Science-based watershed policy for stream corridors:

Integrating economic and ecological considerations

By D. Corlett and M. Phillips[1]

Abstract: *This paper presents a new methodology for sizing protective stream corridors and evaluating existing programs using a combination of literature-based and watershed-based factors. Factoring scientific literature currently used to establish certain thresholds against the physical characteristics of a given watershed, appropriate stream corridor widths can be scientifically determined, implemented, and adjusted to the targeted functions or limiting factors of each sub-watershed. This approach is more cost-effective than the more common uniform (or fixed width) approach widely employed today. Stream corridor widths that are too large can create inefficiencies, given the opportunity cost of alternative land uses. Widths that are too small will fail to provide suitable resource protection. The primary improvement provided by the model is the simultaneous development of eight recommended corridor widths based on a variety of key stream functions; these are applied to individual sub-watersheds, integrating economic and ecological considerations into the analysis.*

[1]Daniel Corlett is a registered landscape architect and restoration ecologist at the Washington State Department of Transportation, Vancouver, Washington. Michelle Phillips is a research assistant at the Public Utility Research Center, University of Florida, Gainesville, Florida. The paper extends Corlett's Master's Thesis presented to the Department of landscape Architecture and Regional Planning at the University of Massachusetts, Amherst. WSDOT did not participate in or fund any portion of this study.

The fringe of riparian vegetation paralleling streams and rivers serves as the transition between terrestrial and aquatic ecosystems. This fragile corridor of streamside vegetation protects and enhances the water quality of streams and rivers, regulates stream flow, reduces flooding impacts, and provides essential habitat for wildlife. Riparian corridors in their natural state reduce flood damage, protect public and private drinking water supplies, and are generally seen as important in urban and urbanizing areas as a primary means for removing pollutants and sediment from storm water runoff (Massachusetts Department of Environmental Protection 1998; Colburn 1992; Barten 1998; Mitsch 1993; Riley 1998). Despite these important ecological and economic benefits, the vegetated corridor has been heavily impacted by the expansion of society, particularly urbanization (Mitsch, 1993; Riley 1998).

Stream corridor widths have traditionally been determined through single attribute processes. According to Ferraro, in order to achieve a given level of an environmental amenity at least cost, decision makers must integrate information about spatially variable biophysical and economic conditions. However, most studies of cost-efficient conservation policy intervention use a single biophysical attribute as a proxy for the environmental amenity that is to be achieved at least cost (Ferraro 2004); this is the case with stream corridor widths. Current width calculation models typically focus on single variables such as sediment or nutrient removal; however, such narrow focus on a single attribute fails to consider the full range of biophysical attributes that are critical to the supply of an environmental amenity (Noss 1990). Furthermore, many politically-derived land use boundaries, including towns and counties, typically conform to simple, straight lines, virtually ignoring ecological function or natural watershed boundaries. The reliance on political rather than ecological boundaries can have profound negative effects on the stream network (Riley 1998). Having widths that are too large can create inefficiencies, given the opportunity cost of alternative land uses. Having widths that are too small will fail to provide suitable resource protection. Greater ecological benefits could be derived by conforming the overall planning and management of urban development to the complex, curvilinear boundaries of watersheds (Dramstad et al. 1996). Application of various landscape ecological principles, specifically to the width of the vegetated stream corridors, may increase understanding of necessary, interconnected processes and help reduce some of the potential limitations of watershed scale planning (Watanabe et. al. 2005).

The extent, basis, and implementation of existing stream corridor or stream buffer programs within urbanizing watersheds, provides a policy basis and political reality for the application of various corridor widths by function. A survey of the literature indicates that most existing models typically establish stream corridor or stream buffer widths for individual functions at specific locations, and do not provide a comprehensive basis in which to simultaneously develop, analyze, and compare appropriate widths for numerous stream corridor functions. The contribution of this paper to the literature is through the development of a single, comprehensive model that can be used in the support of decisions pertaining to the function-based management of stream corridors.

