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Scientific Challenges and Opportunities in Wetland and Riparian Research

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Summary

Within the last two decades public attitude toward wetland and riparian resources has dramatically changed. These aquatic systems were once viewed as areas to be exploited for agricultural and urban development. Current public perception is that wetland and riparian habitats should be protected and preserved. Because of this change in attitude, and because agriculture can and does have a profound impact on aquatic ecosystems, USDA is faced with the challenge of maintaining the agricultural industry and at the same time protecting these important aquatic resources. Critical gaps in information do exist and must be filled before USDA can meet this challenge. ARS scientist will need to develop evaluation techniques and criteria for the evaluation of resource management, restoration/rehabilitation projects, and assessing ecological damage from off site sources. Future research is needed to further develop restoration and rehabilitation techniques. A better understanding of wetland and riparian hydrology is needed to reduce impact of water diversion, direct water withdrawal or pumping from riparian zones. Not only is this research important in understanding of what hydrological effects physical changes to watersheds might have on wetlands and riparian habitat, but also how do these aquatic habitats affect floodwater storage and abatement. Additional research must be directed toward evaluating what impacts various agricultural practices have on our wetland and riparian resources, particularly the effects of non-point source pollutants such as suspended sediments, excessive nutrients and pesticides.

Introduction

The last 16 years have witnessed a change in public attitude toward aquatic resources. Before this time much of society perceived wetland, swamps and sloughs as obstacles to progress. These inundated lands were useless areas, to be drained and put into valuable agricultural production. They were seen as sources of mosquitoes and insect-borne disease.

Although our rivers and streams were valued by sportsmen and fishermen, public attitude seem to be that these lotic resources were best exploited as conduits for commerce, and waste, and sources for irrigation water. The rich alluvial soils within the riparian zones of rivers and streams were valued more for the agricultural potential than for the ecological role they play in the world around us.

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Attitudes have changed over a surprisingly brief period of time. In 1977, President Jimmy Carter issued Executive Order 11990 protecting wetlands and flood plains. In 1988, Vice-President George Bush made the following statement,

> *"[A]ny nation concerned about the quality of life, now and forever, must be concerned about conservation. It will not be enough to merely halt the damage we've done. Our natural heritage must be recovered and restored..... It's time to renew the environmental ethic in America-and to renew U. S. leadership on environmental issues around the world. Renewal is the way of nature, and it must now become the way of man."*

During the 11 years between these two events the Clean Water Act of 1977, the Food Securities Act of 1985, the Water Resources Development Act of 1986, and the Agricultural Credit Act of 1987 were passed in to law, all of which incorporate some provisions for the protection or restoration of aquatic resources. More recently, the Food, Agriculture, Conservation and Trade Act of 1990 (1990 Farm Bill) contains provisions dealing with delineation, conversion, and restoration of wetlands. Furthermore, the Act establishes a Wetlands Reserve Program, which includes the "set-aside" of riparian zones under certain circumstances (Cohen et al. 1991). Our current Vice-President Al Gore is the author of a best-selling book which expresses his concerns for global ecological health including the loss of aquatic resources.

The study of wetlands and riparian ecosystems is not new; however, most detailed research did not begin until the 1960's (Mitsch and Gosselink 1986). Most early investigations took the form of botanical surveys particularly of coastal marshes (Chapman 1938, 1940; Davis 1940, Teal 1958, 1962; Pomeroy 1959). Other researchers focused on botanical studies of freshwater systems (Cowles 1899, Transeau 1903, Kurz 1928, Dachnowski-Stokes 1935, Lindeman 1942, Gorham 1967). Recent research on wetlands and riparian ecosystems has been more varied and diverse. There have been economic and human value studies (Greeson et al. 1979, Reppert et al. 1979, Larson 1982, Adamus 1983, Sather and Smith 1984), investigation of the hydrologic function of wetland and riparian area, including floodwater storage and abatement (Horton 1914, Novitzki 1979, Verry and Boelter 1979, U.S. Army Corps of Engineers 1972, Gosselink et al. 1981, Ogawa and Male 1983). Several studies on nutrient and sediment dynamics in and through wetlands and riparian areas have been conducted (Klopatek 1978, Simpson et al. 1978, Gambrell and Patrick 1978, Nixon and Lee 1985, Richardson 1985, Kitchens et al. 1975, Odum et al. 1977a, Ewel and Odum 1984, Boyt et al. 1977, Nessel and Bayley 1984, Mitsch et al. 1979, Kuenzler et al. 1980). Webster (1975), Elwood et al. (1983), and Sedell and Froggatt (1984) have studied the "spiral" effects of nutrients downstream in lotic environments. Several researchers have examined the ecological function of wetlands and riparian zones, and their biological productivity (Mitsch and Gosselink 1986, Hammer 1992).

