995) study corresponded with Klein's (1979) and others' studies in that they found that if the percent imperviousness of total watersheds, (or in Hick's study of local sub-drainage basins) exceed 10 percent, moderately to severely impaired wetlands are likely to result.

  Runoff from housing developments, commercial establishments, and other land uses produce hydrological changes that also may contribute an array of pollutants harmful to aquatic invertebrates and other animals (Herricks 1995; Ebbert et al. 2000). Nutrients may be beneficial in small quantities as it increases plant production of benefit to some aquatic grazers and shredders but harmful in larger quantities that accelerates eutrophication. Detritus and other allochthonous production is generally beneficial but also may be harmful depending on source, quantity and individual wetland characteristics (Merritt and Cummins 1996).

Wetland Fauna and Habitat: Fish

- **Wetlands**. Fish are common residents of riverine and depressional flow-through wetlands. Several salmonids (e.g., Coho, cutthroat trout) commonly use riverine wetlands and others with connections to streams for rearing or as permanent habitat. Many non-salmonid fish are also found in wetlands. Native fish include sculpin and three-spined stickleback. Introduced species include bass, carp, and sunfish (pumpkinseeds). More recently, goldfish have been captured in wetlands (Richter pers. obs.).

  Clearly wetland hydroperiod, water quality and vegetation directly and indirectly affect fish. Fish need permanent water at wetlands or access to water at wetlands as hydroperiod changes on a seasonal or yearly basis. Water depth is important for cover and cool water temperatures. Vegetation is also important for cover but additionally for it is influence on dissolved oxygen levels as well as other water quality factors (see above vegetation text).
- **Adjoining Areas**. Fish are indirectly affected by adjoining area condition. Details are provided in Chapter 7 – Aquatic Areas.
- **Aquatic Watershed and Greater Landscape.** Activities in the watershed are important in influencing wetland conditions, which in turn determine the distribution and abundance of fish species. Many of these influences have been described in the previous text. Moreover, the landscape influences are similar to those that effect fish in aquatic areas described in Chapter 7 – Aquatic Areas.

Wetland Fauna and Habitat: Amphibians

- **Wetland**. Amphibians are an important component of King County wetlands and play pivotal roles in aquatic and terrestrial food chains (see review in a). Wetlands are essential habitats for many northwest amphibians (Nussbaum et al. 1983; Leonard et al. 1993). It is within the shallow emergent vegetation zone of wetlands that almost all (11 of 12) frogs, with the exception of the tailed frog, and some 4 of 21 of local salamanders breed. It is also in the wetland ecotone, the shoreline between wetlands and dryer uplands, that newly metamorphosed amphibians feed and queue during dry periods prior to moving upland into fields and forests where they live during cooler and wetter conditions. The characteristic moist soil, dense vegetation, and other wetland conditions minimize desiccation and provide cover from predators while simultaneously affording abundant insect, spider, and other invertebrate foods.

Amphibians are extremely sensitive to hydrological and water quality conditions and therefore have been suggested as indicators of wetland health (Sparling et al. 2001). Harmful hydrological (water flows) and water quality (pollutants) conditions significantly alter their survivorship and ongoing breeding at wetlands.

There is a general misconception that the size of the wetland and associated buffer is directly related to its importance for wildlife species diversity. King County amphibian species composition may overlap between large, permanent wetlands and small semi permanent wetlands in that those in semi-permanent wetlands may be found in permanent wetland but those in permanent wetlands cannot survive in temporary wetlands species abundances are significantly different, with higher numbers in respective wetland types (Richter and Azous 2001a; Richter unpub. data). Small, and often seasonal wetlands, may be especially crucial for maintaining regional amphibian biodiversity (Gibbs 1993; Semlitsch and Bodie 1998; Semlitsch 2000; Gibbs 1998b, 2000; Semlitsch 2003) as they serve unique and important breeding sites for many species (Dodd and Cade 1998). Small seasonally flooded and semi-permanently flooded wetlands do not have fish, crayfish, and densities of invertebrate predators that larger permanent ponds exhibit and therefore may have a greater variety and larger numbers of amphibians. Small ponds are also “stepping stones” connecting larger ponds. Semlitsch and Bodie (1998) proposed that wetlands as small as 0.2 ha should be protected because such small ponds may be critical to amphibian metapopulation dynamics by providing an important source of juvenile recruits and connectance between remaining populations. In King County small and isolated wetlands exhibited equal or greater species richness than larger wetlands (Richter and Azous 2001a). Therefore, protecting larger wetlands to a greater degree than smaller, often hydrologically isolated wetlands may not insure the protection of all species, (Richter and Azous 1995). In fact, one can argue that smaller wetlands may need larger buffers than large wetland to maintain their ecological integrity, as they are more sensitive to hydrological and chemical perturbations.

Notwithstanding, wetland conservation and mitigation practices continue to focus on large wetlands. For example, mitigation banking in which losses for numerous small wetlands are compensated for in the creation of one large centralized wetland may pose potential adverse effects on wildlife. Equating 10 small 1-acre wetlands to an equivalent area of one large 10-acre wetland may not result in equal or better wildlife benefits. On the contrary, such practices ignore source-sink dynamics and other aspects of metapopulation processes and may weaken conservation practices for wetland breeding amphibians (Richter and Azous 1995; Semlitsch 2003). Clearly, the benefit of such projects to amphibians are taxa and landscape specific.

- **Adjoining Area.** The width, age, and vegetation management practices of adjoining areas strongly influences usage by amphibians. All wetland-breeding species must move through this area to breed whereas a few species remain close to wetlands most of their lives. Oregon spotted frogs remains close to the water's edge. Summer feeding areas, for example, are generally within 250 m from wetland breeding sites although greater distances have been recorded (Watson et al. 1998, 2000). Similarly, Northwestern salamanders generally remain within 300 m of wetlands although dispersing animals may be found beyond one kilometer (Stringer per. com.). Many other species are thought to remain within a core area of 984-ft (300 m) (Semlitsch 2003). However, it must also be noted that these observations are generally limited to one or a few sites and species (with the exception of the southeastern states) and therefore extrapolation to other sites with differing environmental conditions must be cautiously treated.