According to Azzaino et al., conservation agencies must identify effective ways to allocate their scarce budgets in heterogeneous landscapes (Azzaino et al. 2002). By establishing an optimum corridor width or range of widths for numerous parameters including but not limited to nutrient removal, sediment reduction, temperature modification, and wildlife uses, findings can be incorporated into a conceptual Variable Width Stream Corridor Model, adaptable to the functional needs of any urbanizing watershed or sub-watershed within humid-temperature landscapes, in a way that would both maximize the benefits obtained from protecting the corridor and optimize the use of land. Based on scientific literature currently used to establish certain thresholds factored against the physical characteristics of a given watershed, appropriate stream corridor widths can be scientifically determined, implemented, and adjusted to the targeted functions or limiting factors of each sub-watershed, as opposed to the more common uniform or fixed width approach widely employed today.

Materials and Methods

The Variable Width Stream Corridor Model is a conceptual, multivariable model that seeks to maximize benefits obtained from protecting corridor width area by allowing watershed planners to simultaneously develop, evaluate, and compare widths based on selected stream corridor functions. This model establishes the sub-watershed as the standard spatial unit for corridor implementation, as all sub-watersheds or basins will contain unique attributes including soils, slopes, wildlife needs, land use, and water resource problems. By developing widths specific to each sub-watershed, the model enables watershed planners to manage for a variety of goals or functions across a larger watershed without having to establish a single blanket corridor width. Fixed width systems may not provide the necessary level of protection for certain functions such as wildlife corridors or sediment control, or may be wider than needed, unnecessarily restricting the rights of property owners (Maryland Office of Planning 1993). The intent of this model is to develop corridor widths for a variety of functions.

Four common watershed and stream corridor management functions will be used as the basis of four individual modules. These functions are: water quality, bank, corridor, and wildlife. Using the four modules, optimum fixed widths for each management function are calculated based on thresholds established by scientific literature factored against variables from each specific sub-watershed, giving the watershed planner a key decision support tool that can help to evaluate several different implementation options or scenarios. The implementation model steps are:

1. Identification and definition of problems and issues.
2. Development of watershed management goals.
3. Data collection and analysis.
4. Data input in required fields and calculations.
5. Assessment/analysis/comparison/evaluation of width ranges from the functional modules.
6. Selection of corridor width for target sub-watershed.
7. Implementation of vegetated stream corridor widths.
8. Adaptive management of the vegetated stream corridor.

A general description of each calculation is provided below. For a detailed description including the thresholds established by the scientific literature and their sources, see Table 1 in the Appendix.

1. Water Quality Function

- Sediment Removal: Calculated as a function of base width times a slope factor.

- Nutrient Removal: Calculated as a function of a base width per each hydrologic soil grouping times land use times a slope factor.

2. Bank Function

- Shade integrity: Corridor width is equal to the height of the mature climax vegetation, one tree height, in the streamside area.

- Bank integrity: Corridor width is equal to the height of the mature climax vegetation in the streamside area.

3. Corridor Function

- Hyporheic Zone: Established as the width of the meander belt times a factor for stream order.

- Edge Effect/Blowdown: Measured as twice the height of the mature climax vegetation, two tree heights, in the streamside area.

- Meander Zone: Established using the equation, $A=2.7w^{1.1}$, where A equals the amplitude of the meander zone and w the stream width at bankfull stage.

4. Wildlife Function

- Minimum widths for wildlife are calculated using base widths established by various stream health functions including minimal, expanded, optimum, and specialized, based on the literature. User must enter a width for specialized species such as eagle and salmon, if this function is selected.

The numerous width parameters for the Variable Width Stream Corridor Model simultaneously establish eight different corridor widths based on the functional parameters described above and sub-watershed conditions. Variability among individual sub-watersheds within an overall drainage basin could potentially lead to the creation of several corridor widths for the same function. This scenario is anticipated, and reflects the need to manage stream functions from the smallest implementation unit as possible.

At any time, the model can be used to create “what if” scenarios by changing variables or watershed data.

