JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
VOL. 36, NO. 6 AMERICAN WATER RESOURCES ASSOCIATION DECEMBER 2000

# METHOD TO IDENTIFY EFFECTIVE RIPARIAN BUFFER WIDTHS FOR ATLANTIC SALMON HABITAT PROTECTION[1]

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ABSTRACT: Successful restoration of declining anadromous species is dependent upon effective riparian buffer zone management. Natural resource managers, policy developers and local conservation groups require science-based information concerning the width at which a given buffer will be effective for its stated purpose. This paper summarizes a method developed in 1999 to determine effective riparian buffer widths for Atlantic salmon habitat protection as part of the Atlantic Salmon Conservation Plan for Seven Maine Rivers. A major assumption of the method is that no two buffers are alike with respect to their effectiveness and that various buffer characteristics dictate the required width for a given level of effectiveness. The method uses a predictive model that generates suggested riparian buffer widths as a function of specific, measurable buffer characteristics (such as slope, soil characteristics, and plant community structure and density) that affect buffer function. The method utilizes a variable-width, two-zone approach and specifies land uses that are consistent with desired buffer function within the two zones.

(KEY TERMS: riparian buffer; watershed management; buffer width; buffer function; Atlantic salmon; declining species management; water quality; modeling.)

## INTRODUCTION AND BACKGROUND

Atlantic salmon (*Salmo salar*) populations have declined on several river systems in rural Maine over the last 15 years. Those rivers contain what many scientists believe are the last remaining native runs of this species in the United States (NMFS and USFWS, 1999). On November 13, 2000, as a result of small numbers of this species returning to spawn, and in response to law suits by conservation groups, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service jointly listed the Gulf of Maine wild Atlantic salmon as endangered under the Endangered Species Act. This paper summarizes a "Method to Determine Optimal Riparian Buffer Widths for Atlantic Salmon Habitat Protection (method)" (Kleinschmidt, 1999). The method was developed for the Maine State Planning Office as part of the state's Atlantic Salmon Conservation Plan (Plan) to protect critical salmon spawning and rearing habitat, as identified by the U.S. Fish and Wildlife Service and the Maine Atlantic Salmon Commission, from potential land use impacts. The method identifies the width and type (e.g., fixed or variable width, zoned or unzoned) of riparian buffer zone that should be targeted during implementation of the Plan. It is a scientifically-based method intended to be applied by watershed councils, private landowners, industry, conservation groups, or government agencies to buffer target stream reaches.

For purposes of this method, "riparian buffer zone" was defined as a naturally vegetated terrestrial area bordering streams and rivers. A more widely cited definition of riparian zone that would also apply is: "A three-dimensional zone of interaction between terrestrial and aquatic ecosystems" (Gregory *et al.*, 1991). By three-dimensional, this definition and others take into account that riparian buffer zones extend down into the ground water, up into the canopy, out across the floodplain, and into the slopes that drain to the water course at a variable width (Gregory *et al.*, 1991; Ilhardt *et al.*, 1998).

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[1] Paper No. 00040 of the *Journal of the American Water Resources Association*. **Discussions are open until August 1, 2001.**

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Riparian buffer conservation and management have generally been identified as one important component of a comprehensive effort to protect declining salmonids such as Atlantic salmon (Moring and Finlayson, 1996; Murphy, 1995; Spence *et al.,* 1996), or efforts to protect water resources and their associated riparian zones in general (Chase *et al.,* 1997; Chesapeake Bay Program and U.S. EPA, 1997; Leff, 1998). The resource manager or policy architect must determine appropriate buffer widths for intended objectives, and appropriate land uses that can occur within the riparian buffer zone.

This method recognizes that no two riparian buffer zones are alike with respect to their characteristics or function. It utilizes a variable-width approach based on specific buffer characteristics that either reduce or enhance buffer effectiveness. The method also recognizes that certain limited land uses are consistent with desired buffer functions in the outer portion of the buffer and uses a two-zone approach based on proximity to the river. Zone 1 (no-cut zone), closest to the stream, is a fixed width of 35 ft in which no disturbance to soils or vegetation should occur. Zone 2, landward from Zone 1, is a variable width zone where only limited uses that do not compromise the desired functions of the riparian buffer, such as light recreation and light tree harvesting subject to Best Management Practices (BMPs), should occur. The method generates suggested total optimal buffer widths (Zone 1 plus Zone 2) that range from a minimum of 70 ft to a maximum that is typically not more than 300-400 ft. In very rare cases (e.g., extensive slopes greater than 25 percent), optimal buffer widths can be 1,000 ft or more.

Explanations for these numbers are provided in this paper, but it is important to note that effective buffer widths will change from region to region and as a function of buffer conditions, management objectives, and in-stream characteristics. In addition, conceptual models or methods such as this one need to be considered somewhat qualitative at this time and potentially subject to change, since scientific literature provides the direction of relationships (e.g., direct or indirect) between buffer characteristics and buffer effectiveness, but precise/quantitative data is not always available or in agreement. For functions such as shading and woody debris inputs, the literature provides fairly quantitative/definitive guidance; but for other functions, such as water quality, there is a wider range of scientific opinion. The authors believe that there is significant value in this method, which takes the best available science and uses this to develop a real-world management tool tailored to a specific region and objective. As discussed further in the "Discussion" section, the numbers generated are necessarily approximations.

### *Atlantic Salmon Life History and Habitat Requirements*

Atlantic salmon is an anadromous species inhabiting the northern portion of the Atlantic Ocean basin from Greenland to the Canadian maritime provinces to the Connecticut River in New England. One summary of the life history of Atlantic salmon specific to eastern Maine and southeastern Canada has been provided by Stanley and Trial (1993). These fish spawn in freshwater streams that are tributary to the Gulf of Maine in October and November when water temperatures reach 4.4-5.6°C. Eggs are deposited in redds at the downstream end of riffles or at upwellings of ground water in gravel. Eggs incubate over winter in gravel interstices. After hatching they remain buried in gravel until the yolk sac is depleted, which in Maine is in late May. Juvenile Atlantic salmon grow relatively slowly in freshwater and feed on a variety of invertebrates drifting on the surface and in the water column, whereas adults grow rapidly at sea feeding on larger prey items. Unlike Pacific salmon, Atlantic salmon adults can return to sea after their first spawn and potentially return to spawn again.

Scientists have developed habitat suitability criteria for Atlantic salmon (Stanley and Trial, 1993; Moring and Finlayson, 1996) that point to the specific riparian buffer functions that influence salmon habitat. The growth of Atlantic salmon in freshwater is limited by a variety of micro and macro-habitat parameters including food availability, interspecific and intraspecific competition, channel morphology, substrate, cover, and water depth, clarity, temperature, dissolved oxygen, and velocity. During summer baseflow the most suitable habitats for nonmigratory freshwater life stages (egg, embryo, fry, and parr) are defined by temperatures of 16-19°C, greater than 60 percent oxygen saturation, pH from 5.5 to 6.8, and current velocity of 10-30 cm/s for fry and 10-40 cm/s for parr (Stanley and Trial, 1993).

Naturally vegetated riparian areas are an important aspect of Atlantic salmon habitat. Human disturbance that significantly alters riparian buffer areas adjacent to or upstream of salmon streams can result in degradation of critical habitat. Since salmon lay their eggs in gravel nests in areas exposed to swiftly flowing waters, any land use that results in sedimentation can fill-in gravel beds. This can reduce suitable breeding substrate and smother salmon eggs as well as the many invertebrate species that inhabit the interstices between gravel and serve as important forage items for salmon. Increased turbidity (over background rates) associated with increased erosion and sedimentation can also injure the gills of salmon in all life stages and limit foraging success since this species hunts by sight. Water quantity is important with respect to suitable breeding and rearing habitat. Cool, well-oxygenated water maintained by canopy shading is another important aspect of salmon habitat. Trees and coarse woody debris inputs to salmon streams help create and maintain habitat for invertebrate prey items. Such woody debris inputs also help to create pools and riffles by influencing flow patterns and provide diverse structural habitat important for salmon.