In general, undeveloped vegetated buffers of 30-95 meters have been suggested to help maintain overall diversity of wetland-breeding amphibians (Rudolph and Dickson 1990). In the Oregon Coast Range, larger riparian buffers of 40-m width had twice the amphibian richness as buffers of only 20 m (Vesely 1997). However, because amphibian home ranges and dispersal distances from breeding ponds is regularly beyond100 m (Raymond and Hardy 199l) and often exceed 984 ft. (300 m) (Dodd 1996; Richter 1997), removal of forest cover within this distance presumably may harm species and population processes.

The reduction in dispersal rates attributable to agricultural clearing is clearly demonstrated in the migration behavior of juvenile spotted salamanders and American toads. These species oriented towards, and moved greater distances into, the forest as opposed to open fields, most likely to minimize evaporative water loss, which is significantly greater in fields (Rothermel and Semlitsch 2002). Reduction of dispersal rates between adjacent populations of amphibians separated by open fields suggests potentially negative consequences for population persistence in other habitats separated by open and altered landscapes.

In some cases, amphibians are less common in stream corridors from which vegetation has been removed from surrounding areas (Brooks and Croonquist 1990; Croonquist 1990). Clearly this was the case among 16 ephemeral ponds situated within tree plantations in New Brunswick, Canada, where higher densities and rates of recruitment of several amphibian species were found in the ponds situated closer to natural forest (Waldick et al. 1999). One would suspect the same is true for adjoining riparian wetland zones. Along the West Slope Cascades, seven of nine amphibians were more abundant at sites within or adjoining mature (greater than 80 yr. old) forest (Gilbert and Allwine 1991). The juxtaposition of ponds and forest also was found to be important to amphibian diversity in Shenandoah Mountains of Virginia (Mitchell et al. 1997).

In stark contrast, among 37 Michigan wetlands studied over 20 years, two-thirds of species extinctions occurred in wetlands where forests had grown up in the adjoining area. Here forests most likely shortened the annual duration of inundation of understory vernal pools and cooled the water and substrates (Skelly et al. 1999). Similarly, Murphy and Hall (1981), Murphy et al. (1981), and Hawkins et al. (1983) noted a dense canopy could limit the productivity of some aquatic salamanders. Such mixed findings regarding amphibians at wetlands adjoining open and closed canopy areas suggest that the benefits of vegetated areas adjoining wetlands most likely are species related and that extremes (no canopy or broken canopy) should be avoided. Amphibians adapted to breeding in small vernal wetlands may require open, sunnier and warmer nearshore areas than those adapted to breeding in forested ponds and wetlands.

Hamer (2002) found the distribution of some amphibians was aggregated, therefore a wetland was more likely to be occupied if neighboring waterbodies within 164-ft (50 m) were occupied. Newt presence and densities at a pond directly correlated to the number of nearby wetlands (i.e., within1309-ft.). Consequently, wetland loss and concurrent increasing distances between remaining wetlands may reduce newt populations. Roads and other barriers to migration, between wetlands also increase fragmentation and may have significant impacts on newt populations. Similarly, the chance that a pond (potential reproduction site) was occupied by tree frogs depended on three isolation factors: the density of occupied ponds within 750 m of each other; the density of shrubs; and the height of herbs within 1000 m of occupied ponds (Vos and Stumpel 1995).

- **Watershed and Greater Landscape.** Without consideration of terrestrial home range needs beyond the immediate adjoining wetland areas, conservation efforts will fail to protect amphibians (Dodd and Cade 1998; Richter 1997; Semlitsch 2002). Recorded dispersal distances for amphibians vary by species and habitat. In one review, amphibians of the east and central states of the U.S. were found as far as 3,000 ft. (914 m) from nearest water although they could be found further. Most, (83 percent) were captured within 1,970 ft. (600 m) from nearest water (Dodd 1996). Salamanders may move somewhat less and newts may move greater distances. Rough-skinned newts, for example, traveled up to ,804 ft (550 m) from streams (Efford and Mathias 1969) and percent also exhibited homing from 435 m. Of adult salamanders from wetlands, the mean distance was 410 ft, (125 m). The distance of 50 percent of juveniles was 230 ft. (70 m) for two species. Ninety-five percent of the population would extend 534 ft. (164 m) from wetland edge (Semlitsch 1998).

In the Pacific Northwest, adult amphibians use wetlands primarily for breeding, adjoining areas to temporarily feed and rest and then move into watersheds for the remainder of their life's requirements (Blaustein et al. 1995). Northern red-legged frogs were found up to 984 ft. (300 m) by (Nussbaum et al. 1983), as far as 3,000ft. (914 m) by (Dumas 1966), and up to 0.8 mi. (1.3 km) by Hayes et al. (2001) from breeding ponds. Most recent movement data on the northern red-legged frog indicates that a seasonally spatial scale of 0.62- to miles 1.2 mi. (1 to 2 km) for adults are routine, with some disproportionate use of selected habitats (Hayes pers.com). Movement for Columbia spotted frog is of an equivalent or larger spatial scale (Hayes, pers. com. 2003). Nonetheless, much more movement data are needed to determine average home range requirements and dispersal distances for watershed habitat management consideration.

Roads, agricultural lands, developments and other land use actions fragment amphibian home ranges separating wetlands used for breeding from each other and from upland feeding, aestivation, hibernation and other important habitats. Roads hinder amphibian movement (Gibbs 1998a) and traffic directly kills amphibians. Higher road densities are correlated to decreasing amphibian richness and abundance (Carr and Fahrig 2001) and possible global declines (Fahrig et al. 1995). Newt abundance is negatively correlated to proportion of cultivated land adjacent to ponds. Interestingly, for some newts abundance within wetlands was enhanced by moderate cultivation.

