MANAGING WATER QUALITY IN WETLANDS WITH FORESTRY BMP'S*

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Abstract. Forested wetlands are uniquely critical areas in forest operations that present special challenges to protect water quality. These locations are a direct interface between the impacts of forest operations and water. BMP's are designed to minimize nonpoint source pollution, but much of the science behind current guidelines is based on an understanding of erosion processes in upland situations. In wetlands and around temporary stream crossings, redirection of flow, sedimentation processes, and alterations of How velocity become important. Existing forested wetland BMP's appear to adequately address water quality protection. If existing BMP's became prescriptive regulations, however, there is potential for mis-application and unintended ecological impacts.

Keywords: erosion, forest harvesting, hydrology, roads, sediment, timber

1. Introduction

Forested wetlands are a critical component of the modern southern forest landscape (Ainslie, 2002). The 35 million ha of forested wetland in the southern U.S. are a significant portion (65%) of the nation's forested wetlands and account for one-sixth of all southern forestland. Nearly all of these wetlands (91%) are riverine, placing them in the critical ecological position between uplands and receiving waters. Although they are generally highly productive forests, wetlands serve a much broader role ecologically. Riparian forests act to filter surface and subsurface flows, storing sediment and nutrients (Craft and Casey, 2000). Biogeochemical interactions among passing water, vegetation, and wetland soils affect water chemistry (Clawson et *al.*, 1999; Perry *et al.*, 1999; Snyder *et* ccl., 1998), improving downstream water quality. Forested wetlands are also dynamic environments that exhibit a wide variety of hydrogeomorphic features (Hodges, 1997) leading to diverse floristic and faunal communities. The rich environment supports recreational use including hunting, wildlife viewing, and outdoor enjoyment. Thus, the ecological functions of wetland forests are important far beyond the spatial boundaries of the wetland.

Forested wetlands, however, are susceptible to damage. Attempts to make wetlands more amenable to development through drainage have resulted in permanent loss of wetland acres. Ainslie (2002) observed that the primary cause of forest

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TABLE I

Annual disturbance source of wetland forests that are retained in timberland (Brown *et al.*, 2001)

Disturbance type	Forested wetland area affected	
	Acres	% of total
Final harvesting	294,800	1.67
Thinning or partial cut	72,100	0.41
Site preparation	106,900	0.61
Natural disturbance	375,400	2.10

wetland loss has shifted from agricultural conversion to urbanization. Less than 13 percent of wetland loss from 1982 to 1992 was attributable to silvicultural activity (Brady and Flather, 1994). Although silviculture is not a primary cause of forested wetland loss, the continuing development pressure on extant wetland acreage makes it imperative to manage these forests sustainably and responsibly, with appropriate recognition of the unique ecological functions values that arc involved (Table I).

The public understands that these areas are unique ecologically and threatened by deterioration and landuse change. Environmental concerns helped pass the Clean Water Act (CWA) in 1972 and have maintained pressure to address wetland protection through amendments and new program directions. In 1989, for example, President Bush defined a 'no-net-loss' of wetlands goal. Reflecting public sentiment that more emphasis needed to be placed on environmental issues, President Clinton announced the Clean Waler Action Plan (CWAP) in 1998. One element of the CWAP directed Federal and State agencies to examine, revise and improve existing standards and programs that protect water quality.

The primary method of wetlands water quality protection is Best Management Practices (BMP's) for forest operations. Each state has developed their own set of guidelines appropriate for their specific conditions. While most measures of' effectiveness suggest that adherence to existing BMP's minimizes adverse impacts, it is appropriate to consider the origin and application of wetland forestry BMP's in order to determine whether existing guides may be improved to meet the future demands of wetland forest resource management. By definition, best practices will evolve with time as experience and scientific understanding develop.

