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ISOLATED WETLANDS AND WATER QUALITY

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Abstract: Isolated wetlands occur in many hydrogeomorphic settings, and while they appear to be physically isolated from other water bodies, they are almost never completely decoupled from surface-water or ground-water systems. In this paper, we examine water-quality data for isolated wetlands in three hydrogeomorphic classes (depressions, slopes, flats). Some isolated wetlands are dominated by atmospheric exchanges and have little ground-water or surface-water connections with adjacent systems. Other isolated wetlands are dominated by ground-water inputs and have intermittent or continuous hydrologic connections to adjacent systems. Water-quality characteristics of isolated wetlands are highly variable and depend primarily on the sources of water, substrate characteristics, and land uses associated with the wetland watershed. We were unable to identify any general pattern of water-quality characteristics within or between isolated wetlands in the three hydrogeomorphic classes. Alteration of hydrologic conditions (e.g., ditching, filling), however, usually results in increased nutrient export to downstream systems. From a water-quality perspective, we conclude that so-called isolated wetlands are rarely isolated, and isolation is a term that is not very useful from an ecosystem perspective. Isolated wetlands are nutrient sinks and, because most are hydrologically connected to other waters and wetlands, the loss of isolated wetlands would potentially have negative impacts on the water quality of downstream systems.

Key Words: isolated wetlands, water quality, nutrients, hydrology, depressional wetlands, slope wetlands, playas, prairie potholes, Carolina bays, cypress swamps, mineral flats, organic flats

INTRODUCTION

The term 'isolated wetland' is generally applied to wetlands that are not connected by surface water to a river, lake, ocean, or other body of water. As will be demonstrated in this and other papers (Winter and LaBaugh 2003), few so-called isolated wetlands are, in fact, hydrologically isolated. There is increased concern about the fate of isolated wetlands in the U.S. because of the implications of the Solid Waste Agency of North Cook County (SWANCC) decision by the U.S. Supreme Court (Solid Waste Agency of Northern Cook County U.S. Army Corps of Engineers, No. 99–1178). In brief, the SWANCC decision narrowed the jurisdiction of the U.S. Army Corps of Engineers (USACE) to wetlands that were part of or adjacent to navigable waters. In response to the SWANCC decision, the USACE will no longer regulate most wetlands associated with waters that are non-navigable, isolated, and not part of interstate commerce. Since the SWANCC decision, several states (e.g., New Jersey, Wisconsin, Nebraska) have indicated that it will have little impact on wetland regulation (Bender 2002, Housmann 2002, Piel 2003), and some federal programs continue to offer protection to isolated wetlands (Wood 2003). There is, however, concern that many isolated wetlands will receive little protection (Semlitsch and Bodie 1998), and court rulings since SWANCC (Craig 2002) indicate that the fate of isolated wetlands is yet to be clarified legally. While not stated explicitly, one assumption of the SWANCC decision is that isolated wetlands are not linked in any ecologically meaningful way to waters and wetlands of the U.S. As we will describe, this assumption is most often erroneous.

What are the implications of the SWANCC decision on the ecological relationships between isolated wetlands and other landscape elements? It has been demonstrated, for example, that the loss of isolated wetlands would potentially have detrimental effects on amphibian diversity in the southeastern U.S. (Semlitsch and Bodie 1998). It is important to know if there is an analogous situation regarding water quality because the continued or expanded loss of unprotected isolated wetlands would potentially have negative impacts on the quality of the nation's waters and wetlands. The objective of this paper is to review water-quality data for isolated wetlands. Within the overall objective, we also want to determine if physical disturbances alter patterns of nutrient retention or transport from isolated wetlands.