Application: Salmon Creek Watershed. Function, applicability, and the effectiveness of this model was tested in the Salmon Creek Watershed, in Clark County, Washington. Clark County is located in Southwest Washington, and is part of the Portland, Oregon metropolitan area. The Salmon Creek watershed represents a natural to urban land use gradient, and is typical for many urbanizing watersheds in Western Washington and Oregon, with rapid development converting forested or rural watersheds into dense subdivisions and commercial centres. The creek occupies a basin of 56,900 acres extending west to east across the central portion of the county, with its steep, forested headwaters section located in the foothills of the Cascade Mountains. Of the 20 sub-watersheds that comprise the Salmon Creek basin, only the main stem of Salmon Creek and limited segments of major tributaries have a state-required management area. The Washington State Shoreline Management Act provides for a 200-foot management area adjacent to the creek, although this does not preclude development of associated hill slope, riparian, and even some floodplain areas. The Clark County Habitat Conservation Critical Area Ordinance prescribes additional riparian management areas based on various stream types mapped by the Washington State Department of Natural Resources. The County ordinance requires a 250-foot management area for state shorelines (Type S), 200-feet for fish bearing perennial streams (Type F), 100-feet for non-fish bearing perennial streams (Type Np), and 75-feeet for non-fish bearing seasonal streams (Ns).

This ordinance is intended to protect the functional integrity of habitat associated with streams while allowing for reasonable use of private property.

Three sub-watersheds were selected as test areas for the width calculation portion of the model: Lower Salmon Creek, Woodin Creek, and Upper Salmon Creek. The target sub-watersheds were chosen to represent the general watershed issues and land use patterns of the Salmon Creek Watershed: urban, rural, and forest.

Lower Salmon Creek. Lower Salmon Creek is a 796-acre basin comprised primarily of the floodplain area and associated forested wetland with a portion of adjacent hill slopes. The basin is highly urbanized and continues to face encroachment from residential development. Sedimentation from surrounding subdivisions is, thus, a primary concern, along with loss of floodplain and associated hill slope vegetation. Storm water and septic tank discharge from residential areas and transportation facilities transport nutrients from upland areas directly to the stream or floodplain, contaminating surface and groundwater resources.

While recommended widths for all four functions will be developed in the calculation model, specific management needs for this particular sub-watershed will be the management of **corridor-scale functions**, as long as the model provides a 200-foot minimum width for salmon recovery. In this case, the wildlife function will be expanded to account for salmon recovery and other wetland species, recommended at 200 feet by resource agencies.

By inputting data derived from the soil survey for Clark County, the publication TR-55, and local county GIS sources, and inserting the variables into the model, the recommended stream corridor width to provide maximum function is 160 feet for Salmon

Creek and associated floodplain streams within the sub-watershed. This would be measured against the 200-foot management zone required by the Washington Shorelines Management Act, which would only apply to the main stem. Clark County also manages the affected Type S and F stream segments with 250-foot and 200-foot corridors, respectively. Additional model application analysis could result in other recommended corridor widths for the smaller perennial and seasonal tributaries to Salmon Creek in the sub-watershed. The 160-foot width is slightly less than the 200-foot shoreline management area required by the state and the recommended 250-foot wide corridor that Clark County designates as habitat protection. In this case, the planner could compare the effect of the 200-foot width recommended for wildlife function with the recommended width for corridor functions, using the values to support the overall decision making process. If the state Shorelines Management Act required a strict 200-foot protective corridor, the model could have been used to confirm the suitability of the established corridor for the designed management function. The width calculations are summarized in Figure 1.

Woodin Creek. Woodin Creek is comprised of an 8,757-acre basin that includes rolling foothills, broad plains, and steep side hills near its confluence with Salmon Creek. Woodin Creek contains all of the concerns of larger, more urban, watersheds, including increased flooding due to loss of wetlands, sedimentation, high nutrient loads, bank erosion and incision, loss of streamside vegetation, and loss of wildlife habitat.

While recommended widths for all four functions will be developed in the calculation model, specific management needs for this particular sub-watershed will be the management of **water quality function**s to reduce nutrient and sediment loads into the creek.

By inputting data derived from the soil survey for Clark County, the publication TR-55, and local county GIS sources, and inserting the variables into the model, the recommended stream corridor width necessary for water quality protection is 140 feet for all streams within the Woodin Creek sub-watershed. This sub-watershed is not subject to the provisions of the Washington Shorelines Management Act, although Clark County manages the affected Type F and Np/Ns stream segments with 200-foot and 100/75-foot corridors, respectively. Additional model analysis could result in other recommended corridor widths for the smaller perennial and seasonal tributaries to Woodin Creek in the sub-watershed. The 140 feet width would provide much more than the 50 foot wide corridor needed for minimal wildlife function, and would protect some corridor functions with the exception of edge effect. It is slightly less than needed for bank function; although it can be assumed that most bank functions would be largely protected. The width calculations are summarized in Figure 2.