2. Current BMP's for Forested Wetlands

The CWA directed states to develop programs to control nonpoint source (NPS) pollution and to monitor water quality improvement. All of the southern states have developed BMP manuals and guides for forestry, most have specific sections and provisions for wetland forests (Aust, 1994). Kentucky is the only one of the 13 southern states with a regulatory program, although several others require adherence to water quality standards and accept BMP's as the most appropriate method to comply (Prud'homme and Greis, 2002). Additional impetus for implementation comes from the Sustainable Forestry Initiative (AF&PA, 2002). This industry-sponsored program requires participating companies to meet or exceed all BMP's and applicable state water quality laws and standards.

In addition to the state BMP's, forest operations in wetlands must be part of ongoing, normal silvicultural activities in order to be exempt from federal permitting requirements under the CWA (40 CFR 232.3). Construction of forest roads is only exempt from federal permitting if the activity complies with 15 mandatory BMP's (Table II).

In 1995, the U.S. Army Corps of Engineers and the EPA issued a clarifying memorandum to define additional specific BMP's that exempt certain mechanical site preparation methods from permitting requirements in wetlands. These include: minimize soil disturbance during shearing, raking and piling; avoid excessive compaction; arrange windrows to limit erosion; prevent disposal of logging debris in streamside management zones; maintain natural site contour; and use appropriate water management mechanisms to limit off-site impacts.

3. Wetland Hydrology and Forestry Impacts

The combination of the federal requirements and state BMP guidelines is intended to address the primary causes of water quality impairment associated with forest activities in wetlands. Each BMP recommendation should have some theoretical foundation connected to a scientific understanding of the hydrologic processes that affect water quality in wetlands. The general processes are well-known. Water inputs occur through subsurface flow from adjacent areas, rainfall, streamflow, and overland flow in flood events. Water leaves the wetland system through evapotranspiration, infiltration and subsurface flow, streamflow and overland flow. A number of hydrologic models (e.g., Sun *et* al., 1998a; Sun *et al.*, 1998b) have been developed to evaluate silvicultural manipulations of specific wetland types.

3.1. Harvesting effects on forested wetlands

One of the most common results of wetland harvesting operations is a rise in water table resulting from reduced evapotranspiration (ET) after vegetation removal (Xu *et al.*, 2002; Sun *et al.*, 2000). This effect is most pronounced during the growing season and generally returns to baseline conditions within several years. It is significant to note that the harvesting impact on water table depth does not generally affect wetland hydroperiod, since dormant season ET is negligible anyway.

TABLE II

BMP's required for exempt road construction in wetlands (40 CFR 232.3)

Best management practice	
(i)	Permanent and temporary roads and skid trails shall be held to the minimum feasible number, width and total length
(ii)	Roads shall be located sufficiently far away from water bodies to minimize discharge of fill material into water
(iii)	Roads shall be designed to prevent the restriction of Hood flows
(iv)	Fills shall be stabilized and maintained to prevent erosion
(v)	Minimize equipment operation outside the area of fill
(vi)	Minimize vegetative disturbance in waters
(vii)	Road crossings shall not disrupt migration or movement of aquatic organisms
(viii)	Fill shall be taken from uplands whenever feasible
(ix)	Discharge shall not take or jeopardize threatened or endangered species
(x)	Discharges into waterfowl habitat shall be avoided if alternatives exist
(xi)	Discharge shall not be proximate to public water supply intake
(xii)	Discharge shall not occur in areas of concentrated shellfish production
(xiii)	Discharge shall not occur in a component of the Nat'l Wild and Scenic Rivers
(xiv)	Discharge shall be free of toxic pollutants
(xv)	Temporary fills shall be removed and restored to original elevations

Because the water table response is mediated by vegetation, operations such as site preparation that differentially affect surface vegetation can alter the magnitude of water table rise. Xu *et al.* (2002) found that harvesting during the dry season, coupled with site preparation that avoided bedding, had the least effect on water table levels. Water table elevation could affect downstream water quality if it resulted in increased forest water yield and transport capacity. Sun *et* al. (2001), however, summarize a number of studies and conclude that:

1. The magnitude of water yield increases due to harvesting wetlands is less than similar disturbances of upland sites.
2. Controlled drainage associated with forest management can actually increase water retention compared to free drainage.
3. Hydroperiod of bottomland forests is usually determined by upstream precipitation events rather than on-site disturbance.