Most amphibians are resilient to disturbances of low magnitude and short duration but major changes likely effect populations. Above ground vegetation type, age, density, and cover influence amphibians and their activity. In a bottomland forest wetland in South Carolina, salamanders were much more common in mature stands than in clearcut areas (Phelps and Lancia 1993). Uncut sites also had more gray treefrogs (*Hyla chrysoscelis*) and bronze frogs

(*Rana clamitans*). After a clearcut of a bottomland forest wetland in Louisiana, mole salamanders (*Ambystoma talpoideum*) in the vicinity had lower survival rates (Raymond and Hardy 1991). Clearcutting in a southern Alabama bottomland hardwood wetland resulted in only brief depression of species richness. Interestingly, salamander diversity and abundance were greatly reduced whereas frog and toad species increased (Clawson et al. 1997). Recent clearcuts have fewer salamanders than adjoining old growth areas. Moreover, above ground activity is positively correlated to the density of understory vegetation and the depth of leaf litter. In general, forest fragmentation is likely to reduce dispersal rates between local populations of amphibians as there is a tendency by some species to avoid open-canopy habitat because of the increased threat from predators and desiccation (Rothermel 2002).

In Maine forests, the abundance of frogs and salamanders (*Rana sylvatica* and *Ambystoma maculatum*) declined along a gradient from mature forest-interior habitat (70-90 years old) to recently clearcut habitat (2-11 years old) (deMaynadier and Hunter 1999).

The salamander (*A. maculatum*) in Massachusetts and Michigan uses 98-ft.-wide (30m) travel corridors (Shoop 1968; Stenhouse 1985). Dodd (1996) suggests that a distance and directional component should be considered for adequate protection, however Rosenberg et al. (1997) maintain that the presence of distinguishable corridors connecting the site to nearby natural areas is probably less important than the total area of natural vegetation in the respective areas and the quality of the separating land cover. Others believe it is the connectedness of the landscape that determines the abundance of amphibians at wetlands (Joly et al. 2001).

In the Pacific Northwest amphibian richness and densities are also associated with forest types, ages, structure, and silvicultural activities (Aubry 1997, Gilbert and Allwine 1991; Aubry 2000). In general, amphibian richness and abundance decrease in clearcuts and some other logged areas until vegetation becomes reestablished.

In summary, regulatory agencies should strive to maintain a diversity of wetlands of different sizes (Gibbs 1998b) and hydroperiods (Snodgrass et al. 2000a) to protect breeding and other life-history requirements of diverse amphibian species (Paton and Crouch 2002). Also critical is maintaining minimal nearest-neighbor distances to avoid pond isolation and maintain metapopulation dynamics of species (Semlitsch and Bodie 1998). Consequently regulations to protect amphibians have to be developed on a regional scale (Paton and Crouch 2002). Amphibians have limited mobility and dispersal capability therefore favorable pathways (i.e., corridors) are important to other wetlands and amphibian populations and may be required for metapopulation processes. In fact, amphibians are the animal taxon whose populations are most dependent on the maintenance of dispersal connections and “landscape linkages” in human-altered environments (Gibbs 1998a). Gibbs (2000). Further stresses the importance of evaluating wetland resources as a mosaic. There is variation in amphibians by species, age, sex, and other factors for corridor characteristics; however, overall general requirements are cool temperatures, high moisture, litter, and woody cover. Corridors bridging foraging sites, hibernacula and other critical areas for survival must be available.

Wetland Fauna and Habitat: Reptiles

- **Wetland**. Reptile diversity and distribution at King County wetlands in general is limited to two turtles, the northern alligator lizard, and several species of garter snakes. The Western pond turtle is King County’s only truly native turtle and for most practical purposes, viable breeding populations are no longer found in Washington wetlands (Washington Department of Wildlife 1993; Storm and Leonard 1995). Painted turtles, originally brought over from east of the Cascades are now considered naturalized because of their widespread distribution and abundance (St. John 2002). These mostly occur at marshes, ponds, sloughs and small ephemeral wetlands rather than larger ponds (Nordstrom and Milner 1997) although they are abundant residents of Lake Washington and a few other large lakes. Alligator lizards are often found near rocky areas, garter snakes may be found along shorelines although these as well as other reptiles prefer open, sunny and warmer locations.

Western pond and painted turtles, and the common garter snake extensively use wetlands for feeding and basking and other non-breeding activities. Pond turtles also sometimes overwinter in wetlands as well as uplands, sometimes in communal sites of several turtles (Nordstrom and Milner 1997). Both turtles and snakes feed on amphibian larvae and small amphibians.

- **Adjoining Area.** Western pond turtles use productive wetlands with sunny embankments or open, grassy "prairie" adjoining uplands for breeding, and some overwintering. Cover vegetation, although not so dense as to inhibit movement is needed to provide upland refuge (Nordstrom and Milner 1997). Garter snakes often prefer these same areas although they may be found in wetter areas. According to Bury (1988) riparian habitats in the Oregon Coast Range are twice as important as upland areas in providing cover for reptiles and three times more important than aquatic habitats.

  The affinity of many reptiles for warm microclimates is well known. In South Carolina bottomland wetland landscape the overall herpetofauna diversity increased in clearcut plots when compared to adjacent forested areas (Phelps and Lancia 1993, Perison et al. 1997). Moreover, they found that the freshwater turtles examined required a 902-ft. (275 m) upland buffer zone to protect 100 percent of the nest and hibernation sites. Insulating 90 percent of the nesting sites required a 240-ft. (73 m) buffer zone (Burke and Whitfield 1995). Other than for western pond turtles within large field enclosures the County is unaware of natural dispersal and breeding habitat studies for wetland-dependent or associated reptiles in King County.