Upper Salmon Creek. Upper Salmon Creek is the headwater of the overall stream system, with a 6,910-acre sub-watershed that is dominated by dense evergreen forest interspersed with rural subdivisions and pastures. Commercial timber production on steep and poorly drained soils has led to landslides and surface erosion, creating a high sedimentation rate that has affected spawning habitat throughout the entire Salmon Creek basin. Although the riparian area is primary forested, other concerns include the near complete loss of mature riparian vegetation adjacent to the creek due to past forest fires and timber harvest practices, and minor inputs from residential areas and septic tanks.

Riparian vegetation now consists primarily of short-lived deciduous tree species that do not provide the same stable source of large woody debris that would be expected from a mature coniferous forest.

While recommended widths for all four functions will be developed in the calculation model, specific management needs for this particular sub-watershed will be the management of **water quality functions** to reduce sediment loads caused by logging activities in a steep landscape, and for bank function.

By inputting data derived from the soil survey for Clark County, the publication TR-55, and local county GIS sources, and inserting the variables into the model, the recommended stream corridor width necessary for water quality protection in regards to sediment removal is 235 feet for all streams within the sub-watershed. Very little of Salmon Creek and none of its tributaries within the sub-watershed are subject to the provisions of the Washington Shorelines Management Act, although Clark County manages the affected Type F and Np/Ns stream segments with 200-foot and 100/75-foot corridors, respectively. Additional model analysis could result in other recommended corridor widths for the smaller perennial and seasonal tributaries to Salmon Creek in the sub-watershed. If nutrient removal were required as well, the width would increase to 275 feet, largely due to the steep slopes within the watershed. This width protects bank function and most corridor functions, and is less than needed for optimal wildlife function. If the wildlife function were used, the corridor width would increase to 300 feet. The width calculations are summarized in Figure 3.

Results and Discussion

The corridor widths developed by the model illustrate the high degree of variability that can occur within a single watershed or sub-watershed when viewed from the perspective of individual stream functions factored against varied topography, soils, stream types, and vegetation. Using target sub-watersheds as test areas, the Variable Stream Corridor Model established conceptual corridor widths for eight separate watershed functions, providing planners and watershed managers with a variety of science-based width options for evaluation and comparison within the context of local stream corridor programs. This model provides managers with a valuable tool that can be used to maximize the benefits obtained from establishing riparian corridor width limits by looking at specific functions.

Using the function based, sub-watershed approach, it is clear that a variety of corridor widths are suitable for various stream functions in the overall Salmon Creek watershed, countering the common practice of uniformly applying a single width corridor to entire watersheds or entire regions. Using the Variable Width Stream Corridor Model can help to provide the community with function-based choices that can be compared on a watershed by watershed basis.

Summary and Conclusion

The Variable Width Stream Corridor Model utilizes widths based on scientific literature to develop thresholds or minimums factored against specific watershed parameters such as land use, slope, and stream order, all of which can be easily researched or documented by planning staff. The primary improvement provided by the model is the simultaneous development of eight recommended corridor widths based on a variety of key stream functions applied to individual sub-watersheds.

The effectiveness of recommended corridor widths for each function can be measured against the effectiveness of current stream corridor programs. For example, if an agency recommends a fixed 200-foot width for use within a watershed, city, or region, its effectiveness for water quality, sediment reduction, and wildlife use, can be measured using existing scientific models for that particular function, or by using stream sampling to measure the positive or negative effects of turbidity, benthic communities, stream habitat, or other factors. Corridor widths recommended by the Variable Width Stream Corridor Model would be measured in the same manner, with the results of the two approaches compared. If it is determined that the current method is not providing the necessary protection for a given stream function when compared to the width recommended by the model, the Variable Width Stream Corridor Model can be considered successful. Otherwise, adjustments based on continued research or specific watershed variables could be made to increase model effectiveness and complete the adaptive management cycle.