In-woods traffic associated with ground-based forestry operations can alter soil physical properties and thus affect infiltration rates, hydraulic conductivity and surface flows. Generally, heavy wheeled or tracked equipment operating on soft or wet soils create ruts and churned areas. With wide-tired equipment, soil compaction is not the most significant impact on wet soils (Aust *et al.*, 1993; McDonald et *al.*, 1995) although other studies (e.g., Gent *et al.*, 1983) have documented bulk density increases. The greater effect of traffic is the alteration of soil structure that impedes the movement of air and water. Aust *et al.* (1 993) observed that rutting reduced porosity and saturated conductivity resulting in increased soil moisture retention and elevated water tables. More detailed examinations (Miwa *et* al., 1998) documented lower water holding capacity, sorptivity, and slower internal drainage associated with ruts. Older ruts (2-yr post operation) were exhibiting recovery of drainage characteristics. Aust *et al.* (1998) compared helicopter-logged and skidder-logged sites ten years after harvesting and found little difference in stand development. There were some indications that the soil impacts of skidder ruts may have favored more moisture-tolerant species, although natural successional processes coupled with soil property recovery were eliminating differences.

In order to avoid the hydrologic impacts of rutting, most state wetland BMP guidelines include recommendations to:

1. Plan to operate ground-based equipment during dry periods.
2. Minimize the area of ruts by concentrating traffic on main skid trails.
3. Use special logging systems such as low-ground pressure machines, shovel logging, cable systems, or helicopters when site conditions are too wet.

To meet simple operability concerns, equipment for alternative forest operations has been developed to use on soft or wet soils (FRA, 1999; Stokes and Schilling, 1997). Carruth and Brown (I 996) found that conventional harvesting systems could be used when soil moisture content of the surface soil was below 35 percent. Between 35 and 40 percent moisture content, soil type variations determined the need for special equipment. Above 40 percent moisture content, operability requires tracked feller-bunchers, shovel logging or other special adaptations (Klepac and Rummer, 2002; Rummer *et al.*, 1997b).

Soil disturbance by forest operations, rather than soil physical property alterations, is a different issue. Freshly exposed or loosened soil can be more easily detached through erosion. Askew and Williams (I 984), however, examined sediment transport on intensively disturbed wetland sites and found that clearcut logging, site preparation and road construction resulted in minimal sediment export as long as equipment operation avoided working directly in the drainage ditches. With very low hydraulic gradients, wetlands are generally areas of sediment deposition and detached materials are unlikely to be transported very far. Thus, most BMP guides emphasize keeping soil disturbance away from flowing water by maintaining acceptable streamside management zones (SMZ). While selective harvesting is often permitted within an SMZ, the primary BMP objective is to protect streambank stability and to avoid traffic ruts that create hydrologic connectivity through the buffer strip.

The primary hydrologic impact of forest harvesting on wetlands is elevated water tables, a combined result of reduced ET and altered surface soil properties from traffic. The 'wetting up' of a site is recognized as a transient effect, although full recovery to preharvest conditions may take many years. Re-establishment of the forest stand is the main driver that restores hydric balance. Studies such as Wynn et *al.* (2000) have shown that following the basic BMP's of adequate SMZ areas and skid trail closure is effective in minimizing off-site effects of forest harvesting in wetlands. Post-treatment evaluations of wetland functions (e.g., Rapp *et al.*, 2001; Aust *et* al., 1998) show little significant difference between operable ground-based harvesting and less disruptive harvesting treatments such as helicopter logging. From a landscape perspective, with approximately 2.5% of forested wetlands disturbed by harvesting and site preparation activities in any year, adherence to existing BMP's should be sufficient to protect water quality.

3.2. WETLAND FOREST ROADS

Forest roads are typically identified as the primary cause of' water quality impacts resulting from forest operations. There are many references to water quality impacts from studies of upland forest roads, however relatively few have specifically focused on wetland forest roads. There are several significant differences between erosion concerns on upland roads and wetland roads that should be examined when evaluating appropriate BMP's.