- **Watershed and Greater Landscape**. Little information is available regarding watershed requirements of reptiles of King County or the Puget Lowlands beyond their immediate wetland and adjoining breeding habitat usage. In a bottomland forest wetland in South Carolina, box turtles (Terrapene carolina) were much more common in mature stands than in clearcut areas (Phelps and Lancia 1993). Western Pond Turtles have been found to move between wetlands and nesting burrows located up to 500m (1,640 ft.) from water and land clearing, roads and other developments within 500 m are considered harmful (Nordstrom and Milner 1997). Consequently wetland isolation, or wetland isolation from upland breeding sites, by housing, roads, and forest removal would isolate turtle populations and result in their gradual decline.

  Wetlands, especially with shallow depths, and associated narrow fixed buffer regulations may be inadequate to provide nesting and hibernation habitat for wetland-dependent species such as western pond and painted turtles. Less is known about associated reptiles such as garter snakes and northern alligator lizards although habitat fragmentation would result in declines.

Wetland Fauna and Habitat: Birds

It is well documented that streams, lakes, wetlands and their associated riparian areas are disproportionately used by birds (Gibbs et. al. 1991, Knutson and Neaf 1997, Adamus 2001), Kauffman et al. 2001). This finding is not universal (McGarigal and McComb 1992; Pearson and Manuwal 2001) and the diversity and abundance of species along riparian streams may vary regionally with little difference in the Pacific Northwest perhaps because of the relatively wet, maritime climate that reduces moisture differences between upland and riparian habitats (Pearson and Manuwal 2001). However streams, do not provide the diversity of habitats found at wetlands. The high physical and biological diversity found in wetland ecosystems allow high insect productivity that diminish competition for food and influence diversity via it's effects on bird behavior and use of space (Kauffman et al. 2001). In addition, diverse feeding sites decrease interspecific competition and complex vegetation also provides a diversity of potential breeding sites (Kauffman et al. 2001). Strikingly, despite such vegetation differences in characteristics between riparian and upland habitats, Pearson and Manuwal (2001) still found no differences in bird species richness and species composition between riparian and upland habitats.

Relative to other regions of the country, bird species usage of riparian areas in the Pacific Northwest are poorly known (Knopf and Samson 1988) with the exception of the following more recent local studies in urbanizing regions of King County by Milligan (1985), Martin-Yanney (1992), and Richter and Azous (2001b, d). In King County 90 species were identified during the breeding season at 19 palustrine wetlands of differing size, hydrology, vegetation and other characteristics and within highly developed urban and rural areas (Richter and Azous 2001c). Milligan (1985) detected 60 species during the breeding season in urban wetlands alone. These richness values are up to 19 percent higher than the 73 species identified across a range of Douglas-fir forests (Richter and Azous 2001b). Waterfowl are especially abundant at wetlands, however empirical data regarding requirements for their conservation is primarily available from wetlands studies of the central states and prairie pothole region (Weller 1994, Weller 1979). Waterbird (herons, rails, bitterns, gulls) research, although widespread, is considerably more abundant from the Eastern USA. The characterization of streamside avifauna in variable riparian zones is presented in (Spackman and Hughes 1995, Croonquist and Brooks 1993, Keller et al. 1993, O'Connell et al. 1993; O'Connell et al. 2000; Hawkes et al 2003)). Considerable bird species conservation research has also been undertaken in eastern and mid-western upland-forested environments (see review in Askins 2000). Recently two book volumes have been published with comprehensive coverage of avian conservation issues especially in both forested and non-forested urban environments (Marzluff and Sallabanks 1998, Marzluff et al. 2001). Bird use of wetlands, adjoining areas and watersheds, and conservation suggestions are extrapolated from these regional and national studies as applicable. Habitat suitability models for select species provide additional information on species needs and habitat protection requirements, (i.e., great blue heron Short and Cooper 1985). Regardless of these studies scale considerations are fundamental to understanding the dynamics within any riparian fauna (Knopf and Samson 1988) and need to be carefully considered in reviewing research results.

- **Wetland.** Fluctuating water levels and other hydrological factors are important to birds in some regions and in some types of wetlands as demonstrated by Weller and Fredrickson (1974) and Weller (1988) in marshes in which water level was stabilized after drawdown and reflooding. Bird populations peaked one year after reflooding but thereafter declined. Medin and Clary (1990) found more than three times the bird density and biomass in beaver pond wetland complexes than in adjacent riparian areas. In beaver ponds water depths are relatively stable because flood waters spill over the dams whereas low flows are backed-up against dams. In contrast, more frequent and greater water level fluctuations such as those associated with runoff from watershed development and increases in impervious areas reduces vegetation diversity (Azous, 1995) and concomitant bird community characteristics because bird richness is closely correlated to foliage height diversity (Willson 1974), plant diversity (Balda 1975) and other characteristics (Adamus 1995). Moreover, amphibian richness may also decrease with increasing fluctuations (Thom et al. 2001) thereby reducing the food source for herons and other waterbirds.

Wetland hydroperiod further influences bird usage as shallow wetlands that are inundated for only brief periods each year and that typically lack surface connections to other water bodies (i.e., many “isolated” wetlands), are relied on almost exclusively by shorebirds and several other select bird species (Adamus et al. 2001). In contrast, deeper wetlands have higher richness in large part attributed to their use by a wide diversity of waterfowl (Richter and Azous 2001b). Wetlands near marine environments, lakes, and other large bodies of water also exhibit a greater diversity of bird species, primarily because of waterfowl and waterbird movement between waterbodies (Hruby et al. 1999).

Wetland size is important to bird biodiversity. Presumably, this is because size is often correlated with habitat complexity (e.g., vegetation diversity, open water) and insulation from disturbance (Milligan 1985, Brown and Dinsmore 1986, Hruby et al. 1999, Richter and Azous 2001b). Nevertheless, wetland habitat complexity alone, regardless of other conditions (e.g., buffer widths) may account for avian diversity (Milligan 1985, Martin-Yanney 1992). Groups of smaller wetlands (e.g., pothole) may also exhibit large bird-species diversity most likely a part of a wetland complex which generally show greater bird richness in groups of smaller wetlands in proximity to each other than in isolated wetlands of equal or larger size. A similar finding comes from prairie wetlands studied by Brown and Dinsmore (1986). Moreover, Richter and Azous (2001b) found that the highest richness at the most diverse of 19 wetlands only represented 65 percent of the regional biodiversity suggesting that the avifauna of each wetland, regardless of size and other characteristics, was essential for maximum regional biodiversity.