Because of the direct implications of the SWANCC decision on isolated wetlands in the U.S., we primarily limit our review to wetland studies within the conterminous U.S. For purposes of presentation, we organize the review around hydrogeomorphic (HGM) wetland classes (Brinson 1993). Brinson described five HGM wetland classes (riverine, flats, fringe, slope, depression). Isolated wetlands occur in all HGM classes, but we limit our review to isolated wetlands in the flats, slope, and depression classes because wetlands in those classes are more likely to have characteristics that are typically associated with isolated wetlands (i.e., no surface inlets and outlets). Isolated wetlands in the other two HGM classes (riverine and fringe) are not considered in the review because they would be adjacent to, contiguous with, or located in waters and wetlands of the U.S. and would not be affected by the SWANCC decision.

To have an impact on water quality in other ecosystems, isolated wetlands would need to be hydrologically connected to them. Several studies (e.g., McNamara et al. 1992, Winter and Rosenberry 1995, Rosenberry and Winter 1997, Podniesinski and Leopold 1998, Winter et al. 2001, Winter and LaBaugh 2003) have demonstrated that isolated wetlands have complex but direct hydrologic interactions with other wetlands and uplands. Based on the studies just cited, we assume that most isolated wetlands are, in fact, not hydrologically isolated from other waters and wetlands and, thus, have the potential to impact water quality in downstream ecosystems.

We now consider water quality in three HGM wetland classes (depressions, slopes, and flats). In each section, we first describe the characteristics of the wetland class. We then examine existing water-quality data and evaluate potential water-quality connections with downstream waters and wetlands. When data are available, we also consider what happens when isolated wetlands are disturbed by human activities.

DEPRESSIONS

Wetlands in this HGM category occur in topographic depressions (Brinson 1993). They are widespread and occur in many landscapes (e.g., Hemond 1980, Vitt and Bayley 1984, McNamara et al. 1992, Logan and Rudolph 1997, Keeley and Zedler 1998, Wise et al. 2000, Rheinhardt and Fraser 2001). The best-known and most thoroughly studied wetlands in this class are found in the prairie pothole region of the U.S. and Canada (van der Valk 1989, Galatowitsch and van der Valk 1998, Murkin et al. 2000). Elsewhere in the U.S., playas of the U.S. Southern High Plains (Pezzolesi et al. 1998), Carolina bays and isolated depressional wetlands of the mid-Atlantic Coast (Schalles 1989, Newman and Schalles 1990, Kirkman et al. 1999), vernal pools of California (Witham et al. 1998), cypress domes of Florida (Brown 1981, Ewel and Odum 1984), and intermontaine depressions are other examples of this wetland class. Bogs that develop in depressions occupied by lakes and ponds are also in this category (Hemond 1980, Schwintzer and Tomberlin 1982, Vitt and Bayley 1984, Wilcox and Simonin 1988, McNamara et al. 1992), but they often transition to flats (described in the Flats section) through paludification (e.g., Mitsch and Gosselink 1993, Richardson and Gibbons 1993).

Depressional wetlands may have any combination of inlets or outlets or may lack them completely (Brinson 1993). Depressional wetlands without inlets and outlets may be hydrologically isolated through obvious surface-water connections, but most appear to be linked to other waters and wetlands through groundwater or periodic surface flows (e.g., Winter et al. 2001). The primary sources of water to depressional wetlands are precipitation (e.g., raised bogs) or runoff, either as surface or shallow subsurface flow, from the surrounding watershed (e.g., Winter and Rosenberry 1995, Kehew et al. 1998, Winter et al. 2001). Groundwater discharge may be the primary or occasional source of water for some depressional wetlands (Lide et al. 1995) and ground-water recharge may be an important flow pathway in others (Dierberg and Brezonik 1984b, Heimberg 1984, Winter 1989, Winter and Rosenberry 1995). The flow of water within depressional wetlands is typically upward due to evapotranspiration (Winter 1989).

We found that some authors did not provide information that enabled us to determine whether or not the wetlands that they sampled were hydrologically isolated or had minimal hydrologic connections to downstream ecosystems. Data in Table 1 are limited to those studies in which we had reasonable confidence that the wetlands were not connected by distinct streams to upstream or downstream ecosystems.