On upland roads (Figure 1), rainfall impacts the road surface directly or enters the road section as overland flow from upslope, or as intercepted subsurface flow appearing in the cutbank. Runoff is concentrated in ditches and directed to cross-drains. Exposed soil on cut and fillslopes repose at steeper grades than the natural sideslope. Because of the steepened grades and concentrated flows, transport capacity of the runoff is increased and sediment yield is supply-limited. Erosion control practices focus on quickly getting water off the travelway and dispersing runoff to reduce erosive energy. Luce and Black (1999) measured several factors affecting sediment yield including road slope, slope length, soil type, and maintenance. Actively maintained and trafficked roads have significantly higher sediment yields than less disturbed roads (Ziegler *et al.*, 2001). Elliot *et al.* (1999) describe a process-based erosion model to predict sediment yield from upland roads and to design appropriate erosion control practices.

Forest roads in wetlands arc distinctly different. Slopes are generally insignificant to minor with correspondingly lower erosive energy in overland and ditch flow. Subsurface flow is important to maintain, but is rarely intercepted by fill road construction (in upland roads, subsurface flow is interrupted when the uphill cutbank is deeper than the water table). Drainage ditches in wetlands, however, may be cut below grade specifically to intercept subsurface water and control water table depth. Overland flow in wetlands may occur as flood sheetflow with huge volumes of water from upstream watersheds and extended periods of inundation. With large

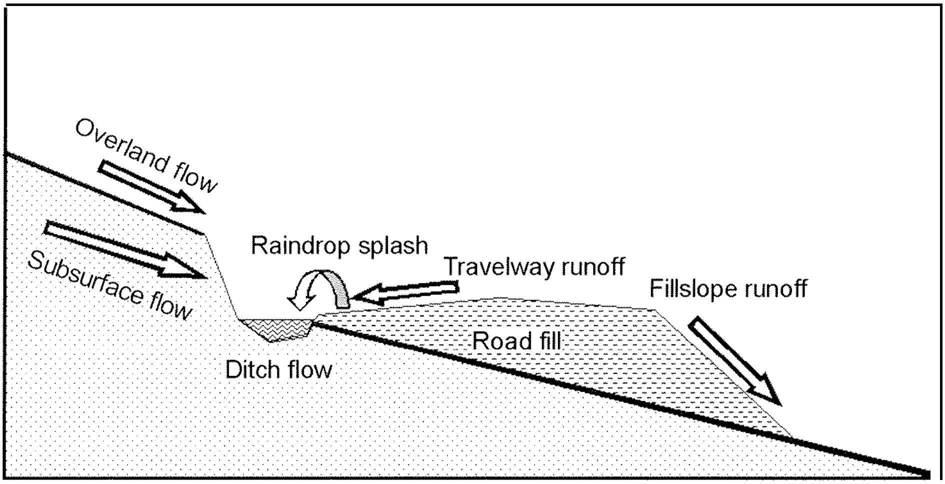

Figure 1. Water movement and erosion pathways for upland forest roads.

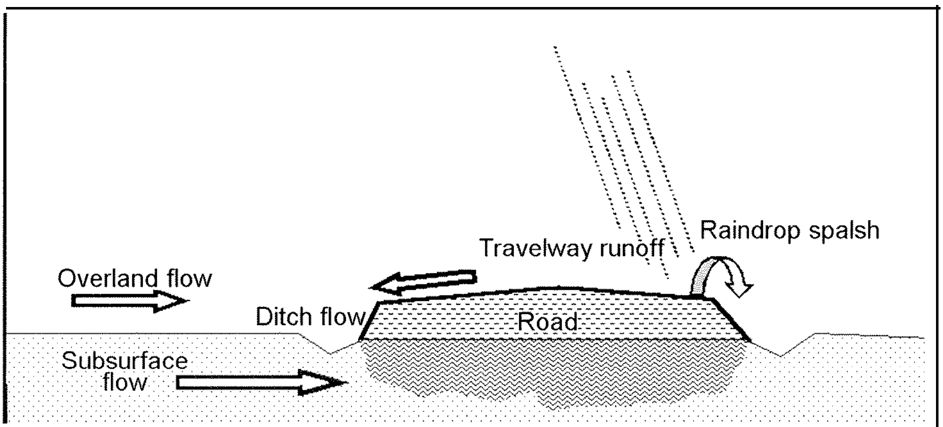

Figure 2. Water flow and erosion pathways on a wetland forest road.