- **Adjoining Area.** Areas adjoining wetlands diminish disturbances, thwart predators, and function as breeding and foraging habitat. Sixty-eight percent of waterfowl nests occur within 98 ft. (30 m) and 95 percent within 30 ft. (9 m) of water bodies (Foster et. al. 1984). Average distance for wood duck nesting, for example, is 262 ft. (80 m) (Castelle et al. 1992a) and it may be that protecting such widths is all that is required for protecting wood duck and other waterfowl-nesting habitat. Milligan (1985) in the first study of avian use of freshwater wetlands in King County, the only study assessing bird community response variables to different width buffers, concluded that bird species richness was positively correlated to buffer widths adjoining wetlands. Equally important however, her analysis showed that there was only a small increase (5 percent) in the predicted richness with increased buffer widths of 50, 100, and 200 ft. and that bird richness demonstrated a moderate positive correlation with length of edge. Moreover, the width of buffer was not correlated to relative abundance, the number of breeding birds or the number of only wetland breeders. Correspondingly, Pearson and Manuwal (2001) found somewhat similar results in their 2-year (pre-and post-year logging) study of bird diversity and abundance adjacent to streams that were logged beyond 46 ft. (14-m) and 98 ft. (30-m) along each side. They found little difference in species turnover or species richness between the wide-buffer treatment and the control indicating that a 30-m buffer on both sides of second-order and third-order streams maintains most of the pre-logging bird community in the first two years postharvest. High species turnover on narrow-buffer treatments, however, indicated that buffers <46 ft. (14 m) on each side of the stream did not maintain the pre-logging bird community. Because the Black-throated Gray warbler, a riparian -associated species, declined within the 30 m buffer and regression calculations suggested that their numbers would be comparable to that found in controls in buffer strips of 45-65 m, they recommended a minimum of 45 meters as a very conservative minimum forested buffer along each side to maintain the entire pre-logging bird community along second- and third-order streams in the Pacific Northwest. This value seems to agree with other recommended riparian stream buffer widths of 147 ft (45 m) (Hagar 1999), although Hagar found four species to be less abundant in buffers narrower than 230 ft (70 m). Interestingly, upland bird communities influence species composition within a riparian site and vice-versa (Knopf and Samson 1988). Therefore the removal upland habitat with it's associated bird species may be considered to impact the bird species within the remaining buffers, regardless of frequently left widths.

Numerous studies throughout the U.S. suggest somewhat similar size riparian widths may be necessary to maintain richness of area-sensitive birds. In Pennsylvania, sensitive passerine species may not be adjacent to a stream (and assumed wetlands) unless an undisturbed buffer of at least 82 ft. (25 m) is present on each bank (Croonquist & Brooks 1993). In Maryland, bird presence increased with wider forest corridors adjoining streams. Moreover, the probability of occurrence increased most rapidly between 25-100 m widths (Keller et al. 1993) resulting in a recommendation of a100 m (328 ft) minimum width riparian forest buffer to provide some nesting habitat for area-sensitive species, although they noted that wider buffers are preferable. For Vermont streams, Spackman & Hughes (1995) found that 246-574 ft. (75-175 m) adjoining riparian habitats maintained 90 percent of riparian species. Castelle et al. (1992) state that migratory birds need 328 ft. (100 m) buffers.

Two years after harvest O'Connell (2000) indicate high bird species turnover on the state treatment (30 [9.1 m]-50 ft [15.2 m] with leave trees). Standard Riparian Management Zones (RMZs) and furthermore that riparian buffers less 45.9 ft. (14 m) on each side of streams do not maintain the pre-logging bird communities. Neither buffer treatment maintained residents species as well as unharvested controls. Despite small sample sizes, they found poor reproductive success of cavity nesters on State treatments suggest additionally suggesting that riparian buffers wider than that required by State Forest practices would benefit cavity nesting species. Other species such as the Black-throated Gray Warbler, was the only riparian associate not detected on sites with buffers narrower than 98.4 ft. (30 m) on a side. Thus in order to maintain the entire breeding bird community associated with forested riparian habitats in the coastal Northwest, they recommend a minimum buffer of 98.4 ft. (30 m) along both sides of second and third order streams. Preliminary results in subsequent studies 9-10 years after harvest in these same forested environments suggest that modified sites with a larger 100-ft (30 m) buffer and additional types of leave and reserve trees and all shrubs within 30-50 ft. of streams, have the greatest species diversity, followed by state and control sites and that both state and modified sites have greater diversity compared to forested control sites suggesting that bird communities respond to temporal changes of silvicultural practices (Hawkes et al. (2003).

Buffer strips help reduction noise (Harris 1986). Road noise within 200m of forests can decrease habitat quality, affects breeding dispersal, and reduces population density (Foppen and Reijnen 1994; Reijnen and Foppen 1994; Reijnen et al. 1995). Although it is known that some birds get acclimated to consistent, predictable noises and disturbance they remain agitated by sudden and or unexpected disturbances and others remain intolerant of disturbance (Werschkul et al. 1976).

Natural vegetation of sufficient widths, density, and type may also protect against predation. Ninety-four percent of female breeding cowbird locations was within 220m of forest edges with 60 percent within 164 ft, (50 m) (Gates and Evans 1996). However, nest predation may extend up to 984 ft. (300 m) – 1968 ft, (600 m) (Reese and Ratti 1988; Brown et al. 1990; Yahner and Scott 1988) from forest edges.

Cats are often encountered in buffers of wetlands in urban areas (Milligan 1985; Richter, pers. obs. Svendsen pers. obs.). House cats have ranges from 74 to 563 acres (30 to 228 ha) and can kill 1,600 mammals and 60 birds in 18 months and equivalent to 3 small mammals and 2 birds per day (Brown et al. 1990); presumably large vegetated forests adjoining wetlands may afford some protection from them although thick buffers of salmonberry, devil's club and other spiny vegetation would offer a better deterrent.