By questioning the application of a single fixed width corridor or even simple tired width approaches to entire watersheds, the Variable Width Stream Corridor Model becomes an adaptable tool, responsive to local needs and conditions. The sub-watershed application level creates a neighbourhood-scale approach where watershed issues are easily seen and understood by residents and introduces corridor width variability throughout the watershed.

A shortcoming of this model is that even though it has been developed to be extremely responsive to watershed conditions, it does rely on the creation of several fixed width corridors to provide thresholds for certain functions. However, the application of the model to the sub-watershed as the standard planning unit, the flexibility to apply the model at the detail of individual drainages, and the ability to easily change and analyze multiple variables simultaneously, outweighs any potential disadvantages. Fixed widths used for the Variable Width Stream Corridor Model are based on a comprehensive review of available scientific literature, although the concern of establishing fixed widths, especially minimum ones, remains. However, even with this potential risk, the Variable Width Stream Corridor model represents a substantial improvement over programs that apply a single fixed width corridor to entire watersheds or regions.

This paper has presented a new and effective methodology of sizing protective stream corridors or evaluating existing programs using a combination of literature-based and watershed-based factors. The Variable Width Stream Corridor model can be seen as an additional tool for planners to consider and use when balancing many competing land use factors. This model provides needed flexibility for watershed managers to address a variety of specific issues, while allowing for a more efficient use of corridor widths when compared to current fixed-width programs.

References

Azzaino, Z., J.M. Conrad, and P.J. Ferraro. (2002). Optimizing the Riparian Buffer: Harold Brook in the Skaneateles Lake Watershed, New York. Land Economics 78(4): 501-514.

Barten, Paul K. (1998). The Riparian Zone. Unpublished report. Department of Forestry and Wood Technology, University of Massachusetts, Amherst.

Bauer, Stephen B., and Stephen C. Ralph. (1999). Aquatic Habitat Indicators and their Application to Water Quality Objectives within the Clean Water Act. EPA 910-R-99-014. US Environmental Protection Agency, Region 10, Seattle, WA.

Binford, Michael and Michael J. Buchenau. (1993). Riparian Greenways and Water Resources, in D.S. Smith and P.C. Hellmund, eds., *Ecology of Greenways: Design and Function of Linear Conservation Areas.* University of Minnesota Press, Minneapolis.

Bottom, D.L., P.J. Howell, and J.D. Rodgers. (1983). Final Report: Fish Research Project Oregon Salmonid Habitat Restoration. Oregon State Department of Fish and Wildlife. Portland, OR.

Brazier, J.R. and G.W. Brown. (1973). Buffer Strips for Stream Temperature Control. Research Paper 15, Paper 865, School of Forestry, Oregon State University, Corvallis.

Brooks, Kenneth, Peter Ffollior, Hans Gregersen, and Leonard F. DeBano. (1997). Hydrology and the Management of Watersheds. Iowa State University Press, Ames, Iowa.

Brown, E.R. (1985). Riparian Zones and Freshwater Wetlands. Management of Wildlife and Fish Habitats in Forests of Western Oregon and Washington, Part 1. University of Washington, Seattle, WA.

Budd, W., P.L. Cohen, P.R. Saunders, and F.R. Steiner. (1987). Stream Corridor Management in the Pacific Northwest: Determination of Stream Corridor Widths. *Environmental Management*, 11.

Chesapeake Bay Program. (1995). Water Quality Functions of Riparian Forest Buffer Systems in the Chesapeake May Watershed. EPA 903-R-95-004. US Environmental Services, Portland, OR.

Clark County GIS. Clark County, WA., data layers for slopes, streams, and existing stream buffers. Clark County Geographic Information Systems, Vancouver, WA.

Colburn, Elizabeth A., editor. (1992). A Guide to Understanding and Administering the Massachusetts Wetlands Protection Act, second edition. Massachusetts Audubon Society, Lincoln, MA.

Croonquist, Mary Jo. And Robert P. Brooks. (1993). Effects of Habitat Disturbance on Bird Communities in Riparian Corridors. *Journal of Soil and Water Conservation*, Vol. 48(1).