inputs of sediment from off-site flow and the lower erosive energy in flat lands, sediment yield in wetland forest roads is generally transport-limited. Deposition occurs readily from sediment-saturated water when velocity decreases.

Appelboom *et al.* (2002) found that wetland forest roads generated little sediment beyond the travelway. Containing surface runoff with a berm to cause infiltration reduced sediment yield in the roadside ditches by 99 percent compared to an unsurfaced road. Simply graveling the road surface reduced sediment loss by 67 percent. Rummer *et al.* (1997a) and Rummer (1999) examined sedimentation associated with inundated wetland roads. Different road surfacing treatments had no significant effect on sediment generation. Road design, however, was significant. A conventional crowned road constructed by pulling material from side ditches to the road centerline was compared to a flat profile road constructed by simply flat-blading the surface. The crowned road acted as a net sink for sediment, while the low-profile road proved to be a small source of sediment.

The impact of wetland roads on water quality is driven by the interaction of road design and water velocity. Design features that constrict flow and increase velocity will generate sediment, while features that slow water will cause deposition. Ditches and ruts, for example, are sediment sinks where water pools and settles. Cross-drains, stream crossing abutments, and road crowns on the other hand, are critical areas that may experience increased water velocity and erosion.

Cross-drainage is necessary to avoid ponding or impoundment on the upstream or upslope side of a road. Upland road BMP's emphasize regular cross-drain spacing at intervals determined by road slope. In wetland roads, cross-drains are more simply placed at the low spots. Sizing may be difficult, particularly if flooding occurs. Culvert pipes are susceptible to plugging by debris or beavers. A study in New York (Jensen *et al.*, 2001) found that pipes needed to be over I m in diameter to discourage beaver plugging. Several states recommend 0.6 m culverts as a minimum BMP. Given the cost and installation requirements for such pipes, a feasible alternative is a hardened road dip.

Broad-based dips were originally designed as cross-drains for upland roads to ensure that water running down the travelway would be diverted to a ditch. In a wetland situation, a broad-based dip serves as an open-top cross-drain to channel water across the road surface. If subgrade soils are soft, hardening the bottom of the dip with rock or geotextile and rock may be necessary. Using dips for cross-drains reduces maintenance and avoids plugging problems.

Stream crossings involve more consideration to sizing and installation. Most BMP guides provide a table to estimate culvert size required based on watershed area. For upland roads, size should be adequate to handle extreme events. In a wetland, however, it is more appropriate to install crossings anticipating that they will be overtopped. Some states (e.g., South Carolina) illustrate the installation of pipes with hardened spillways to handle the initial overtopping flows. Temporary bridge crossings can handle excess flow by simply floating out of the way. With adequate anchors in place, the temporary structure can be re-installed after extreme events.

Most wetland road BMP's state that fills, particularly around stream crossings, should be properly stabilized. Stabilization serves to anchor soil and to increase surface roughness. Proper stabilization needs to be selected based on the type of flow expected. Vegetative stabilization is adequate for flow velocities below about 1.3 m/s (Ring, 1978). Where higher water velocity is expected, rip-rap armoring would be necessary. For wetland roads oriented across the expected flow direction, gravel surfacing may be necessary to protect the road surface from the increased velocity of overtopping flow. Roads that parallel Aoodfiows, however, may be adequately stabilized with vegetation.

The few studies of wetland forest roads show that sediment movement can be minimized through some basic practices. Planning is clearly important-placing roads in wetlands with an understanding of how to avoid problem locations. Most sediment will be generated from specific areas, generally where water velocity is greatest. Stabilization methods adequate for the expected velocity should be employed. Finally, cross-drain and stream crossings should be designed to maintain their integrity in overtopping events without mass failures of the road fill.