### *Buffer Functions*

Buffer functions that are important with respect to Atlantic salmon habitat protection, as identified in the literature (Hewlett and Fortson, 1982; Bryant, 1983; Davies and Sowles, 1984; Lisle, 1986; Phillips, 1989a and 1989b; U.S. ACOE, 1991; Welsch, 1991; Sweeney, 1992; Ohio EPA, 1994; Chase *et al.,* 1997; Chesapeake Bay Program, 1995; Kahl, 1996; Mitchell, 1996; Moring and Finlayson, 1996; Spence *et al.,* 1996; Burton, 1997; Chesapeake Bay Program, 1997; Constantz, 1998; USDA Forest Service, 1998), are:

- **Water Quality Protection.** Buffers filter sediment and pollutants from upslope areas and stabilize stream banks.
- **Shading and Temperature Regulation.** Canopy cover helps maintain cool temperatures during late summer.
- **Regulation of Streamflows.** Buffers attenuate peak flows and maintain base flows through the storage and slow release of runoff.
- **Coarse Woody Debris and Other Organic Matter Inputs.** Forested buffers provide wood inputs that are important for salmon habitat structure/cover. Litter inputs are also an important energy source for the detritus-based community of aquatic macro-invertebrates and the entire aquatic food chain.

Riparian buffers provide the entire influence on in-stream habitat functions such as shading and organic matter inputs, whereas functions such as stream flow regulation and water quality protection are provided by the entire watershed (i.e., not just the immediate buffer). Therefore, management efforts such as this method should be considered only a component part of an overall watershed management approach. Note too that effects are cumulative. For example, overall water temperature through a river system is influenced by percent canopy cover over the entire riparian system, not just the specific buffer being evaluated (Spence *et al.,* 1996).

### *Buffer Attributes that Affect Buffer Function*

Buffer attributes that affect the degree to which buffers effectively perform desired functions (and so the width of riparian buffer needed to protect in-stream habitat) are described below. A range of biotic and abiotic buffer variables was considered, including attributes related to topography, vegetation, soils, hydrology, and topographic position. (It is beyond the scope of this paper to summarize all of the buffer widths reported in the literature as being effective for various functions, however there is ample data available, including many references that summarize the range of widths reported (Kleinschmidt, 1999).) Buffer attribute data (method input), in addition to correlating with buffer function, had to be readily measurable or available, easily replicated, and subject to as little subjective interpretation as possible. Buffer attributes chosen were slope, percent canopy closure, soil hydrologic group, surface water features, surface roughness, ground water seepage/springs, sand and gravel aquifers, floodplains and wetlands, and stream order.

Since factors such as sedimentation and reduced water quality reduce the quality of salmon habitat, slope and optimal buffer width vary directly. Slope has a strong relationship with erosion potential and other water quality factors such as retention or conversion of nutrients and chemical pollutants (Phillips, 1989a, 1989b; U.S. ACOE, 1991; Welsch, 1991; Ohio EPA, 1994; Chase *et al.,* 1995; Chesapeake Bay Program, 1995; Murphy, 1995; Spence *et al.,* 1996; Mitchell, 1996; Kahl, 1996; Correll, 1997; Chesapeake Bay Program, 1997; USDA Forest Service, 1998). Among all variables considered in the method, slope has the greatest (weighted) influence on calculated width.

A high degree of canopy closure is associated with several functions important for salmon habitat including optimal shading and organic matter inputs, nutrient and sediment retention (relative to cut forests with disturbed duff layers), and wind-firm conditions (Hewlett and Fortson, 1982; U.S. ACOE, 1991; Maine DEP, 1992; Sweeney, 1992; Chesapeake Bay Program, 1995; Spence *et al.,* 1996; Mitchell, 1996; Kahl, 1996; Correll, 1997; Jacobson *et al.,* 1997). Optimal buffer width and percent canopy closure are, therefore, inversely related.

Wooded buffers with a high degree of canopy closure, intact duff layers, and well developed shrub and herb strata generally provide greater uptake or retention of runoff and associated pollutants than do systems which have been selectively cut or disturbed (Maine DEP, 1992; Sweeney, 1992; Chesapeake Bay Program, 1995; Jacobson *et al.,* 1997). Much of the literature indicates, however, that nonforested systems can perform as well as or better than forested systems for sediment retention and uptake and retention of sediment-bound nutrients (Welsch, 1991; Chesapeake Bay Program, 1995; Lyons *et al.,* 2000), which is why some riparian buffer prescriptions call for a zone of low, dense grass-dominated vegetation upgradient from forest at the stream edge (Welsch, 1991).

Intact forested riparian areas also provide organic debris inputs which directly enhance salmon habitat through the provision of in-stream structural habitat characteristics from fallen tree and coarse woody debris input and indirectly enhance salmon habitat since wood and leaves provide food and habitat for detritus-based aquatic organisms such as macroinvertebrates (Dolloff, 1998). Woody debris inputs promote "hydraulic heterogeneity" by creating varied conditions such as pools, runs, and riffles (Ohio EPA, 1994; Jacobson *et al.,* 1997). Coarse woody debris also provides a mechanism for increasing buffer zone surface roughness in terrestrial areas and provides an energy source for denitrification, thereby limiting concentrated surface runoff patterns and enhancing the ability of the buffer to perform optimal water quality maintenance functions relative to degraded forests with reduced woody debris input (Chesapeake Bay Program, 1995; Correll, 1997).

Soils with low infiltration capacities and high runoff potentials (i.e., hydrologic group D soils as determined by USDA NRCS soils mapping) require greater optimal widths than soils with high infiltration capacities and low runoff potentials (i.e., group A and B soils). In general, the greater the infiltration capacity of the soils, the greater the ability of the buffer to perform water quality and water quantity functions (Welsch, 1991). Soils with a high infiltration capacity discourage concentrated, erosive flows, thereby reducing sediment and sediment-bound nutrient (i.e., phosphorous) export. Such soils are also well suited to providing a flow de-synchronization function. A caveat to the benefits of infiltration capacity is that extremely permeable soils such as sand and gravel outwash can be leaky with regard to nutrients (especially nitrogen) (Chesapeake Bay Program, 1995; Grantham, 1996; Speirman *et al.,* 1997) and chemical pollutants.

Where surface water features that have a hydrologic connection to the receiving stream are present in the buffer, the optimal buffer width is larger, since these features can allow contaminants to quickly bypass the soils and root zone of the riparian buffer (Adamik *et al.,* 1987; Ohio EPA, 1994; Murphy, 1995; Chesapeake Bay Program, 1997; Correll, 1997). Such surface water features include intermittent streams, perennial streams, ditches and gullies. The presence of surface water features provides increased potential for "leaky" or ineffective buffers since they provide a potential concentrated flow path whereby sediments, dissolved nutrients and other potential pollutants can effectively circumvent the buffer. Conversely, diffuse flows (e.g., sheetflows) through a buffer encourage infiltration and energy dissipation, allowing sediments and nutrients to be trapped. Surface water features surrounded by forested buffers are more effective at trapping sediments and pollutants to the extent that coarse woody debris inputs increase channel roughness, deflect flows to the adjacent forest, and prevent channel incision. In addition, there is a direct relationship between the width of forested buffer that the surface water feature flows through and the degree of shading and temperature regulation.

In the method, lower degrees of surface roughness (as function of micro-topography, coarse woody debris, herbaceous vegetation, and forest floor) generate higher optimal buffer widths. Higher degrees of surface roughness encourage infiltration and discourage concentrated flows (Murphy, 1995). Features such as pit-and-mound topography, dense herbaceous vegetation, dead-and-down wood, and a thick duff layer increase surface roughness. Exposed mineral soils or roads or other development features in a buffer characterize the lowest degree of surface roughness.

Spring or ground water discharge in the buffer increases optimal width. Springs can indicate a close relationship between the water table and the buffer soils/vegetation. Where ground water is near the surface as it flows through the buffer, undisturbed soils and root systems play an important role in removing nutrients and other pollutants from ground water prior to discharge to the stream (Caswell, 1987; Sweeney, 1993; Correll, 1997; Lowrence *et al.,* 1997; Speirman *et al.,* 1997). This function may be particularly important where land uses such as agriculture or residential development occur upgradient from the buffer. Springs may also provide important base flow inputs in the summer and help moderate stream temperatures, and can also enhance spawning habitat when located in the stream channel.