Significant effort has been exerted in an attempt to define or characterize wetlands and riparian zones. Smith (1980) described these aquatic resources as "half-way worlds" between aquatic and terrestrial habitats. Zinn and Copeland (1982) provided two definitions of wetlands, one for scientist and another for managers. They also provided a list of common characteristics that all wetlands share as well as characteristics that make defining distinct boundaries difficult. The U.S. Fish and Wildlife Service has adopted perhaps the most comprehensive definition of wetlands (Cowardin et al. 1979):

Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water ... Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.

A study by Lefor and Kennard (1977) indicated differences in the definition of wetland were primarily differences in emphasis and depended to a great extent upon the definer's background and training.

The Federal Government's definition is provided by the U.S. Army Corps of Engineers in Section 404 of the 1977 Clean Water Act Amendments. Their definition is given as follows:

The term "wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. (33 CFR323.2(c); 1984).

Most arguments against this definition involve the period of inundation. Some groups desire a longer period of inundation and others a shorter period of inundation. This definition does not tie wetlands to a particular soil type nor does it specify what plant species or density of plant species must be present.

Since the early 1970's, several authors have presented information on the use of constructed wetlands for the treatment of waste waters, particularly for the removal of nutrient contamination. Hammer (1989, 1992) has published several books and articles devoted to the planning, site selection, design, construction, plant species selection, and operation and maintenance of wetlands constructed for the treatment of waste water. Most constructed wetlands have been employed to remove suspended solids, nutrients, biological oxygen demand (BOD) and bacteria from municipal, industrial or mining waste (Cooper 1989). Marble (1992) provided a guide on how to construct wetlands for various purposes, based upon the U.S. Army Corps of Engineers wetland model called WET. Appendix A supplies a glossary of wetland terms which are used commonly among those working in wetland research. Appendix B lists wetland/native plant suppliers.

Some of the latest research on wetlands and riparian zones is oriented toward developing models. Most of these models concern themselves with habitat assessment and evaluation, some with cumulative effects, while others are more comprehensive such as the WET model mentioned above. (WET evaluates such functions as groundwater recharge and discharge, floodflow alteration, sediment stabilization, sediment/toxicant removal, nutrient removal/transformation, production export, aquatic diversity/abundance, etc.) (The World Wildlife Fund 1992). The U.S. Environmental Protection Agency (1992) evaluated some 21 models for use in water quality research at the watershed scale. These models were evaluated for their potential use in wetland studies as they relate to non-point source pollution and total maximum daily loads (TMDL). Some of the models evaluated, like AGNPS and SWRRBWQ, are probably familiar to those in the USDA.

Agriculture is a major user of water. The U.S. Bureau of the Census (1986) reported that the 20 top irrigation states had a total of more than 42 million acres in irrigation. It was estimated that in 1985 agriculture used about 141 billion gallons of water per day. This represents approximately 41% of all water used in 1985 and a significant portion to the total water available (Solley et al. 1988). Although it is true that about 50% of this water is returned for reuse, it is often laden with pollutants such as sediments, pesticides and nutrients. U.S. Environmental Protection Agency (1990) has reported that non-point sources are responsible for 65% of pollution in degraded streams with 60% of that contamination attributable to agricultural sources (e.g., pesticide and herbicide runoff, sediments, nutrients such as nitrogen and phosphorus, runoff from feed lots).