Narrow buffers with little vegetative screening may also encourage human activities at wetlands. Trails are often observed (Richter pers, obs.) so hiking, bird watching and other recreational opportunities increase. Interestingly, the feeding of birds, especially ducks, by people increased the number of birds in urban wetlands (Milligan 1986).

Although these findings provide an indication of the value of wetland buffers, there are several limitations to these studies that need to be considered in identifying the importance and widths of adjoining areas required for protecting wetland bird diversity. Foremost is the recognition that most of these studies are short-term and may not accurately reflect the longer, and perhaps permanent effects of identified and suggested buffer widths. Long-term studies of wildlife-habitat relationships have been advocated for more than a decade (see Verner et al. 1986) with meaningful bird studies spanning 5 to 10 years (Peterson and Manuwal 2001). It is also uncertain how long narrow riparian areas maintain fitness and reproductive potential in birds with relatively large breeding territories that vary in shape and size and that exceed the buffer widths suggested (e.g., passerines use 3 to 30 ha Pearson and Manuwal 2001).

- **Watershed and Greater Landscape**. The watershed and greater landscape may be important to wetland bird species (Naugle 2001). In Maine aquatic bird community richness at individual wetlands correlated with adjacent wetland density (Gibbs et al. 1991). Richness also increased in wetlands that were within 400 meters of each other. Proximity is especially important to waterbirds in the prairie region (e.g., Rotella & Ratti 1992a, b; Cowardin et al. 1995) and in regions where precipitation varies greatly from year to year (Meyers and Odum 1991, Fleming et al. 1994). In contrast, Gibbs et al. (1991) found no increase in richness with distance to the nearest wetland.

  Other surveys indicate that the variety of species not only increases with the size of wetlands up to 4 ha, but also in wetland clusters in which wetlands are less than 0.4 km from at least two other wetlands (Williams 1985). Diving ducks prefer large marshes for nesting within 0.4 km of large lakes (Low 1945).

- Wetland bird diversity is partly an extension of the upland bird fauna and is correlated to land use changes within 500 m (1640ft.), and possibly influenced up to 1,000 m (3,281ft) (Richter and Azous 2001d). According to Bushman and Therres (1988), 250 acres is the minimum forest size to maintain a viable breeding population of seven forest interior birds of Maryland. Eight species required smaller contiguous forest blocks and three required larger blocks.

Factors of importance to upland birds may affect nest predation in wetland birds. Specifically nest predation in 4-10 ha lots increased from 2 percent in wood lots in continuous forests to 70 percent in suburban woodlots (Wilcove 1985b). Alternatively, 70 percent predation in 10ha suburban lots, but only 2 percent in forest lots was recorded.

The proximity of roads is another potential landscape factor of importance to wetland associated birds. For example, Dutch studies in open grasslands found the disturbance affect from roads ranged from 500 to 600 meters for rural roads and from 1600 to 1800 meters for busy highways (Forman and others 2003).

Wetland Fauna and Habitat: Mammals

Wetlands are important to many mammals. Large mammals (furbearers, ungulates, carnivores) are dependent on wetlands and riparian areas for critical stages of their live cycles (Oakley et al. 1985) or for high quality forage (Raedeke 1988). Richter (unpublished data) observed muskrat, beaver, river otter, raccoon, bobcat, cougar, bear, deer and elk or their sign at 19 wetlands in the Puget Sound lowlands of King County. Furbearers dramatically influence wetland vegetation and wildlife. For example, both beaver and muskrat control wetland vegetation, and their lodges provide vertebrates and invertebrates houses for nesting (Willner et al. 1980). Wetlands created by beaver contain significantly more waterbird species than inactive beaver sites or potential beaver sites of the same size (Medin and Clary 1990, Drover and Baldassarre 1995). Richter, (Richter and Azous 2001c) also captured 19 small mammal species native to the Puget Sound Basin immediately adjoining flooded areas of wetlands suggesting that they are also of importance to many small mammals. They also observed various species of bats as expected because riparian areas are of primary importance to all bat species as they forage more often over water than clearing, fields, or forests (Knutson and Neaf 1997). Habitat suitability models provide additional review information for beaver, muskrat, and other wetland-dependent species and have been applied at a river basin scale in Oregon (Adamus 2000).

- **Wetland.** Fluctuating water levels are important. Muskrat populations peaked three years after reflooding and thereafter declined (Weller and Fredrickson 1974). Muskrats remove emergent vegetation for constructing lodges and feeding, thus increasing area of open water and reducing food and habitat for both birds and other mammals (Willner et al. 1980). Natural periods of wetness and drought renew the cycle of plant and animal interactions and cause pulses in animal and habitat availability to occur.

  Similar to findings in birds Richter and Azous (2001b), Richter and Azous (2001c) found that no single wetland exhibits the range of small mammal diversity found across all wetlands in the area; the best only having 68 percent of 22 species. Hence, to preserve small mammal diversity, a wide range of wetland types may need to be preserved.

- **Adjoining Area.** Noss and Harris (1989) describe 163 m buffers on either side of rivers used by river otters, bobcats, and black bears; however, no data are available on the width of buffers used by deer. Beavers use up to 328 ft. (100 m) adjoining wetlands in western Washington (Castelle et al. 1992a). Raccoons readily move up to one-quarter mile (0.4 km.) (Gustafson and Parker 1994). Mink use is most concentrated up to 100m but extends to180 m (591 ft.) (Allen 1983 in (Castelle et al. 1992). The white-footed mouse moves 279 to 2,845 ft. (85 to 867 m).

Although small mammal richness increases with wetland and hence buffer size, this relationship is significantly greater in areas of adjacent forest with large woody debris (Richter and Azous 2001c). Increased densities of development and pets may be tolerated if "enough" intact forest and groundcover remain available as alternative food and shelter, although the presence of Norway and brown rats may override such benefits (Thom et al. 2001).