Dillaha, T.A., and S.P. Inamdar. (1997). Buffer Zones as Sediment Traps or Sources, in N.E. Haycock, T.P. Burt, K.W.T. Goulding, and G. Pinay, eds., *Buffer Zones: Their Processes and Potential in Water Protection.* Quest Environmental, Harpenden, Hertfordshire.

Dramstad, Wenche E., James D. Olson, and Richard T.T. Forman. (1996). Landscape Ecology Principles in Landscape Architecture and Land-Use Planning. Island Press, Washington D.C.

Ferraro, P.J.(2004). Targeting Conservation Investments in Heterogeneous Landscapes: A distance-function approach and application to watershed management. *American Journal of Agricultural Economics* 86(4): 905–918.

Forman, Richard. (1997). Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge, UK.

Gilliam, J.W., J.E. Parsons, and R.L. Mikkelsen. (1996). Nitrogen Dynamics and Buffer Zones, in N.E. Haycock, T.P. Burt, K.W.T. Goulding, and G. Pinay, eds., *Buffer Zones: Their Processes and Potential in Water Protection.* Quest Environmental, Harpenden, Hertfordshire.

Hill, A.R. (1996). The Potential Role of In-Steam and Hyporheic Environments as Buffer Zones, in N.E. Haycock, T.P. Burt, K.W.T. Goulding, and G. Pinay, eds., *Buffer Zones: Their Processes and Potential in Water Protection.* Quest Environmental, Harpenden, Hertfordshire.

Lowrance, R.R. (1992). Groundwater Nitrate Denitrification in a Coastal Plain Riparian Forest. *Journal of Environmental Quality*, Vol. 21.

Lynch, J.A., E.S. Corbett, and K. Mussallem. (1985). Best Management Practices for Controlling Nonpoint-Source Pollution of Forested Watersheds. *Journal of Soil and Water Conservation*, Vol. 40.

Maryland Office of Planning. (1993). Managing Maryland’s Growth: Models and Guidelines. Preparing a Sensitive Areas Element for the Comprehensive Plan. Pub. 93-04. Maryland Office of Planning, Baltimore.

Massachusetts Department of Environmental Protection. (1998). The Massachusetts Rivers Protection Act: Protecting the Commonwealth's rivers, streams, and adjacent lands. Massachusetts Department of Protection internet web site. http://www.state.ma.us/dep/consumer/rpa.htm. Accessed October 24, 1998.

Metro. 1997. Policy Analysis and Scientific Literature Review for Title 3 of the Urban Growth Management Functional Plan. Metro Growth Management Services Department. Portland, OR.

Metro. 1998. Title 3, Urban Growth Management Functional Plan. Portland Metropolitan Planning Council, Portland, Oregon.

Mitsch, William J. (1993). Wetlands, second edition. Van Nostrand Reinhold, New York.

Morning, J.R. (1982). Decrease in Stream Gravel Permeability After Clear-cut logging: an Indication of Intragravel Conditions for Developing Salmonid Eggs and Alevins.In *Hydrobiologia*, Vol. 88.

Natural Resources Conservation Service, 1972. Clark County, WA., Soil Survey

Newbold, J.D., D.C. Erman, and K.B. Roby. (1980). Effects of Logging on Macroinvertebrates in Streams With and Without Buffer Strips. *Canadian Journal of Fisheries Aquatic Science*, Vol. 37.

Norman, A.J. (1993). Use of Vegetative Buffer Strips to Protect Wetlands in Southern Ontario, in G. Mulamoottil, B. Warner, E. McBean, eds., *Wetlands: Environmental Gradients, Boundaries, and Buffers.* Lewis Publishers, Boca Raton, FL.

Noss, R.F. (1990). Indicators for Monitoring Biodiversity: A Hierarchical Approach. Conservation Biology 9(1990):355–64.

Noss, R. F. (1993). Wildlife Corridors, in D.S. Smith and P.C. Hellmund, eds., *Ecology of Greenways: Design and Function of Linear Conservation Areas.* University of Minnesota Press, Minneapolis.

Oregon Department of Forestry. (1994). Guide to Placing Large Wood in Streams. Oregon Department of Forestry Forest Practices Section, Salem, OR.