The presence of sand and gravel aquifers increases optimal riparian buffer width since these features are highly permeable and allow nutrients and other contaminants to enter the ground water more easily than with less permeable surficial deposits such as tills (Caswell, 1987; Weddle *et al.,* 1988; Correll, 1997; Lowrence *et al.,* 1997; Speirman *et al.,* 1997). Ground water in riparian sand and gravel deposits is assumed to discharge to the adjacent stream (Stanley and Trial, 1993).

Streamside floodplains (defined as areas with alluvial soils) and open wetlands (emergent and scrub-shrub), no matter how wide, are considered part of the stream resource being protected. The baseline for buffer width measurement begins at their landward edge. Streams meander over time and the main channel could potentially occupy any part of the floodplain in the future. Floodplains are of vital importance in terms of accommodating and attenuating overbank flows during high flow periods, and perform some of the same water quality and quantity functions as wetlands (Poff *et al.,* 1997).

The presence of wetlands in the buffer increases optimal buffer width for salmon. Riparian wetlands are typically connected by surface and/or subsurface hydrology to streams, and perform important water quality functions (Chase *et al.,* 1997; Spence *et al.,* 1996; Correll, 1997; Lowrence, 1997). Wetlands typically have water tables within the root zone and are more effective than uplands, for example, at converting potentially available nitrogen to a gaseous form through denitrification. Wetlands are often effective in trapping sediments and to a lesser extent phosphorous and pollutants adsorbed to sediments. Disturbance to wetland soils may compromise wetland functions. Wetland preservation in the riparian zone enhances buffer function. Any surface water between connecting the wetland and the salmon stream (e.g., wetland has intermittent stream outlet) increases the potential risk of sedimentation related to inadequate buffer width or wetland protection. Forested wetlands adjacent to streams provide important functions such as shading, and woody debris and litter inputs that are not provided by open-canopy wetlands to the same degree.

Optimal buffer width is not lessened for first or second order streams no matter how narrow since smaller headwater stream reaches are often more sensitive to water quality and quantity impacts (Davies and Sowles, 1984; Murphy, 1995; Chesapeake Bay Program, 1995; Kahl, 1996). In most cases, smaller streams are afforded less regulatory protection than are larger streams (USDA Forest Service, 1997). For many functions, such as the provision of wildlife corridors and terrestrial wildlife habitat, this makes sense. However, smaller headwater streams are typically more vulnerable to water quality and quantity impacts as they are less able to dilute or buffer impacts such as sedimentation, solar heating, nutrient loading, or base flow alterations (e.g., water withdrawal). The primary reason that smaller streams are not afforded greater buffer widths in this method is that larger streams have a greater potential floodplain and more energy available for bank cutting and sediment and debris transport (Murphy, 1995).

### *Regional Considerations and Objectives*

Buffer width models or designs, as with all models of complex natural systems, should consider specific objectives as well as unique regional biotic and abiotic variables (Haberstock, 1998). The following examples illustrate the need for such considerations. Perhaps the most widely known version of the multi-zone, variable-width buffer concept was developed by the USDA Forest Service (Welsch, 1991; USDA Forest Service, 1997, 1998). This multi-zone riparian management concept, which has been referred to as the Forest Service Standard, specifies standards for each zone for purposes of maintaining various riparian water quality functions in the Chesapeake Bay Watershed and uses three zones (USDA Forest Service, 1998). This approach assumes that periodic timber harvesting is compatible with optimal buffer function in the zone between about 15 ft and 75 ft (Welsch, 1991). For our application, however, it was determined from the literature that at least 35 ft of undisturbed forest was necessary for desired Zone 1 functions such as shading and woody debris inputs important for salmon habitat (Table 1).

TABLE 1. Functions of Zone 1 and Zone 2.

| Function | Zone 1 | Zone 2* |
|---|---|---|
| Shading and Temperature Regulation | Primary | *Secondary* |
| Large Woody Debris and Organic Matter Inputs | Primary | *Secondary* |
| Water Quality Functions (other than shading) | Primary | Primary |
| Water Quantity Functions | *Secondary*** | *Secondary*** |

*An additional function of Zone 2 is to provide wind-firm conditions in Zone 1.

**Baseflow maintenance is provided by the entire watershed, not primarily by the immediate riparian buffer. Flood storage during overbank flows is a primary function of riparian buffers. However, this method includes floodplains as part of the resource to be buffered. Zone 1 begins at the landward edge of floodplains.

Since mature tree heights of dominant trees in eastern Maine range from about 50 ft (*Abies balsamea*) to 65 ft (*Picea rubens*), Zone 1 (the 35 ft undisturbed zone) alone will provide the majority (roughly 75 percent for a 60 ft tree) of the total potential for coarse wood inputs and shading where these species are dominant (FEMAT, 1993; Murphy, 1995). Further, since Zone 2 stocking levels for the method require that the majority of trees be left (only thinning or light harvesting is prescribed for Zone 2), Zone 2 will provide additional woody debris inputs and shading so that the vast majority of the total potential function is achieved (Beechie *et al.,* 2000). Again, it was site-specific or regional data (tree heights) that dictated effective buffer widths. In the Pacific Northwest, where site potential tree heights can be approximately double that of eastern Maine, greater buffer widths are necessary to achieve the majority of the full potential for woody recruitment and shading.

The increased potential for nutrients and chemicals to reach in-stream habitat via ground water flows where highly permeable sand and gravel deposits are found is taken into consideration by adjusting the optimal buffer width upwards to account for the presence of significant sand and gravel aquifer areas and ground water discharge or spring occurrences. Restrictions on tree removal in Zone 2 are designed to take into account the fact that shallow-rooted conifer dominated systems may be more susceptible to windthrow. The wide range of slopes and soil types found in the region is accommodated by a buffer width key which considers slopes ranging from gentle to very steep and soils ranging from high infiltration capacities to low infiltration capacities.

As another example of the importance of considering objectives, Chase *et al.* (1997) summarize the work of others to estimate required riparian buffer widths for various wildlife species. One riparian species, mink, requires about a 330 ft buffer width. Therefore, if the objective of estimating effective buffer widths is to provide optimal mink habitat, our method would generate suboptimal buffer widths for most buffers. Optimal buffer widths for terrestrial and semi-aquatic (e.g., amphibians, aquatic furbearers) wildlife habitat are typically wider than those for water quality or other functions, as indicated in the literature. Many researchers have indicated that riparian buffers intended to provide optimal corridors for a variety of wildlife species, including forest interior birds and riparian mammals such as beaver, should have widths of several hundred feet, at least along target management areas (U.S. ACOE, 1991; Chase *et al.,* 1997). Our method had to consider water quality and quantity objectives as they relate to salmon habitat but did not consider such goals as the provision of habitat for interior species.

## METHODS

A multi-disciplinary team that included terrestrial biologists, aquatic biologists, hydrologists, and foresters developed the method. Appropriate buffer widths were determined by a review of scientific literature that describes the relationship between buffer characteristics and buffer effectiveness. Technical information and feedback was received from numerous state and federal agencies, non-profit organizations, and industry biologists. The method was field tested prior to final publication in 1999, and outreach training programs were conducted for potential users.

The following specific steps were taken during method development, largely by researching the existing science-base as reported in the literature:

1. Determine buffer functions important for Atlantic salmon habitat protection.
2. Identify dominant and regionally unique characteristics of target protection areas (e.g., soil characteristics, disturbance regimes, vegetative structure, topography).
3. Determine buffer attributes having the greatest effect on buffer effectiveness for the functions identified in step 1.
4. Identify readily available sources (such as soil surveys) or rapid techniques for measurement of buffer attributes selected as having the greatest effect on buffer effectiveness.
5. Determine range of widths (given various functions studied and their relationship with buffer characteristics) required for effective buffer function as reported in the literature in a manner similar to other research efforts such as Chase *et al.* (1997).
6. Develop predictive conceptual model that uses simple (e.g., linear) relationships between input variables (e.g., slope) and effective widths.
7. Determine what lands uses are compatible with desired buffer function.