The agricultural industry is the major user of land in the U.S. and has played a significant role in the destruction of wetlands and riparian habitats. Frey and Hexem (1985) reported that (excluding Alaska) agricultural lands account for 65% of the total land surface or approximately 1.2 billion acres. U.S. Fish and Wildlife Service estimates that 117 million acres of the original 221 million acres of wetlands in the lower 48 states have been lost (Dahl 1990). Twenty-two states have lost 50% or more of their wetlands. Most of these loses (87%) have been attributed to draining for agricultural conversion (Council on Environmental Quality 1989).

Because of the role the agricultural industry had played in the destruction of wetlands and riparian areas and because of the impact agriculture continues to have on aquatic resources, USDA should direct some of its resources toward reducing environmental impact to aquatic ecosystems and restoring or rehabilitating wetlands and riparian zones. The Agricultural Research Service (ARS), the primary research agency within USDA, employs about 2,600 scientists at 122 US locations and seven overseas laboratories. This represents a significant fraction of the national agricultural research capability. Of the $624 million budgeted for FY91 about $77 million were allocated for research on natural resources and the environment including about $29 million for water quality research (Anonymous 1991).

The ARS program plan for 1992-1998 (U.S. Department of Agriculture 1991) included objectives dealing with soil, water, and air conservation and development of new agricultural practices and systems, but was silent on wetland and riparian zone issues. However, in 1991 four agencies within USDA, including ARS, participated in a work shop to identify and develop cross cutting water resources and technology transfer topics that USDA should pursue into the 21st century. One of the four major areas targeted for discussion was wetland and riparian research. Three common or cross-cutting issues concerning wetlands and riparian areas were identified. Vision statements were composed for each issue and major barriers were identified. Recommendations for strengthening interagency cooperation and for the implementation of the vision statements were listed.

Current State of Knowledge

Although the ARS mission includes development of technology needed to insure maintenance of environmental quality and natural resources, ARS remains a relatively small contributor to riparian and wetland research with only seven or eight projects which are directly relevant. Complementary research projects conducted at the Tifton, GA, Beltsville, MD, and University Park, PA, deal primarily with the effects of natural riparian wetlands on hydrology, water quality, and sedimentation. The Oxford, MS, location has two riparian wetland projects. One investigation involves the use of constructed wetlands to treat dairy cattle waste and the other tests effectiveness of four stream rehabilitation measures. Studies in Durant, OK, document sedimentation rates in natural water bodies. Research at Reno, NV, and other western locations focus on impact of

grazing on riparian zone plant communities in watersheds of the semiarid western United States (Shields and Cooper 1992).

Hydrologic Research and Modeling

Although research on riparian and wetland areas per se may number only 7 or 8 projects, there is considerable ARS research being done on upland hydrologic flux of heat and water. The Climate and Hydrologic Systems Element of the ARS Global Change Research Program encompasses research being undertaken by the Northwest Watershed Research Center in Boise, the Hydrology Laboratory in Beltsville, The National Agricultural Water Quality Laboratory in Durant, the Southwest Watershed Research Center in Tucson, the Grassland, Soil and Water Research Laboratory in Temple, and the Great Plains Systems Research Center in Ft. Collins. These locations are all doing research to "Improve predictions of water and energy fluxes to, within and from managed ecosystems by incorporating physically-based components that account for spatial, temporal and scale influences into models." (Global Change, Water Resources and Agriculture, 1992, USDA-ARS, NWRC 92-3; this document presents the Climate and Hydrology Research Component of the Agricultural Research Service Global Change Research Program). The models developed by these research units will be central to understanding water and energy transfer as they relate to streamflow. The Water Research Laboratory in Tifton, GA, is also developing an ecosystem model for the management of riparian areas (Altier et al. in press). This model links riparian processes to upland water input but relies on other models (GLEAMS or NLEAP) for the input.