4. Discussion

The literature generally shows that when current BMP's are followed, the impacts of forest management on water quality in wetlands are minimal and short-lived. Because of the natural filtration and storage functions of forested wetlands, sediment export is not a significant issue. The appropriate focus of water quality BMP's should be on maintaining or enhancing these ecological functions. While current BMP's are apparently effective, is there any way you can go wrong following their guidance'?

One direction that may have the greatest potential for mis-application is the general recommendation to minimize forest roads in wetlands. The basis for this is an understanding that forest roads are the source of most adverse water quality effects. Therefore it seems reasonable that getting rid of roads will get rid of the adverse effects. The problem here is that forest roads are an integral part of the overall management system, providing access for efficient timber management and recreation. An efficient access system is linked to the terrain, off-site transportation networks, and type of local forest operations. The federal wetland road BMP's recognize these points and include qualifying words such as minimum feasible', 'consistent with the purpose . . . and local topographic and climatic conditions'. Simply reducing roads without careful consideration of the rest of the management operation may only exchange one impact for another.

A rubber-tired skidder system, for example, forced to operate with wider road spacing will have more loaded passes over the main extraction trails, possibly resulting in greater soil disturbance in the stand. Standard procedures are available to estimate economically optimal road spacing based on local roadbuilding costs and extraction costs for a typical logging system. Using a classical formula for economically-optimal road spacing and the following assumptions:

- $6,214/km road building cost
- 4.8 km/hr for off-road skidding
- $70/Scheduled Machine Hour (SMH) for rubber-tired skidders
- $90/SMH for clambunk skidders
- 561 tonnes/ha

would give you an optimum road spncing of 185 m for a skidder system, 460 m for a shovel logging/clambunk system. Another way to look at it would be about 2.2 km road/km’ for a clambunk system, 5.5 km road/km’ for a skidder system. While different harvesting systems will work efficiently at different road densities, the type of logging system should be selected for the stand and management constraints. Then an appropriate road network can be designed that provides sufficient access to support the operation.

Another BMP guideline that may be mis-applied is the recommendation to minimize tills for road construction. The intent is to avoid impeding or re-routing overland flow. However, depth of fill for road subgrades should be based on criteria for developing adequate road strength to support traffic. A subgrade that is too weak will lead to rutting and road failure. Failed forest roads can have adverse impacts as traffic either makes the hole deeper or finds alternative routes around the failed section.

Clearly, improperly implemented forest operations can damage resources and water quality. However, the interests of lggers, landowners and water quality proponents are all served by having a well-built, well-planned operation. Roading, for example, is a significant expense that everyone wants to minimize. Building the minimally-sufficient road network is in the interests of all. Rutting and site damage should be avoided. When harvesting systems begin to generate significant rutting, cost-effectiveness begins to suffer. Productivity drops and costs rise. Again, the interests of cost-effective operation and reduced water quality impacts are consistent. Because of the common benefit of avoiding site impacts in wetlands, the most effective approach to improving compliance would appear to be better training for loggers and forest landowners on how to plan and implement the most cost-effective and ecologically-sensitive operation.

BMP’s represent a consensus approach to defining appropriate forest operations practices for wetlands. In most cases, the HMP recommendations for forested wetlands have a basis in scientific principle. In fact, the literature shows that existing BMP’s make a difference in water quality. As performance guidance, BMP’s are useful to incorporate water quality protection into operational plans. If they were to become prescriptive regulatory requirements without site-specific flexibility, however, existing BMP’s could be mis-applied in some situations leading to unintended costs and ecological impacts.

Additional research and development of improved BMP’s should be pursued. There is a lack, particularly of forest-road related studies, in the scientific literature of forested wetlands. Given the wide range of wetland types and management systems, additional work should be undertaken to examine effects of soils, flooded vs. non-flooded systems, and typical maintenance practices. BMP’s arc a culmination of knowledge and further studies will lead to better BMP’s for the future.

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