The chemistry of surface waters in isolated depressional wetlands is highly variable, ranging from oligotrophic to eutrophic (Table 1), and water-quality conditions have most often been related to the dominant water source. Isolated depressions that have precipitation as the primary source of water are usually ombrotrophic (e.g., Hemond 1980) and those with ground water as the primary source of water have water-quality characteristics that are similar to wetlands with mesotrophic to eutrophic conditions (LaBaugh 1989).

Driver and Peden (1977) and LaBaugh (1989) described a wide range of chemical conditions in surface waters of prairie pothole wetlands, and a high degree of variability was also found in Carolina bays (Schalles 1989, Newman and Schalles 1990) (Table 1). At one end of the water-chemistry gradient were oligotrophic Carolina bays that had thick peat layers and little contact with ground water. At the other end of the spectrum were Carolina bays that had thin peat layers and water-quality characteristics that were similar to local ground water. Differences in water chemistry between ground-water-influenced wetlands were related to differences in the chemistry of the underlying substrates.

Watershed area and position of wetlands within a watershed also influence water quality in depressional wetlands. Small watersheds provide little hydrologic input to vernal pool wetlands, resulting in surface waters that are mostly oligotrophic with low conductivity (Keeley and Zedler 1998). Prairie pothole wetlands that are located in topographically higher locations within a watershed are less influenced by seasonal and annual changes in precipitation and have lower surface-water salinity (Driver and Peden 1977), unless they receive significant inputs of ground water (LeBaugh 1989). Winter and Rosenberry (1995) demonstrated that ground-water interactions between depressional wetlands are complex, and water chemistry undoubtedly is influenced by variations in water sources. For example, one wetland studied by Winter and Rosenberry received ground-water discharge most of the time, but at times, it was a source of water to adjacent systems through seepage.

Isolated depressions in climates where annual plant production exceeds decomposition become filled with peat (e.g., bogs) and eventually switch from ground-water to precipitation as the primary nutrient source (e.g., McNamara et al. 1992). Consequently, undisturbed peat-filled depressions, whether there are or are not any obvious surface or subsurface hydrologic connections to downstream systems, are usually oligotrophic and have surface water and shallow ground water that have a low pH, conductivity, and alkalinity as well as low cation concentrations (Table 1).

From a nutrient mass balance perspective, isolated depressions would be considered nutrient sinks (Hemond 1980, Davis et al. 1981, Ewel and Odum 1984, Neely and Baker 1989, Pezzolesi et al. 1998). Hemond (1980) found that only small amounts of nutrients were exported from Thoreau's bog. Similar results have been reported for cypress domes in Florida (Ewel and Odum 1984) and playa wetlands in Texas (Pezzolesi et al. 1998). It is difficult to determine, however, whether or not there is any general pattern for nutrient retention or transport to downstream or adjacent ecosystems from isolated depressions. There have been relatively few detailed water quality studies of isolated depressions that also include all or most of the relevant hydrologic data (Winter 1989). Most available hydrologic information suggests that some isolated depressions are hydrologically linked to adjacent ecosystems by ground water or surface water (Driver and Peden 1977, Heimberg 1984, Nessel and Bayley 1984, Wilcox et al. 1986, Schalles 1989, Schalles and Shure 1989, Shedlock et al. 1993, Lide et al. 1995, Logan and Rudolph 1997, Quinton and Roulet 1998, Wise et al. 2000) while other wetlands are not (Driver and Peden 1977, Deghi and Ewel 1984, Dierberg and Brezonik 1984a, b, Wilcox 1986, Wilcox and Simonin 1988). When isolated depressional wetlands are hydrologically linked to downstream systems or when they have been physically altered to create artificial connections to downstream systems (i.e., subsurface or surface drainage), is there a potential for a deterioration of downstream water quality?