Coastal Plain Riparian Zone Research

Pionke and Lowrance (1991) found that riparian zones tend to discharge ground water to their associated streams, sometimes providing 50-95% of the stream flow; therefore, riparian processing of nitrogen input from agricultural watersheds is important. Nutrients from agricultural runoff can cause water quality degradation (Lowrance et al. 1985b). Riparian wetlands are sinks for nutrients (due to plant uptake and microbial denitrification) and sediments. Pionke and Lowrance (1991) also found that riparian plant uptake of nitrogen range from 22 to 220 kg N $ha^{-1}yr^{-1}$. Which is in agreement with the range of microbial denitrification in riparian zone soils reported by Gburek et al. (1986) of 0.0007 to 0.0378 g N /M3 /hr which equates to 60-3,000 kg N $ha^{-1}yr^{-1}$. Three ARS investigations, described in greater detail below, have documented nutrient removal from subsurface waters as they pass through riparian wetlands in eastern watersheds.

Lowrance et al. (1983, 1984a) measured water movement and waterborne nutrients for riparian forest ecosystems located in the Little River Watershed and found bottomland hardwood forests were effective sinks for N, P, Ca, Mg, and K. Denitrification capacity could be maintained only if tree harvest was restricted to removal of mature tree and soil disturbance was kept to a minimum (Lowrance et al., 1983, 1984b,c, 1985a). Annual denitrification, found mostly to occur in the top 10 cm of soil, was estimated to be approximately 30 kg N $ha^{-1}yr^{-1}$ (Lowrance et al. 1984c, Hendrickson 1981, Ambus and Lowrance 1991). Riparian zone may also accumulate nutrients in aboveground woody biomass. Lowrance et al. (1984c) and Fail et al. (1986) estimated about 50 kg N $ha^{-1}yr^{-1}$, are stored in the riparian forest of the Little River Watershed. These nutrients can be permanently removed with tree harvest.

Riparian areas are efficient traps of sediments as well as nutrients. Although average erosion rates from cropped lands in the Little River watershed were estimated to be 15,000-20,000 kg $ha^{-1}yr^{-1}$, 99% of this sediment was trapped resulting in relatively low concentrations of sediments in

streamflow (Sheridan et al. 1991). Heede (1991) described similar sediment retention efficiency for vegetated riparian zones in a radically different and western watershed.

Upland Riparian Zone Research

The Northeastern Watershed Research Laboratory has measured water and nutrient movements in ridge and valley watersheds in central Pennsylvania. Land use was 57, 35, and 8% cropland, forest, and pasture, respectively (Schnabel et al. 1990). Although comprising only 2-4% of the watershed, the nearstream zone exerted major controls on streamflow chemistry and hydrology (Pionke et al. 1988). Stream nitrate concentrations were found to be dependent on the amounts of surface runoff, groundwater inflow, and rainfall present. Each of these contributors to streamflow were found to have different concentrations of nutrients. Schnabel (1986) and Schnabel et al. (1990) found that shallow groundwater contributed a greater proportion to streamflow following storm events. Based on this information Pionke et al. (1988) developed a conceptual model of near-stream zone hydrology.

Western Montane Riparian Zones Research

The Landscape Ecology of Rangelands Research Laboratory has investigated the effects of cattle grazing on plant communities and water and nutrient movements in northern Sierra Nevada montane meadows. Grazing was found to have virtually no effect on water table, soil redox potential, and shallow ground water nitrogen concentration in these N-limited meadows (Riegel et al. 1991b). Plant community composition, vegetative growth (Riegel et al. 1990, 1991a; Svejcar et al. 1991), and root densities (Manning et al. 1989), were primarily dependent on water table depth. Successful establishment of shrubby willows (*Salix geyeriana* and *S. lemmonii*) (Conroy and Svejcar 1991, Svejcar et al. 1991) was also dependent upon depth of water table. Lowering of water table depth due to channel downcutting could severely impact plant physiology and production.