The science-base for the method included data developed primarily for forested regions of the northern United States and Canada. To the extent possible, data specific to northern New England was utilized, however this area-specific data was insufficient to be solely relied upon. The scientific literature provided ranges of buffer widths required for effective buffer function (both for specific functions, such as sediment filtering, as well as for a whole suite of functions). The literature also provided relationships between specific buffer attributes and buffer functions. The range of effective buffer widths generated by the method (i.e., 70 ft to 300 ft +) represents the preponderant ranges from the literature for functions important for the objective of protecting salmon habitat. The relationship between input variables and effective buffer width within this range was developed using simple, linear relationships. For example, for each one unit change in soil hydrologic group, suggested effective buffer width changes by 20 ft. The 20 ft was arrived at using best professional judgement given the overall buffer range of method output and a known relationship between soil hydrologic group and buffer effectiveness. Variables were weighted according to the relative influence on buffer effectiveness.

Much of the literature on riparian buffers gages effectiveness in terms of potential (i.e., percent of total potential for a particular function) (Collins and Pess, 1997). For example, the potential for coarse woody debris inputs is a function of site potential tree height. The full potential for woody debris inputs is achieved at a width approximating one site potential tree height (FEMAT, 1993). However beyond a width of approximately two-thirds to three-quarters of a tree height the incremental gain in wood recruitment diminishes rapidly (Spence *et al.,* 1996), so effective widths for this function might be considered by best professional judgement to be less than one tree height.

## STUDY AREA

### *Watershed Descriptions*

Figure 1 identifies the principal native Atlantic salmon rivers that were targeted in the development of this method. These rivers include: Dennys, East Machias, Machias, Pleasant, Narraguagus, Ducktrap, and Sheepscot.

Most of the principal native Atlantic Salmon rivers are located in Washington County and extreme eastern Hancock County – a coastal region in eastern Maine. Moderate to gentle topography and a predominance of shallow-rooted conifers (e.g., *Abies balsamea, Picea rubens*) characterize this region. Some portions of the region are characterized by a more rugged topography, but these areas are typically in the upper portions of the watershed, away from the

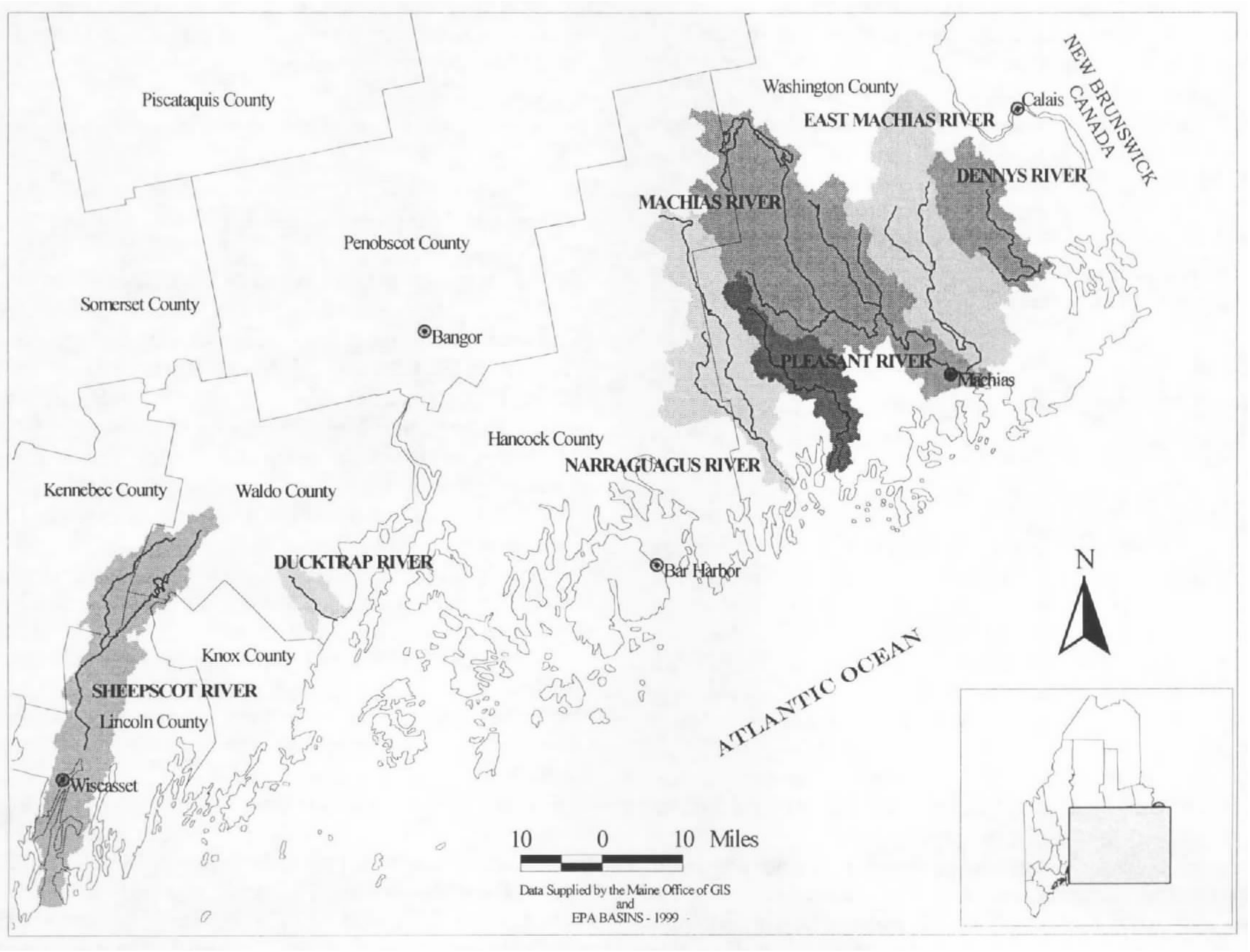


Figure 1. Principal Coastal River Basins With Native Atlantic Salmon Runs.

critical habitat reaches. Portions of the salmon rivers in this region meander through vast peatlands (wetlands characterized by a large component of small-stature shrubs from the family *Ericaceae* and organic soils such as peat).

The surficial geology of the region is complex. Relative to most other regions of the glaciated northeast, this region contains a predominance of glacial meltwater-sorted sand and gravel deposits. As much as 40 percent of Maine's streamflow is thought to be derived from ground water discharge and this percentage is likely higher in areas dominated by highly permeable substrates such as occur in Washington County (Caswell, 1987). Dominant land uses in the sparsely populated region include timber, blueberry, and cranberry production.

Additional salmon rivers are located further down the coast in a mid-coast region characterized by a more bedrock-controlled topography, including areas with slopes in excess of 25 percent. Hardwoods (such as *Acer saccharum, Betula papyrifera,* and *Quercus rubra*) are more numerous, although shallow-rooted conifers are also an important component of the forest. The dominant surficial materials are glacial tills and fine-textured glaciomarine deposits. Many of the soils are shallow-to-bedrock, and glacial meltwater-sorted sand and gravel deposits are not as common as in Washington County, although they are present. This mid-coast region is more populated (although still rural) and is characterized by a more complicated land use mosaic still dominated by forests, but including residential and more diverse agricultural uses.

## PROCEDURE

### *Overview*

The method entails gathering data on buffer attributes, and utilizing a buffer width key (much like a plant key) and subsequent adjustment factors to determine a suggested riparian buffer width for each buffer unit. The method requires field and desk-top measurement of the most important attributes affecting buffer functions important for Atlantic salmon habitat conservation. It is designed to be flexible in that it recognizes that there is variability in the amount and type of data (input variables) that will be able to be collected for different sites.