Dierberg and Brezonik (1984a) and Deghi and Ewel (1984) found that isolated depressional wetlands in Florida that received wastewater had no significant hydrologic or nutrient connectivity with downstream systems. Almost all ($>$ 90%) of the organic matter and nutrients applied in wastewater were removed within the wetland, and the vast majority of the nutrients were stored in the substrate, except for significant nitrogen losses through denitrification. Relatively small amounts of nutrients were stored in plant biomass. Chloride data demonstrated, however, that small amounts of water were exchanged between the cypress dome and ground water, but there was no evidence of increased nutrient concentrations in the ground water. In contrast, other studies have demonstrated that isolated depressions export nutrients to downstream systems (e.g., Nessel and Bayley 1984, Wise et al. 2000). Nessel and Bayley (1984) studied a cypress system in Florida that included a cypress dome connected to a downstream cypress strand via intermittent surface water flows. Nessel and Bayley (1984) did not describe the frequency or magnitude of the intermittent surface flows, but given the seasonal nature of precipitation in the study area (Ewel and Odum 1984), surface flows were most likely restricted to periods of high water during the rainy season. The important point to make in the context of this review is that the wetland was not always hydrologically isolated from downstream systems and therefore had the potential to impact downstream waters and wetlands.

Prairie pothole wetlands have also been shown to improve water quality and to efficiently retain nutrients (e.g., Magner et al. 1995). Many pothole wetlands have enriched nutrient conditions as a result of agricultural inputs (Neely and Baker 1989), and enrichment of N and P in surface waters often results in nutrient enrichment of interstitial water. Unaltered prairie pothole wetlands thus have a high potential for downstream discharge of nutrients if they are con-

Table 1. Water-quality data for isolated wetlands (depressions = D, mineral flats = F(M), slopes = S). Means, single data points, and ranges are provided. In some instances—indicated with a @ before the first data point—ranges were estimated from data provided in tables, figures, and text. A '?' indicates that a definitive answer to the category (e.g., HGM class) could not be determined from the information provided in the primary literature source. A '—' indicates that data were not provided. Data for all nutrients are in mg/l and were taken directly or converted from other units provided in the primary literature course. Conductivity data are in microsiemens/cm. In the Stream connection(s) column, a '+' indicates that the wetland was connected to a stream, a '—' indicates that there was no connection, a '?' indicates that we could not determine if there was a connection based on the text, tables, and figures provided in the primary literature source, and 't' indicates trace amounts.

Reference	# Wetlands	HGM Class	Common Name and Location	Stream Connections(s)	Conductivity	pH
Hemond (1980)	1	D	Bog (Massachusetts)	?	—	—
Podniesinski and Leopold (1989)	5	D	Peatland (New York)	+/−/?	100.8–352.2	5.20–7.56
Schalles and Shure (1989)	1	D	Carolina Bay (South Carolina)	−	16.7	4.3
Newman and Schalles (1990)	49	D	Carolina Bays (South & North Carolina)	?	29–177	3.4–6.7
Dierberg and Brezonik (1984a)	1	D	Cypress Dome	−	52	3.5–5.4
Dierberg and Brezonik (1984b)	1	D	Cypress Dome (Florida)	+	373	6.13
Dierberg and Brezonik (1984b)	1	D	Cypress Dome (Florida)	−	461	6.58
Driver and Peden (1977)	@20	D	Prairie potholes (Canada)	?	0.03–23,095	6.4–9.3
LaBaugh (1989)	1?	D	Prairie pothole (region)	?	140	—
Kehew et al. (1998)	2	D	Bog? (Michigan)	−	93.5–135	5.93–6.94
Schwintzer and Tomberlin (1982)	5	D?	Bog (Michigan)	?	57	4
Quinton and Roulet (1998)	1	F(M)	Peatland (Canada)	−/?	@15–95	@5–6.7
Walbridge and Richardson (1991)	?	F(M)	Pocosins	?	51–108	3.0–4.0
Hall et al. (2001)	@30	S	Seeps (New York)	+/?	—	@4.5–6.5

nected to other potholes by surface or ground-water discharges and drainage or ditching has the potential to significantly increase the amounts of nutrients discharged to downstream systems. Winter et al. (2001) suggested that management of water chemistry in the prairie pothole region and the Nebraska sandhills requires management of upland watersheds because of the complex interactions between wetlands and regional hydrology.