Estuarine Buffer Zone Research

Parken et al. (1988) of the Environmental Chemistry Laboratory conducted research which examined the removal of nitrate from groundwater moving from soybean fields through a grass buffer strip, a forest and a marsh before the Wye River, a tidal river tributary to Chesapeake Bay. Comis (1990) reported nitrate declined most rapidly during winter while plants are dormant, indicating denitrification as a mechanism for nutrient removal. Research is complicated by the variable hydrology of the site which changes seasonally due to tidal influence (Parken et al. 1988).

Riparian Zone Restoration

Bowie (1982) and Grissinger and Bowie (1982), at the National Sedimentation Laboratory, studied the use of riparian vegetation and structural materials to control stream bank erosion as well as channel-riparian zone vegetation interactions. Shields et al. (in press) have developed aquatic habitat restoration techniques for unstable, agricultural channels using native black willow (*Salix nigra*) in combination with stone to promote improved habitat for fish and macroinvertebrates at base flow. A 1.5 ha riparian forest along with a first-order stream channel has been restored with native tree species including yellow poplar (*Liriodendron tulipifera L.*), green ash (*Fraxinus pennsylvanica* var *biflora* (Walt.) Sarg.), and slash pine (*Pinus elliotti* Engelm.) and will be treated with liquid dairy waste to examine nutrient movement and uptake by a restored riparian forest.

Constructed Wetlands

Researchers at the National Sedimentation Laboratory in cooperation with the SCS built a constructed wetland for the treatment of dairy farm waste in northwestern Mississippi. Waste water from an anaerobic lagoon was gravity fed to 20 ft. by 80 ft. wetland cells planted in giant

bulrush (*Scirpus validus*). Cooper et al. (1993) measured calculated reductions in fecal coliform, ammonia, chlorophyll and BOD of 96%, 91%, 77%, and 70%, respectively. Filterable ortho-phosphate and total phosphorus were reduced by 57% and 70%, respectively, using a constructed wetland to treat dairy cattle waste.

Scientific Challenges

A seemingly simple, but necessary challenge that faces ARS researchers is in defining what is or what is not a wetland or riparian zone. Although several authors have attempted to define these ecosystems, there is no agreement on definition among scientist, managers, or lawmakers (Smith 1980, Zinn and Copeland 1982, Lefor and Kennard 1977). Perhaps the most widely accepted and most comprehensive definition of wetland is the one adopted by the U.S. Fish and Wildlife Service (Cowardin et al. 1979). Riparian habitat is even more difficult to define or delineate. This is a difficult issue to resolve because of the indefinite character of wetlands and riparian zones. These habitats are ectones between dry land and deep water. Before research goals can be established or results can be coordinated, a common language must be developed. Although, some researchers and resource managers are delineating wetlands, as ARS scientists we must decide if their definition is sufficient to meet our research needs? Other related issues that should be addressed are: "Do we have adequate technology to delineate aquatic resources? Can we use remote-sensed data to delineate wetlands and riparian areas? How do you define the boundaries of a wetland or riparian area? What information do we need to define these environments."

A cross-cutting issue concerning wetlands and riparian zones identified during the USDA Water Resource Research and Technology Transfer Workshop was the need to help managers set a clear goals for wetland/riparian management. Goals should address society's needs and yet be practical enough to allow for a reasonable chance of success. Scientific challenges that face ARS researchers include testing various management strategies so the reasonable estimation of success might be extrapolated to different resources through out the United States.

Often the success or failure of an environmental management strategy is "in the eyes of the beholder." For example what might meet SCS needs might not be acceptable to EPA. A critical question that must be answered is "How do we evaluate wetlands/riparian resources and management strategies?" An agreed upon standard of measurement will be required. This standard might use biological criteria such as species diversity, community composition, or productivity, or may incorporate hydrological, chemical, or physical characteristics or some combination. A possible solution might entail the identification of references resources so that researchers and managers alike would have a "yard stick" by which to measure successful management or technology. Related challenges include measuring functional value of wetlands and riparian zones, evaluating wetlands and riparian zones while taking into account tremendous natural variability within these systems and developing a fundamental understanding of wetland/riparian resource function in time and space.