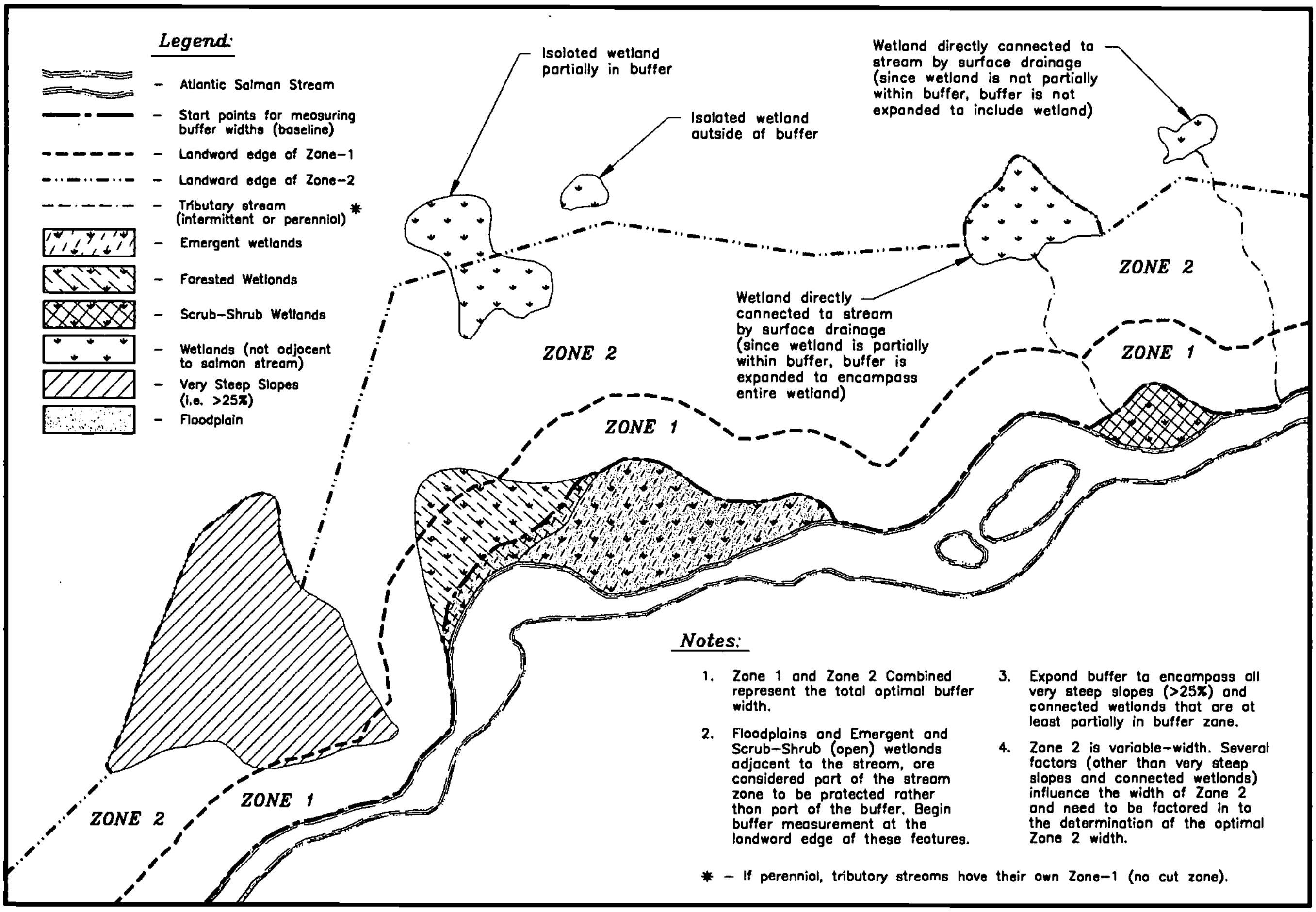
Project Data Forms were developed and are used to record data from various map resources as well as data collected in the field. The data forms guide the user through the calculations and data collection methods and include several attachments that provide guidelines and information to be used in completing the data form. The buffer width key identifies unadjusted optimal buffer widths as a function of slope, soil hydrologic group, and percent canopy closure (primary buffer attributes). These primary attributes can readily be determined using desk-top resources to the extent that soil survey data and aerial photos are available for the specific area being evaluated. Secondary buffer attributes (i.e., remaining buffer attributes such as surface roughness, wetlands, and ground water seepage/springs) determine specific upward or downward adjustments to the numbers generated by the buffer width key.

Field investigations are used, if possible, to identify important buffer attribute data (e.g., microtopography, ground vegetation, ground water seepage/springs, land use, small streams) that may not be readily identifiable using desk-top resources alone. Field investigations should also be used to confirm or modify desk-top data as necessary. For example, if the percent canopy closure estimate is based on aerials that are several years old, the actual conditions may be found to be different in the field and the data should be adjusted accordingly.

### *Steps*

The method follows these steps:

1. Identify the stream reach to be protected and the adjacent buffer evaluation area on resource maps including, but not limited to, aerial photographs, USDA SCS Soil Survey, National Wetland Inventory, USGS Topographic, Maine Significant Sand and Gravel Aquifer, and Maine Surficial Geology.
2. Determine the baseline for buffer width measurement (Figure 2).
3. Divide buffer evaluation area into discrete buffer units for evaluation (Figure 3).
4. Gather buffer attribute data using data sheets for each buffer unit. Field work is recommended to supplement/refine desk-top data.
5. Determine the unadjusted optimal buffer width for each buffer unit using the key. Three "primary" attributes (slope, soil hydrologic group, and percent canopy closure) determine the unadjusted buffer width.
6. Adjust the number generated from the key according to additional factors affecting buffer function. This consists of two sub-steps: (a) adjust buffer widths from the key for factors that result in specific increases or decreases to the optimal buffer width (i.e., surface water features, ground water seepage/springs, degree of surface roughness, significant sand and gravel aquifers, and wetlands); and (b) in places



Isolated wetland partially in buffer

Isolated wetland outside of buffer

Wetland directly connected to stream by surface drainage (since wetland is not partially within buffer, buffer is not expanded to include wetland)

Wetland directly connected to stream by surface drainage (since wetland is partially within buffer, buffer is expanded to encompass entire wetland)

Notes:

1. Zone 1 and Zone 2 Combined represent the total optimal buffer width.
2. Floodplains and Emergent and Scrub-Shrub (open) wetlands adjacent to the stream, are considered part of the stream zone to be protected rather than part of the buffer. Begin buffer measurement at the landward edge of these features.
3. Expand buffer to encompass all very steep slopes (>25%) and connected wetlands that are at least partially in buffer zone.
4. Zone 2 is variable-width. Several factors (other than very steep slopes and connected wetlands) influence the width of Zone 2 and need to be factored in to the determination of the optimal Zone 2 width.

* – If perennial, tributary streams have their own Zone-1 (no cut zone).

Figure 2. Baseline for Buffer Width Measurements and Buffer Expansions for Connected Wetlands and Very Steep Slopes.

where wetlands connected to the stream by surface hydrology, and/or very steep slopes extend beyond the calculated optimal buffer width, expand the optimal buffer width to include them (Figure 2).

7. Map a continuous optimal buffer width line over the entire riparian buffer area (all buffer units) under evaluation. Do this by plotting data points representing optimal buffer width for each buffer unit as well as the shared lines between buffer units, and connecting them (Figure 3).