SLOPES

Slope wetlands form where there is a discharge of ground water to the land surface (Brinson 1993). The slope of the land surface associated with this wetland class may be gentle or steep, and the sources of water are predominantly ground water (shallow or deep) and precipitation. Wetlands in this category are also called 'seeps', and they can support a wide variety of wetland plant communities (Podniesinski and Leopold 1998, Crow et al. 2000, Winter et al. 2001). Wetlands associated with seeps have been shown to be important sites for regional biodiversity because they often contain rare species (Weakley and Schafale 1994).

There have been very few studies of water-quality characteristics of surface or ground water associated with slope wetlands, hydrologically isolated or not (Table 1). In contrast, there have been numerous studies of riparian buffers associated with streams (e.g., Gregory et al. 1991), but we did not consider those types of wetlands in this review because they would be considered to be part of the riverine HGM class. Hall et al. (2001) found that seeps in New York were important sources of water for streams and that they had water-chemistry characteristics that typically differ from those of surface waters, primarily because of ground-water inputs. All of the seeps studied by Hall et al. (2001) had outlets that entered into a stream system. We assume that slopes with no surface outlets are also important sites for nutrient transformation and potential sources of nutrients to downstream waters and wetlands because of ground-water connections to streams.

In our literature review, the study of Burns et al. (1998) was the only one that we could find that evaluated nutrient uptake or changes in water quality in slope wetlands. Burns et al. (1998) found that slope wetlands associated with springs removed significant amounts of nitrate during the summer. The water quality of ground water emerging into slope wetlands would be similar to shallow or deeper ground water (Hall et al. 2001) because of the often direct connection between sources of ground water and slope wetlands (Winter et al. 2001). We could find no data demonstrating the downstream impacts of hydrologic alteration of slope wetlands. The study by Burns et al. (1998), however, suggests that alteration of slope wetlands would result in the loss of nutrient retention ca-

Table 1. Extended.

PO_4–P	NO_3–N	K	Ca	Mg	Na	Cl	SO_4–S	HCO_3–C	DOC
—	1.4	0.46	—	0.30	—	2.27	3.9	—	—
—	—	—	4.1–44.1	—	—	—	—	—	—
—	—	—	0.98	—	0.73	2.43	1.57	—	—
—	—	0.27–16.22	0.16–11.75	0.36–3.53	1.06–14.19	3.4–9.9	0.2–23.9	<0.1–11.4	2.1–70.0
<0.005–0.48	<0.005–1.04	0.08–1.07	1.10–5.50	0.42–3.08	2.27–9.82	—	<0.5–12.0	0.00–9.75	—
4.6	0.38	7.96	18.2	11.6	39.0	57.5	28.9	110.0	—
6.7	0.27	8.43	210.0	9.6	43.2	46.9	34.4	123.0	—
0.003–0.29	<0.01–0.82	—	—	—	—	—	—	—	—
—	—	33	7.0	3.4	0.4	4.6	17.0	59.0	—
—	—	8.6–11.4	—	—	0.5	6–9	5.0	—	22.0–26.5
0.11	0.008	0.7	2.3	0.5	1.7	1.5	—	0	—
—	—	—	@0.5–9	@0.5–4	—	—	—	—	—
0–0.09	0–1.36	t	0.5	0.6	3.5	8.6	45.6	—	—
—	@0–1.3	—	—	—	—	—	—	—	—

pacity, and drainage would result in the export of nutrients to downstream waters and wetlands.