All wildlife use of riparian habitats was reviewed by Knutson and Neaf (1997) and O'Connell et al. (1993). Short term (2 post-harvest years) responses of small mammals to differing riparian management zones in Western Washington Forests were reported in O'Connell et al. (2000). They found that over the first 2 post-harvest years both 20-50 ft. and 100-ft. buffer treatments provided habitats intermediate in quality for small mammals. Four species (marsh shrew, Trowbridge's shrew, shrew-mole, and forest deer mouse) showed statistically significant declines on the adjacent clearcut uplands, but none showed such strong declines on the buffer transects. Only the southern red-backed vole showed a strong declining trend in abundance although for this species the riparian zone may be suboptimal habitat in the first place. Interestingly Connell et al. (2000) supported the contention that small mammal communities of the riparian and adjoining uplands are similar with the exception of the water shrew being more common along streams and deermice more abundant in upland zones. Consequently they indicate that although attention to the riparian zone is appropriate, the structural complexity and habitat diversity of uplands also plays an important part in maintaining our native small mammal fauna.

Roads adjoining wetlands may pose significant barriers to mammal movement (Bennett 1991). Several studies show less than 10 percent probability of small mammals successfully crossing even lightly traveled roads of 6- to 15-m width to adjacent habitat. In another study, small forest mammals rarely crossed successfully road corridors over 15 m wide. Mid-sized mammals crossed roadways up to 30 m wide, but never highway corridors of 387 ft. (118 m) and 449 ft. (137 m) width. Large mammals cross most roads but the rate of crossing is typically lower than movement in more favorable habitat (Forman 1995). For example, in an eastern Canada study, several species of small mammals rarely ventured onto road surfaces when the road width exceeded 20 m (0xley et al. 1974). In Germany, two species of forest rodents rarely or never crossed two-lane roads or even smaller unpaved roads Mader 1984) (Knutson and Neaf 1997). Collectively these studies suggest that roads deter small mammal movements and those that surround wetlands may totally isolate small mammal populations from each other. However, for small rodents, linear corridors such as fencerows can ensure a valuable level of connectivity (Fahrig & Merriam 1985; Bennett 1990; Merriam & Lanoue 1990; La Polla & Barrett 1993) and some studies suggest that adequately designed culverts can aid the conservation of vertebrate populations (Yanes et al. 1995).

- **Watershed and Greater Landscape.** The influence of the greater watershed condition on obligate wetland mammals and population dynamics needs further investigation. Nevertheless, for small mammals in general, Richter and Azous (2001c) found that the highest richness occurred in wetlands that had greater than 60 percent of the first 1,640 ft. (500 m) in forest land. Subsequent surveys and analysis suggested that a forest component, specifically with large woody debris, might provide the habitat for the 22 species captured at wetlands.

  Although small mammals generally have smaller home ranges, their life requirements may not be met in habitat solely adjoining wetlands. Watershed vegetation reduces fragmentation and provides connecting habitats between wetlands and upland habitats. In managed forests 384 plus or minus 66 ft. (117 plus or minus 20 m) wide corridors between unlogged habitats maintained higher population (genetic) connectivity for red-backed vole (not deer mouse) (Mech and Hallett. 2001) and may similarly be assumed to provide corridors to upland habitat for wetland associated species. Clearly, larger mammals, especially predators, require larger territories and home range needs not available in most jurisdictional wetland buffers.

To create sustainable landscapes the ecological networks need to consider of a number of high-quality patches, but small and seemingly insignificant habitat patches could also play an important role and should be taken into consideration also (Foppen et al. 2000). Such a strategy seems prudent, especially for wetland small mammals, but it is also essential for amphibians, reptiles, and birds.

Table 5 provides a brief outline of the BAS for the conservation of wetland habitat and wildlife.

Table 5. Summary of Best Available Science for the Conservation of Wetland Food Chain Support and Wildlife Habitat Function Benefits

Function	Wetland, Local Area and Watershed Conditions (Potentially for all Wetland Types)					
	WITHIN WETLAND		ADJOINING AREA (300 m)		WATERSHED AND GREATER LANDSCAPE	
	Factors of Influence	Comments	Condition & Distance of Influence	Comment	Factors of Influence	Protection
Invertebrates	Specific attributes of Peak Flow are ▪ Magnitude ▪ rate of change ▪ velocity ▪ frequency ▪ duration ▪ timing (Seasonality) Depth		Undetermined although minimal compared to vertebrates	Microclimatic changes are thought to extend up to two tree lengths (distance provided) inside a forest patch (Harris 1984, Franklin and Forman 1987). Roads are known to pose a functional barrier to small-bodied ground-dwelling animals such as snails, and butterflies (Bennett 1991).	Low current velocities of streams entering wetlands. Also watershed, geology, topography, soils & vegetation influence runoff and infiltration.	Imperviousness exceeding 10% of total watersheds (Klein 1979) or of local sub-drainage basins (Hick's 1995) moderately to severely impaired wetlands are likely to result.

Function	Wetland, Local Area and Watershed Conditions (Potentially for all Wetland Types)					
	WITHIN WETLAND		ADJOINING AREA (300 m)		WATERSHED AND GREATER LANDSCAPE	
	Factors of Influence	Comments	Condition & Distance of Influence	Comment	Factors of Influence	Protection
Amphibians			Forest : 3,281 for ≈ 99% 1,600 for ≈ 85% 1,000 for ≈ 75%	Based on amphibian dispersal (Richter's 1997 extensive review of existing amphibian literature).	Alternate wetland breeding sites and soils, litter and vegetation cover are beneficial	
			Native Vegetation: 1,968 for 83%	Based on extrapolation from dispersal curve (Richter's review of literature).		
			Native Vegetation : 538 for 95%	(Dodd 1996)		
			Forest : 328 for? % dispersal	Salamanders only (Semlitsch 1998).		