*Buffer Width Key*

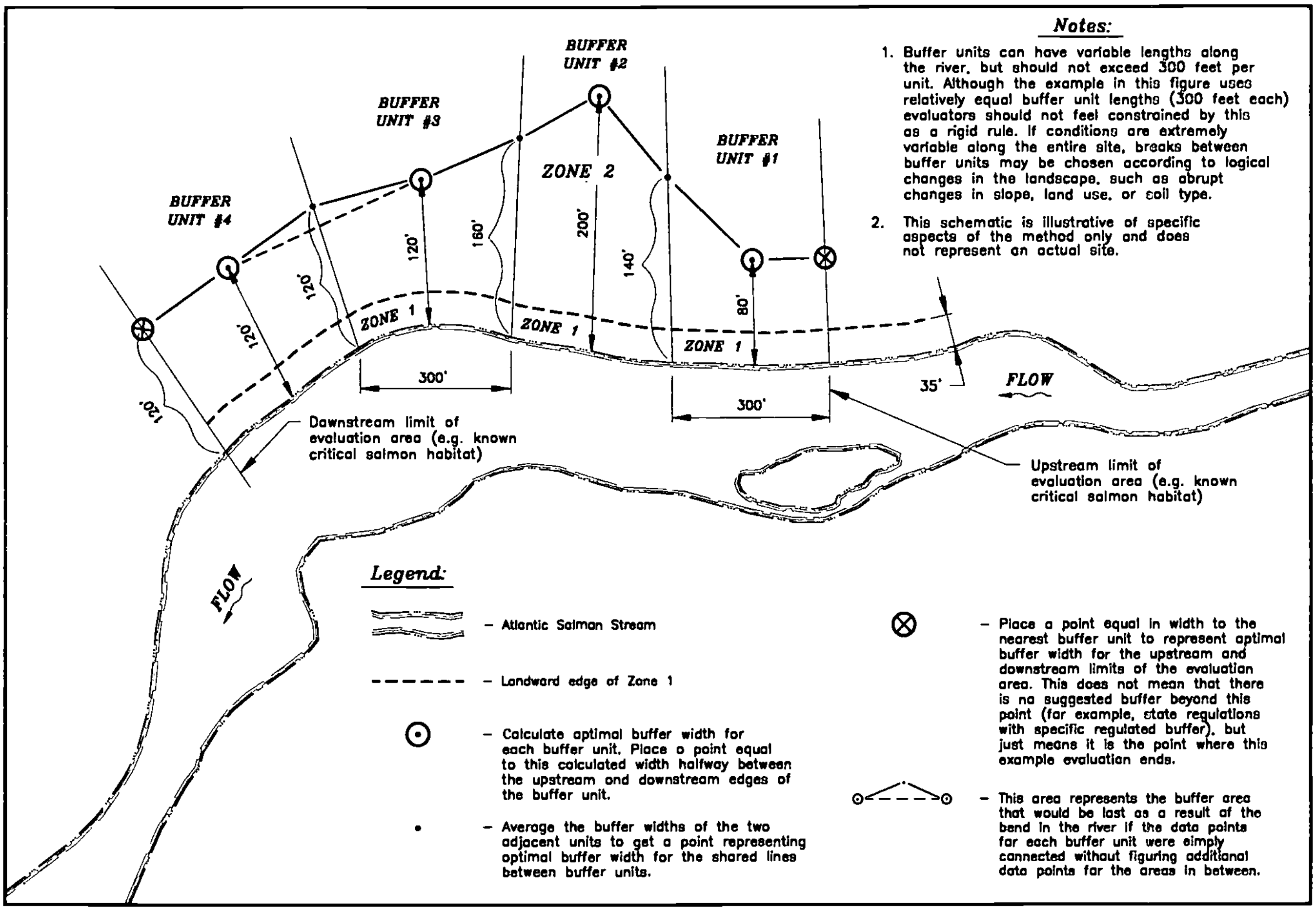
The buffer width key is structured much like a plant key. The example below is the portion of the key for one of the four slope classes used:

1. Slopes 8-15%
    2. Hydrologic Group A and B Soils
        3. % canopy closure 76-100% . . . .100 ft
        3. % canopy closure 51-75% . . . . .110 ft
        3. % canopy closure 26-50% . . . . .120 ft
        3. % canopy closure 0-25% . . . . . .130 ft

    2. Hydrologic Group C Soils
        3. % canopy closure 76-100% . . . .120 ft
        3. % canopy closure 51-75% . . . . .130 ft
        3. % canopy closure 26-50% . . . . .140 ft
        3. % canopy closure 0-25% . . . . . .150 ft

    2. Hydrologic Group D Soils
        3. % canopy closure 76-100% . . . .140 ft
        3. % canopy closure 51-75% . . . . .150 ft
        3. % canopy closure 26-50% . . . . .160 ft
        3. % canopy closure 0-25% . . . . . .170 ft

The key generates an "unadjusted" buffer width from the three primary attributes that is subsequently



Notes:

1. Buffer units can have variable lengths along the river, but should not exceed 300 feet per unit. Although the example in this figure uses relatively equal buffer unit lengths (300 feet each) evaluators should not feel constrained by this as a rigid rule. If conditions are extremely variable along the entire site, breaks between buffer units may be chosen according to logical changes in the landscape, such as abrupt changes in slope, land use, or soil type.
2. This schematic is illustrative of specific aspects of the method only and does not represent an actual site.

Downstream limit of evaluation area (e.g. known critical salmon habitat)

Upstream limit of evaluation area (e.g. known critical salmon habitat)

Legend:

- Atlantic Salmon Stream
- Landward edge of Zone 1
- Calculate optimal buffer width for each buffer unit. Place a point equal to this calculated width halfway between the upstream and downstream edges of the buffer unit.
- Average the buffer widths of the two adjacent units to get a point representing optimal buffer width for the shared lines between buffer units.
- Place a point equal in width to the nearest buffer unit to represent optimal buffer width for the upstream and downstream limits of the evaluation area. This does not mean that there is no suggested buffer beyond this point (for example, state regulations with specific regulated buffer), but just means it is the point where this example evaluation ends.
- This area represents the buffer area that would be lost as a result of the bend in the river if the data points for each buffer unit were simply connected without figuring additional data points for the areas in between.

Figure 3. Procedure for Determining a Continuous Buffer Width Line Over an Entire Evaluation Area.

adjusted up or down depending on additional important buffer attributes (secondary attributes). During field tests, this adjustment was almost invariably upwards since several factors can result in upward adjustments, whereas only one factor (high degree of surface roughness) can result in a downward adjustment. The unadjusted recommended buffer widths range from a low of 70 ft for buffers with gentle slopes (0-8 percent), soils with a high infiltration capacity (hydrologic group A or B soils), and closed or nearly closed canopy forest cover, to a high of 230 ft for buffers with very steep slopes (greater than 25 percent), low infiltration capacity (hydrologic group D soils), and an open canopy. Slope is weighted most heavily, followed by soil hydrologic group, and percent canopy closure, based on their estimated relative influence on buffer effectiveness as indicated in the literature.

Ideally, all three variables should be determined. However, the model is designed to be flexible and can be used if only one or two of the three variables are known. If the only information known, for example, is that slopes are 8-15 percent, the unadjusted recommended buffer width would be 135 ft which is the average width for the 8-15 percent slope portion of the key. As a second example, if slopes are 8-15 percent and the hydrologic group is D, but percent canopy cover is not known, the recommended unadjusted buffer width would be 155 ft. Alternatively, users can be conservative and assume that all unknown variables are the worst case scenario to ensure effective buffer widths. Using this approach, the last example would result in a recommended unadjusted buffer width of 170 ft.

### Adjustment Factors

Upward adjustments to the suggested buffer width are made if surface water features (inclusive of intermittent drainage and gullies/ditches), ground water seepage/springs, sand and gravel aquifers, low degree of surface roughness or wetlands are found in the buffer unit. In addition, areas of very steep slopes (i.e., greater than 25 percent), and wetlands connected to the stream by concentrated surface flows (including intermittent streams and ditches) result in further expansion of the suggested buffer width. Specific adjustments and definitions are summarized in Table 2.

The exact adjustment numbers are necessarily somewhat arbitrary (e.g., the method could call for an increase of 43 ft rather than 50 ft for surface water features), but the direction and general magnitude are based on the best available science as well as best professional judgment specific to the region. For example, we know that small intermittent streams in a buffer may provide a mechanism for nutrients and sediment to circumvent desired buffer treatment (i.e., uptake and settling). We also know that increasing the size of buffers that contain surface water features will help mitigate this, so wider buffers are called for. However, the exact suggested increase then requires best professional judgement and is a generalization/approximation. As addressed elsewhere in this paper, all models of complex ecosystems are necessarily approximations or simplifications of reality.