FLATS

Flats develop in landscapes where there is little topographic relief and water accumulates at or near the surface for extended periods of times, resulting in the presence of hydric soils and wetland vegetation. Flats typically have no surface flooding or flooding depths of only a few centimeters. Brinson (1993) recognized two types of flats: mineral and organic. Mineral flats are most commonly associated with poorly drained mineral soils with slopes < 0.5%, and the main source of water is precipitation (Rheinhardt et al. 2002). The dominant vector for water movement is vertical due to downward infiltration of precipitation and upward movement of water from evapotranspiration. Organic flats are similar to mineral flats except that they are associated with landscapes where there has been a vertical accretion of the substrate due to accumulation of organic matter where annual decomposition rates are less than annual rates of primary production.

Extensive peatlands are examples of the flats class (e.g., Glooschenko et al. 1993, Glaser et al. 1997). Many peatlands have their origin in depressions that filled with organic matter and the peat mat then developed horizontally over a relatively flat surface by paludification (van Groenendael et al. 1983, Podniesinski and Leopold 1998). Vast peatlands develop in boreal climates (e.g., Alaska, Canada, Russia) on both steep slopes and relatively flat topography (Glooschenko et al. 1993, Post 1996, Reeve et al. 1996). Northern peatlands have been studied extensively, and there is a vast literature on their classification, ecology, biology, hydrology, and biogeochemistry (e.g., McNamara et al. 1992, Mitsch and Gosselink 1993, Vitt et al. 1995, Glaser et al. 1997, Quinton and Roulet 1998, Adamson et al. 2001). The movement of water into and through peatlands is complex (e.g., Siegel 1988, McNamara et al. 1992, Glaser et al. 1997), but parts of peatland systems that are isolated from stream systems have been shown to be sources of diffuse runoff when the water storage capacity of the system is exceeded (Quinton and Roulet 1998).

Flats are also found in warmer climates, and both mineral and organic flats occur in the southeastern U.S. Pines and hardwoods dominate wet mineral flats (Stout and Marion 1993, Rheinhardt et al. 2002), and evergreen shrubs and small trees dominate wet organic flats knows as pocosins (Richardson 1981, Walbridge and Richardson 1991, Richardson and Gibbons 1993).

In the context of this review, we limited our consideration to flats in the U.S. and a few studies in Canada where, based on descriptions in the source documents, the sampling sites had no direct connection to a surface-water stream. We found that this requirement limited the number of studies that we were able to use because the authors of most of the papers that we examined did not provide adequate information to determine whether or not there were surface-water connections. Most often, we found water-quality studies that had been done in areas where there were no surface-water connections, but we could not determine if the areas studied had any continuous or intermittent connections to stream systems.

Most water-quality studies have been done in organic flats, with fewer studies of mineral flats. We would expect, however, that water quality in the two systems would differ because of a greater probability of hydrologic connections between mineral flats and underlying ground water. The chemistry of surface water or shallow ground water in organic flats has been shown to be variable. Karlin and Bliss (1984) examined substrate chemistry (pH, Ca., Mg) in six mires in Canada and found that they fell into three categories: strongly minerotrophic, moderately mineortrophic, and weakly minerotrophic. Walbridge and Richardson (1991) reviewed water-quality data for pocosins and compared them with water-quality data from other ombrotrophic bogs and fens (Table 1). Pocosins are similar to isolated depressions (Carolina bays) of the southeastern Coastal Plain in that water quality depends on the degree of contact between the wetland and the underlying substrate. Water quality in short pocosins, characterized by lower stature vegetation and a thick peat layer, is similar to water quality in ombrotrophic bogs. Tall pocosins, characterized by taller vegetation growing on a thin peat layer or on mineral soil, have water-quality characteristics that are more similar to ground water.