Function	Wetland, Local Area and Watershed Conditions (Potentially for all Wetland Types)					
	WITHIN WETLAND		ADJOINING AREA (300 m)		WATERSHED AND GREATER LANDSCAPE	
	Factors of Influence	Comments	Condition & Distance of Influence	Comment	Factors of Influence	Protection
			Forest: 984 for ≈ 100%	Removal of forest cover as far as 328 ft. (100-m) away from breeding ponds can affect amphibian dispersal movements (Raymond and Hardy 199l), that for many species span a distance of at least 984 ft. (300-m).		
Reptiles			Native Vegetation : 902 for 100% & 240 for 90%	Freshwater turtles examined in this study required a 902-ft (275m) upland buffer zone to protect 100% of the nest and hibernation sites (Burke and Whitfield 1995).		

Table 5, continued

Function	Wetland, Local Area and Watershed Conditions (Potentially for all Wetland Types)					
	WITHIN WETLAND		ADJOINING AREA (300 m)		WATERSHED AND GREATER LANDSCAPE	
	Factors of Influence	Comments	Condition & Distance of Influence	Comment	Factors of Influence	Protection
Birds			Forests ; 1640' for 100 % species richness	Human avoiders decrease, exploiters increase (Richter & Azous 2001).		
			Native Vegetation : 394'	Willow warbler successful breeding (Foppen 1994).		
			Forest: min 82' for 100%	For sensitive passerine species (Croonquist & Brooks 1993).		
			Forest: 656' for 100%	Less than 656- decrease bird habitat quality, affects breeding dispersal, and reduces population density (Foppen and Reijnen 1994, Reijnen and Foppen 1994, Reijnen et al. 1995).		

Function	Wetland, Local Area and Watershed Conditions (Potentially for all Wetland Types)					
	WITHIN WETLAND		ADJOINING AREA (300 m)		WATERSHED AND GREATER LANDSCAPE	
	Factors of Influence	Comments	Condition & Distance of Influence	Comment	Factors of Influence	Protection
Mammals			Forest : 1640' for 100% species richness	Large woody debris in buffers significant correlate to small mammal species richness (Richter & Azous 2001).		

9.3 CONCLUSION

Wetlands are extremely important, diverse, and complex ecosystems. Moreover, wetland science is a relatively recent discipline, only becoming vigorous at the onset of government wetland policies in the early 1960s. Historically wetland science incorporated and synthesized materials unique and limited to immediate wetland conditions such as their characterization and functions (although there were some exceptions). Only more recently has wetland science incorporated a broader focus, including function and process-oriented themes from landscape ecology, conservation biology, population biology, wildlife sciences, and environmental health. Consequently, wetland identification and wetland delineation is more well founded in science and generally accepted in the broader community. In contrast, Best Available Science (BAS) for wetland protection, particularly safeguarding the processes that protect wetland functions, varies in quantity, quality and local relevance and remains an active field of research.

The BAS for wetland protection is neither complete nor consistently covered for all functions. Proportionately greater useful and locally relevant information is available regarding wetland water quality functions and how to protect them than there is regarding other functions. Even then, much of the information is from agricultural and mature/old growth forest stream studies rather than from wetland studies. Relatively good information exists regarding wildlife use of local wetlands. However, with the exception of amphibians, few empirical studies regarding wildlife and habitat protection, especially on the population scale, exist. Moreover, information regarding impacts to wetland birds other than waterfowl, and particularly their buffer needs, comes largely from streamside riparian studies from other regions. Finally, little local information appears to be available regarding the groundwater interaction functions between wetlands and the greater watershed and landscape. Regardless, most of the research is based on the survey approach and identifies correlations between wetlands, their impacts, and methods of protection. Consequently, it may be argued that correlations are circumstantial evidence and do not account for causation of effects and hence wetlands should not be protected based on correlative findings. Clearly, experimental approaches are required to identifying specific cause and effect relationships enabling the development of policies and rules that are direct and provide greater predictability of outcomes.

The literature appears to be clear that there is a continued loss in wetland acreage and wetland functions despite replicate agency policies and regulations requiring “no-net-loss.” Furthermore, despite the caveats of insufficient science (mentioned above), several underlying approaches to protecting wetland functions can be extracted from the national and local literature including all of the following.

- Wetland functions are determined by wetland characteristics, adjoining environment, watershed characteristics, and position of wetland within the watershed and the greater landscape condition.
- Wetland functions are interdependent and to some extent, mutually exclusive.
- Wetland functions vary over time.
- Protection of wetlands is context and scale driven. That is, wetland protection is dependent on the functions of wetlands and the condition of ecological processes in adjoining areas as well as greater watershed and landscape area.

- Protection of wetland functions is primarily through the use of buffers. Buffers alone, although necessary in many cases, may be insufficient to completely protect important functions unless exceptionally large.
- Fixed narrow-widths vegetated buffers between 50-200 ft significantly reduce most pollutants entering wetlands (exceptions are microorganism and pharmaceuticals).
- Fixed narrow-width buffers of 50-300 ft play mixed roles in protecting groundwater interaction functions.
- Fixed narrow-width buffers of 50-300 ft play marginal roles in permanently protecting fish and wildlife habitat functions of wetlands.
- Protection of wetland complexes is important to stem wetland isolation and habitat fragmentation, two consequences of development leading to decreased species richness and local extinctions at wetlands.
- Fixed narrow-width buffers of 50-300 ft. provide little core area and therefore are prone to invasion by invasive species, one of the most difficult challenges to wetland protection.
- Presently, wetland mitigation is an inexact and difficult science and hence wetland protection remains the highly preferred option for meeting the “no-net-loss” standard.
- Mitigation for wetland functions is equally critical to simply protecting wetland acreage.
- If mitigation is required, traditional mitigation as well as mitigation banking each provide advantages and disadvantages depending on local conditions and project size.
- Long-range studies and monitoring activities by which to evaluate successful protection are lacking, therefore such studies and findings should be incorporated into an adaptive management program.

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