### *Measurement of Buffer Attributes*

The method outlines procedures or data sources to measure or collect the buffer attribute data. Most data, such as slope and soil hydrologic group is very straightforward to collect from readily available desktop resources. Surface roughness is the only input variable that is subject to some level of interpretation

TABLE 2. Adjustment Factors for Secondary Attributes: Definitions and Adjustments.

| Attribute | Definition | Adjustment |
|---|---|---|
| Surface Water Features | Includes perennial and intermittent streams, ditches, gullies and ponds that have a surface drainage connection to the salmon stream. | The presence of surface water features in the buffer results in a suggested buffer width increase of 50 ft. |
| Surface Roughness | Function of the degree of microtopographic complexity and forest floor integrity, as influenced by such features as pit-and-mound topography, dead-and-down wood, condition of the duff layer (surface organic horizon), and herbaceous vegetation. | A low degree results in suggested buffer width increase of 25 ft; a moderate degree results in no adjustment; a high degree results in a reduction of 25 ft (this is the only secondary attribute input variable that reduces suggested buffer width. |
| Groundwater Seepage Springs | Constant, cool (in Maine 4 to 10°C) discharge that is directly connected to the underlying water table/aquifer is included. Excludes perched, seasonal seepage such as might occur on side-slopes of drumlins or other slowly permeable features (these are typically included as wetlands though). | The presence of springs/seepage in the buffer results in a suggested buffer width increase of 25 ft. |
| Sand and Gravel Aquifers | Includes such features as mapped by the State of Maine Geological Survey. | The presence of sand and gravel aquifers results in a suggested buffer width increase of 25 ft. |
| Wetlands | Defined according to state of Maine definition (similar to federal definition). | Wetlands in the buffer result in a buffer width increase of 25 ft whether the wetland is isolated or connected to the stream by surface drainage. Suggested buffer width is further expanded to include all wetlands connected to the stream by concentrated surface drainage (including intermittent) (Figure 2). |
| Floodplains | Soils derived from recent (post glacial) alluvium(whether uplands or wetlands). | Considered part of the stream resource being protected, not part of the buffer. |
| Very Steep Slopes | Slopes greater than 25 percent. | Suggested buffer width is expanded to include all areas of contiguous very steep slopes (Figure 2). |
| Stream Order | The relative position of the stream in a drainage basin based on a number ranking from headwater to river mouth. | Suggested buffer widths are not adjusted as a result of stream size or position in the watershed. |

(this data is less easily replicated than other input data).

For surface roughness, the method provides detailed guidelines including representative pictures (Figure 4) and the percent areal coverage of surface roughness features for each category. Forested buffers with features such as undulating or pit-and-mound topography, dense, low vegetation, a high degree of dead-and-down wood, and an intact duff layer have a high degree of surface roughness. Buffers with a low degree of surface roughness lack these features. High degrees of surface roughness are limited to complex forested systems lacking exposed mineral soils, and roads or other slowly permeable or impermeable land use features. Exposed mineral soils are typically an indication of erosion potential or land uses that have resulted in removal in places of the organic soil horizon. If exposed mineral soils have resulted from tipups (toppled trees where the root crown has ripped out of the earth exposing mineral soil horizons), or other natural phenomena, then the organic horizon is considered intact.

This feature requires field work to determine. Although the cutoffs are somewhat arbitrary, the guidelines specify surface roughness categories that: leave little room for interpretation, were easily replicated during field testing, and reflect conditions found in downeast Maine (Kleinschmidt Associates, 1999).

### *Baseline and Buffer Unit Locations*

The normal high water mark of the stream serves as the baseline for measuring riparian buffer widths where floodplains and open (non-forested) wetlands are not present immediately adjacent to the stream. Where there are floodplains and/or open riparian wetlands immediately adjacent to the stream channel, the baseline for measuring riparian buffer widths and buffer characteristics is the landward edge of these features. Open wetlands include emergent and scrub-shrub wetlands. The rationale is that forested wetlands serve to provide riparian buffer functions such as shading, coarse woody debris inputs, and water quality renovation. Open-canopy wetlands at the stream margin are not able to optimally perform shading and woody debris input functions. Such wetlands are generally ponded for much of the growing season and are closely linked to the stream by surface waters and functionally can be considered to be part of the stream itself. Floodplains accommodate potential future river meanders and are also closely linked by surface hydrology to the stream during flood periods.

In order to determine the width of the riparian buffer to gather attribute data for, the user starts by determining slope in the area between 0-100 ft, and

Figure 4. Example of a High Degree of Surface Roughness in Washington County, Maine (the photo is taken in November, so only evergreen foliage/herbs are evident).

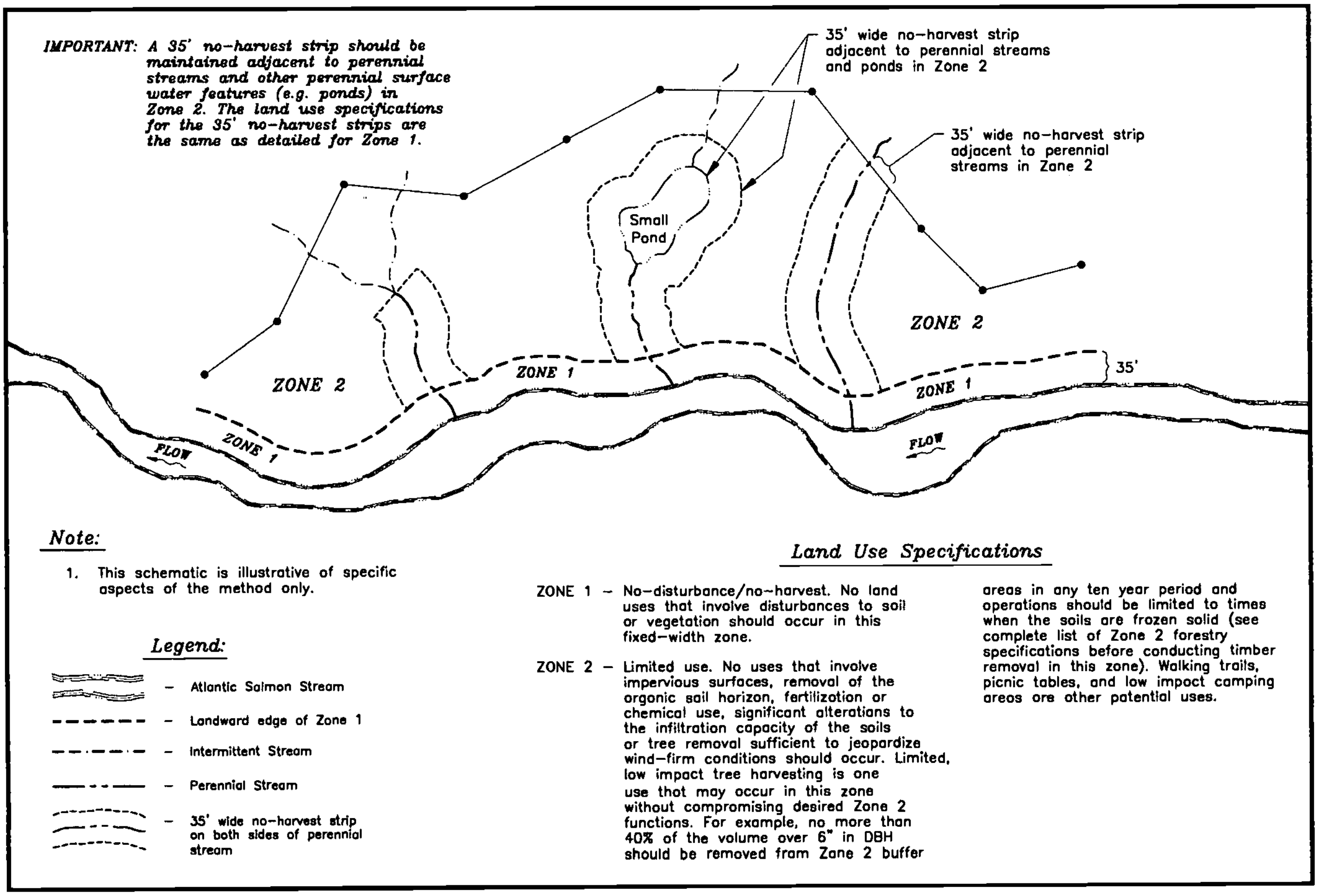
proceeds as necessary through a simple table presented in the method. At the start of the evaluation, the optimal buffer width is not yet known. Since slope is the most important readily-measurable buffer attribute affecting buffer function, this is a good way to get a quick initial approximation of how far landward to measure buffer attributes. The optimal buffer width generated may not be identical to the width of buffer being measured but should be similar.

The length of buffer units, as measured parallel to the baseline, depends on the size of the parcel being evaluated and possibly other factors (e.g., land ownership/permission to enter the property, location and size of critical in-stream salmon habitat areas). As a general rule of thumb, buffer evaluation areas are divided into units that are no more than 300 ft along the stream (Figure 2). Smaller buffer unit lengths result in a more refined determination of optimal buffer width. In situations of high landscape variability, evaluators should divide buffer units at natural break points such as abrupt changes in slope, soil type, vegetative cover, or sharp bend in the river. Measure buffer widths perpendicularly to the baseline (or if floodplains or open wetlands are not present, measure perpendicular to the stream axis) and on a horizontal plane.