Hydrogen ion is the dominant cation in pocosins, and levels of sulfate and calcium are similar to those measured in northern bogs (Table 1). Walbridge and Richardson (1991), however, found that pocosins in the coastal plain of the Carolinas had higher levels of sodium, sulfate, and chloride than northern bogs that had no atmospheric input from oceans (Schwintzer and Tomberlin 1982).

Hydrologic modification of natural peatlands for purposes of conversion into plantation forests or peat mining has been practiced in Europe for many years and more recently in the U.S. (Richardson 1981, Williams and Askew 1989). While there have been few quantitative studies of nutrient export from altered peatlands in Europe, there is evidence that nutrient export increases (Heikkinen 1990, Lundin and Bergquist 1990). Walbridge and Richardson (1991), Richardson (1983) and Williams and Askew (1989) considered the effects of disturbances (e.g., ditching, peat mining) on water quality and nutrient exports from pocosins. They found that all disturbances resulted in an increase in nutrient availability. However, it is not clear if nutrient transport to downstream ecosystems increased because few investigations have focused on nutrient export, either qualitatively or quantitatively. Walbridge and Richardson (1991) suggested that nutrient exports would be least in drained pocosins that had no vegetation modification and were not fertilized and would be greatest when pocosins are converted into agricultural fields.

In drained but unfertilized pocosins, increased hydrologic output may not result in increased nutrient discharge because of increased plant uptake of nutrients. Removal of pocosin vegetation would result in increased water discharge, but there is no evidence that nutrient exports would increase if fertilizer were not added (Walbridge and Richardson 1991). Burning is a common form of disturbance in pocosins, both of natural and anthropogenic origins, and results in increased nutrient availability. There had not been any quantitative studies of hydrologic and nutrient export from burned pocosins at the time of Walbridge and Richardson's 1991 review, and we were unable to locate any recent studies. Walbridge and Richardson suggested that phosphate export would not increase after fire unless the root mat was burned and/or the fire was associated with conversion of the pocosin to agricultural fields, a process that includes drainage.

Conversion of natural pocosins into plantation forests or agricultural fields usually involves vegetation clearance, burning of slash, ditching, and fertilization. The combination of disturbances would have a high probability of increasing nutrient export. Walbridge and Richardson (1991) speculated that fertilization could result in increased export of nitrogen (mostly gaseous losses through denitrification), phosphorus, and carbon. The potential for phosphorus losses would increase if P additions in fertilizer were in excess of plant and microbial uptake. Carbon export in water would be expected to decrease as a result of increased carbon loss in response to increased decomposition rates. Skaggs et al. (1980) found large increases in N and P export following conversion of pocosins to agriculture. Walbridge and Richardson (1991) suggested that the impacts of converting pocosin to forestry production are less than the conversion to agriculture because forests are less frequently harvested and forests are fertilized less often than agricultural fields. Skaggs et al. (1980) and Williams and Askew (1989) found increased nutrient concentrations in stormflow in drained pososins compared to control areas.

DISCUSSION

The objective of this literature review is to determine if there are any general patterns when water-quality data are compared for different categories of isolated wetlands. Not surprisingly, we found that there are still relatively few water-quality data for isolated wetlands and most of the data are from regions where wetlands have received considerable attention (e.g., prairie potholes, Carolina bays, and northern bogs).

Water-quality data for isolated wetlands clearly demonstrate that all parameters have a very large range (Table 1) and are seasonally variable. Depressions with ground water as the primary water source have water-quality characteristics that are similar to those of the ground-water source. Salinity is one of the few variables with a geographic pattern related to regional climate as wetlands in drier climates (e.g., prairie potholes, playas, vernal pools) have higher salinities than wetlands found in more humid climates (e.g., Carolina bays, cypress domes).