A third major challenge that must be addressed by the ARS scientist is evaluating what impacts various agricultural practices have on our wetland/riparian resources. Further research is need to determine the effects of water borne pollutants such as excessive nutrients, sediment and pesticides and metals on wetlands and riparian areas. Additional research is needed to evaluate the effects of grazing on riparian habitats, particularly in the arid western states. More information is needed to fully understand the hydrologic function of wetlands and riparian zone. Not only is research needed to understand what hydrological effects channelization, levee construction and regulation of flood

regime has on these resources, but also how do these aquatic habitats affect floodwater storage and abatement. Other hydrology related issues include the impact of water diversion, direct water withdrawal or pumping from riparian zones on these aquatic resources. One of our greatest current challenges will be to more directly relate riparian and wetland processes to the upland hydrologic events that ultimately drive in-stream availability of water. These upland events will determine the spatial and temporal variability, of water in riparian/wetland areas and, therefore, processes associated with water quality and instream plant and animal life.

A related scientific challenge addressed in the USDA Water Resource Research and Technology Transfer Workshop included developing ways of protecting these ecosystems in a way that is sensitive to agricultural needs and formulating repair strategies such as restoration or rehabilitation for damaged ecosystems. Further research is needed to develop restoration/rehabilitation methods that are based on hydrologic manipulation and/or re-vegetation. Key plant species that exert the greatest influence on success or failure of a restoration or rehabilitation project should be identified. Adequate sources of this material must be located. ARS research may develop these plant materials as a new agricultural product.

The fourth scientific challenge addressed in the USDA Water Resource Research and Technology Transfer Workshop included issues of scale. Most research, management and restoration/rehabilitation efforts have been on small scale "manageable size" locations such as subwatersheds, 1 km stream reaches, or 0.1 ha wetland cells. Although "do-able," small scale projects are not always applicable or suitable for answering questions in a landscape context. Integrated aquatic ecosystem restoration also requires a broader approach that include linking wetland/riparian processes to upstream and downstream features. ARS scientists must first determine what is the most effective scale at which the most significant improvements in habitat quality can be made.

Research Opportunities

ARS should direct some research efforts in developing new technology to delineate aquatic resources. Techniques using remote sensed data and geographical information systems (GIS) to delineate wetlands and riparian areas should be developed.

ARS scientist should develop evaluation techniques and criteria for the evaluation of resource management, restoration/rehabilitation projects, and assessing ecological damage from off site sources. Research should identify reference resources as a standard by which to measure successful management or technology. A fundamental understanding of wetland/riparian resource function in time and space would aid ARS research in measuring functional value of wetlands and riparian zones and in evaluating wetlands and riparian zones while taking into account tremendous natural variability within these systems. More information is needed to fully understand the hydrologic function of wetlands and riparian zones. Not only is this research important in understanding of what hydrological effects physical changes to watersheds might have on wetlands and riparian habitat, but also how do these aquatic habitats affect floodwater storage and abatement.

ARS researchers should test various resource management strategies so that better alternatives may be passed on the managers. Better management strategies may reduce the effects of grazing on riparian habitats, particularly in the arid western states. Hydrology research could provide information needed by resource managers to reduce impact of water diversion, direct water withdrawal or pumping from riparian zones.

Research is needed to evaluate what impacts various agricultural practices have on our wetland/riparian resources. Further research is need to determine the effects of non-point source pollutants such as suspended sediments, excessive nutrients and pesticides on wetlands and riparian areas.

To date no wetland restoration project has recreated a fully functional wetland that has maintained regional biodiversity (Committee on Restoration of Aquatic Ecosystems: Science, Technology and Public Policy, 1992). Further research is needed to develop restoration/rehabilitation methods that can recreate fully functional wetlands, at the most effective scale to provide the most significant improvements in habitat quality.

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