### *Land Use Specifications*

Land use specifications for Zone 1 and 2 are summarized in Figure 5. No land uses that involve disturbance to soils or vegetation should occur in Zone 1. Many of the intended Zone 1 functions such as shading and woody debris inputs (Table 1) will not operate optimally if tree removal or other land uses occur in this area. Limited tree removal is one of the only uses compatible with desired Zone 2 functions aside from light recreation.

Land uses affect buffer attributes such as percent canopy cover, surface roughness, and soil hydrologic group (infiltration capacity). These, in turn, affect



***IMPORTANT:*** *A 35' no-harvest strip should be maintained adjacent to perennial streams and other perennial surface water features (e.g. ponds) in Zone 2. The land use specifications for the 35' no-harvest strips are the same as detailed for Zone 1.*

35' wide no-harvest strip adjacent to perennial streams and ponds in Zone 2

35' wide no-harvest strip adjacent to perennial streams in Zone 2

*Note:*

1. This schematic is illustrative of specific aspects of the method only.

*Legend:*

*Land Use Specifications*

ZONE 1 – No-disturbance/no-harvest. No land uses that involve disturbances to soil or vegetation should occur in this fixed-width zone.

ZONE 2 – Limited use. No uses that involve impervious surfaces, removal of the organic soil horizon, fertilization or chemical use, significant alterations to the infiltration capacity of the soils or tree removal sufficient to jeopardize wind-firm conditions should occur. Limited, low impact tree harvesting is one use that may occur in this zone without compromising desired Zone 2 functions. For example, no more than 40% of the volume over 6" in DBH should be removed from Zone 2 buffer areas in any ten year period and operations should be limited to times when the soils are frozen solid (see complete list of Zone 2 forestry specifications before conducting timber removal in this zone). Walking trails, picnic tables, and low impact camping areas are other potential uses.

Figure 5. Land Use Specifications for Zone 1 and Zone 2.

optimal buffer width. Therefore, buffers that contain agricultural uses, lawns, roads or other development will, all else being equal, create wider optimal buffer width determinations. But additional buffer width adjustments are not made as a result of specific land use practices historically occurring in the buffer. There are recommended land use restrictions in each buffer zone (Zone 1 and Zone 2), however in many cases it is impractical to eliminate historical uses, such as residential development or berry or crop production already in these zones. To the extent that such uses can be discontinued and the nonconforming portions of the buffer allowed to revert to natural vegetation, buffer effectiveness will be maximized. As succession or restoration activities occur, and abandoned lands revert to forested systems, the calculated optimal buffer width will decrease (i.e., due to greater percent canopy coverage, higher degrees of surface roughness, etc.).

## DISCUSSION

### *Limitations of Model and Future Research Needs*

Models of complex natural systems, such as models of effective buffer width, are approximations or simplifications of reality. Limitations include the fact that the model is only as good as the science-base and the model assumptions. For example, for this model, it was assumed that data generated for other forested systems in the northern United States and Canada was applicable to Maine. Another potential limitation of model accuracy includes the reliability of the input data. For example, if the soil survey data used to estimate soil hydrologic group is inaccurate or the user incorrectly estimates an input variable, model output is less accurate. Overall, it was felt that the method resulted in estimates of effective buffer widths that were appropriate for the conditions, easily applied, and easily replicated.

The categories chosen for each input variable had to be easily determined. Slope, for example, was separated into four categories (0-8 percent, 8-15 percent, 15-25 percent, greater than 25 percent). These categories were chosen at least in part because soil surveys (USDA SCS soils mapping units) generally use these categories for the counties in Maine included in our study area. USGS topographic maps were found to be inadequate for measuring slope because the 10 ft contours were too coarse to accurately determine slope, especially in the more narrow riparian buffers. So, for evaluation areas where more refined slope data was not available or detailed field work was not practical, soils maps were determined to be the best readily-available source of slope data. The literature clearly indicated the direct relationship between buffer function and slope, and provided ranges of effective buffer widths that established the ranges of suggested buffer widths generated by our method. Therefore, the selection of the specific breaks in input variable categories involved best professional judgement, and practical considerations such as the availability of data and the format it was available in. The general direction of the relationship between input variables and effective buffer widths is grounded in science, however since category breaks of input variables are based largely on more practical constraints, the recommended buffer widths generated are approximations. Although the method results are approximations, the conceptual model is an improvement over fixed-width prescriptions and over variable-width approaches that are less science-based.

Many of the input variables used for this method have intercorrelations with each other to at least some degree (i.e., buffer attributes are related to each other as well as the output or dependent variable). There is also the possibility that the degree of influence a particular variable has on the dependent variable (buffer width) becomes more important or less important as a second variable changes. For example, it is possible that a low percent canopy cover has a greater effect on effective buffer width for water quality functions on very steep slopes than on flat terrain, where it may be of less importance to buffer function and buffer width. We were aware of no work that attempted to conduct multivariate or multicollinearity analyses of buffer attributes and buffer width or buffer effectiveness for particular functions. Such research would be of value for applications such as this method. This method assumed simple linear relationships between independent variables and the dependent variable.

### *Buffer Design*

The method results in buffer widths that are more appropriate for the given conditions than are fixed width buffer protection methods. Standard fixed width riparian buffers are typical in the context of regulatory programs throughout the country. One of the most common all purpose, fixed-width regulated setbacks for nonexempted land uses adjacent to watercourses in the eastern U.S. is 100 ft; however, lesser widths such as 35ft are common (Chase *et al.*, 1997; Tjaden and Weber, 1997; Todd, 1998). Chase *et al.* (1995), after reviewing available literature, determined that 100 ft was the most reasonable width if a standard fixed-width riparian buffer was to be chosen to protect New Hampshire's streams and rivers for all functions and values.

Variable width approaches, unlike fixed width approaches, can be designed to take into account the relationship between site-specific conditions and desired buffer functions. Fixed-width buffers are much more widely applied and easier to implement (Chase *et al.,* 1997). Variable-width buffers are better able to protect desired buffer functions in a customized manner and are flexible with regard to site-specific physical buffer conditions. Variable width approaches are also able to provide better protection of the target resource without overprotecting unnecessarily. Unless fixed-width approaches are conservative and use buffer widths that would be effective under the worst-case scenario (i.e., steep slopes, erosion-prone soils), they will offer inadequate protection for some buffers. If they are conservative, however, unnecessarily large or overprotective buffers result.

Similarly, multi-zone buffers are able to be flexible in that they account for the fact that land uses have different effects on buffer function. The concept of applying multi-zone, variable-width buffers around target resource protection areas has precedent (New Jersey Department of Environmental Protection, 1989; Welsch, 1991; Chesapeake Bay Program, 1995). Even in those cases where buffer managers choose to implement fixed-width, single-zone approaches for practical reasons, it is the authors' hope that this method will provide a framework for determining important factors to consider (e.g., site-specific conditions, management objectives, ranges of buffer widths required for buffer effectiveness).

Lastly, it should be noted that this method is not a total watershed management approach. This method focuses on the immediate riparian buffers in the vicinity of identified critical habitat reaches. Land uses outside of the immediate riparian buffers, in the upper portions of the watersheds, and in non-target stream reaches would also need to be considered in order for the method to be a total watershed management approach.

### *Other Applications*

The general framework developed for this method has potential applicability to buffer protection efforts in other regions and with other objectives. Such applications would likely require adjustments, such as adding or dropping specific buffer attributes according to objectives and unique regional conditions.

As information such as slope, soils, and vegetative cover becomes increasingly available in digital format and tools such as geographic information systems (GIS) are increasingly used for modeling of natural systems, methods such as the one presented in this paper will become increasingly efficient to apply. We did not attempt to utilize GIS to generate recommended effective buffer widths over large areas. However, the use of GIS data layers, as soils and other variables become available in digital format, would facilitate large-scale application of this method or similar approaches.

## ACKNOWLEDGMENTS

This article is based on work conducted by Kleinschmidt Associates, Consulting Engineers, Scientists and Planners for the Maine State Planning Office. Project funding and technical input was received from the following organizations: Maine State Planning Office, Maine Outdoor Heritage Fund, Atlantic Salmon Federation, and Project SHARE (Salmon Habitat and River Enhancement). The authors would also like to acknowledge the valuable technical input received from the anonymous reviewers.

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