Isolated depressions with ombrotrophic water-quality parameters occur in all regions for which data have been collected, and most are ombrotrophic because the source of water is precipitation (e.g., Hemond 1980). Even in depressions that have ground water as the primary water source, surface water and shallow ground water are also ombrotrophic when the sediments in the source area are nutrient poor (Keeley and Zedler 1998) and when the surface of the wetland has little hydrologic contact with deeper ground water. Isolated depressions that have ground water as the primary water source are most often mesotrophic to eutrophic, but they can become oligotrophic if peat accumulates and eventually limits interactions between the surface vegetation-substrate and ground water. The change in the plant composition of the vegetation from the conversion of mesotrophic-eutrophic species rich wetlands to species poor ombrotrophic wetlands has been documented (Kooijman 1992, McNamara et al. 1992).

There are few water-quality data for isolated depressions in some parts of the U.S. (e.g., playas, vernal pools). Studies of isolated depressions in Florida (cypress domes) included detailed hydrologic studies and experiments to determine system responses to nutrient additions (Ewel and Odum 1984). Cypress domes are oligotrophic systems but are capable of efficiently removing nutrients from wastewater because the organic sediments adsorb or otherwise retain most of the nutrients (Dierberg and Brezonik 1984a, b; Nessel and Bayley 1984). Primary production in cypress domes increased in response to wastewater addition, and most nutrients were retained; however, periodic downstream export of nutrients can occur when the water storage capacity of the wetland is exceeded (Nessel and Bayley 1984).

Flats, like isolated depressions, can range from oligotrophic to mesotrophic depending on the dominant water source (precipitation or ground water, respectively) (Table 1). Compared to isolated depressions, however, there have been few detailed studies of flats, especially mineral flats. Most detailed hydrologic studies of flats have been of northern peatlands and pocosins in the Carolinas (Walbridge and Richardson 1991, McNamara et al. 1992). Like isolated depressions, flats respond to nutrient additions, but most nutrients remain in the system unless artificial drainage is imposed.

There are too few water-quality data for isolated slopes to determine the range of water-quality conditions that exist for that wetland category. We believe, however, that they are mostly mesotrophic to eutrophic because the primary source of water is ground water. Variability in water quality, similar to mineral flats and ground-water discharge depressions, would be determined by the variability in water-quality characteristics of the ground-water sources.

In reviewing the literature, we were also interested in determining if disturbances altered patterns of nutrient retention or transport from isolated wetlands. The export of nutrients from disturbed isolated wetland would be expected because this review and papers on the hydrology of isolated wetlands (e.g., Winters et al. 2001) clearly demonstrate that the majority of so-called isolated wetlands are really not isolated but instead have intermittent or continuous hydrologic connections to other waters and wetlands. This point was demonstrated clearly by Winter et al. (2001) in their examination of two depressional wetlands and one slope wetland. All three wetlands had complex hydrologic patterns and were hydrologically connected, either continuously, or intermittently, to other waters and wetlands. Winter and colleagues discussed the implications of the hydrologic connections for wetland management and protection. While their conclusions were slightly different for each of the wetlands, they suggested that effective water management could only be accomplished by managing the sources of water that entered the wetlands. Only by appropriate management of water sources would it be possible to maintain acceptable ecosystem functions within the wetlands. The study by Winter and colleagues also suggested that the wetlands provided important water-quality functions in the landscape where they occurred, and it is clear that alteration of the wetlands would result in undesirable water-quality impacts on downstream surface waters and subsurface waters connected to local and regional ground-water systems.

Our literature review agrees with the findings of Winter et al. (2001), and we echo their conclusions that isolated wetlands are important elements of landscapes. Isolation is a relative term and not a very good term from an ecosystems perspective. Most isolated wetlands appear to be continuously or intermittently linked hydrologically to other ecosystems, and disturbances would result in negative effects on water quality within and external to the wetlands. We conclude that SWANCC does have potentially negative impacts on water quality of the nation's waters and wetlands.

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