Palone, Roxane S., and Albert H. Todd. (1998). Chesapeake Bay Riparian Handbook, Guide for Establishing and Maintaining Riparian Forest Buffers. USDA Forest Service – Northeastern Area, Morgantown, WV.

Petts, Geoffrey and Peter Calow, eds. (1996). River Restoration: Selected Extracts from the Rivers Handbook. Blackwell Science, London.

Phillips, J.D. (1989). Evaluation of North Carolina's Estuarine Shoreline Area of Environmental Concern from a Water Quality Perspective. *Coastal Management*, Vol. 17.

Richman, Tom, Jennifer Worth, and Patric Dawe. (1997). Start at the Source: Residential Site Planning and Design Guidance Manual for Stormwater Quality Protection. Bay Area Stormwater Management Agencies Association, San Francisco, CA.

Riley, Ann L. (1998). Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens. Island Press, Washington D.C.

Riparian Habitat Technical Committee. 1985. The Best Practices for the Management and Protection of Western Riparian Stream Ecosystems. American Fisheries Society, Western Division.

Ritter, Dale, R. Craig Kochel, and Jerry R. Miller. (1995). Process Geomorphology, third edition. William C. Brown Publishers, Dubuque, IA.

Rosgen, David. (1994). A Classification of Natural Rivers. *Caetena*, Vol. 22.

Schueler, Tom. (1995). Site Planning for Urban Stream Protection. Center for Watershed Protection, Washington D.C.

Schueler, Tom. (1994). The Importance of Imperviousness. *Watershed Protection Techniques* Vol.1, No.3. Center for Watershed Protection, Washington D.C.

US Department of Agriculture. 1998. Stream Corridor Restoration: Principles, Processes, and Practices. US Department of Agriculture, Washington D.C.

Uusi-Kamppa, J., E. Turtula, H. Hartikainen, and T. Ylaranta. (1996). The Interactions of Buffer Zones and Phosphorus Runoff, in N.E. Haycock, T.P. Burt, K.W.T. Goulding, and G. Pinay, eds., *Buffer Zones: Their Processes and Potential in Water Protection.* Quest Environmental, Harpenden, Hertfordshire.

Washington County Unified Sewer District. 1999. Standard Design Requirements for Storm and Surface Water. Washington County Unified Sewer District, Beaverton, OR.

Washington State Department of Ecology. 1992. Wetland Buffers: Use and Effectiveness. Washington State Department of Ecology, Olympia, WA.

Washington State Department of Ecology. 2000. State Master Program Approval/ Amendment Procedures and Shoreline Master Program Guidelines, Chapter 173-26 WAC. Washington State Department of Ecology internet web site. http://www.ecy.wa.gov/programs/sea/SMA/guidelines/newguid.htm. Accessed January 4, 2001.

Washington State Department of Fish and Wildlife. 1992. Buffer Needs of Wetland Wildlife. Habitat Management Division, Washington State Department of Fish and Wildlife, Olympia, WA.

Washington State Department of Fish and Wildlife. 2000. Integrated Streambank Protection Guidelines. Washington State Department of Fish and Wildlife, Olympia, WA.

Watanabe, Michio, et. al. (2005). Toward efficient riparian restoration: integrating economic, physical, and biological models. *Journal of Environmental Management*, *Volume 75, Issue 2*.

Welsch, David J. (1991). Riparian Forest Buffers. USFS Publication No. NA-PR-07-91. US Department of Agriculture, Randor, PA.

Wentz, Dennis, Bernadine A. Bonn, Kurt D. Carpenter, Stephen R. Hinkle, et.al. (1998). Water Quality in the Willamette Basin, Oregon, 1991-95. US Geological Survey Circular 1161. US Department of the Interior, Washington D.C.

Winter, Thomas C., Judson Harvey, O. Lehn Franke, and William Alley. (1998). Ground and Surface Water: A Single Resource. US Geological Survey Circular 1139. US Department of the Interior, Washington D.C.

Figure 1

Width Calcultion for Lower Salmon Creek.

Variable Width Stream Corridor Model - width calculation			
Name of Watershed/ Sub-Watershed		*Lower Salmon Creek*	
Required Data		*** note: fill all blank fields for "required data"*	
general stream order	**high**	soil permeability *(high, medium, low)*	**low**
(intermittent; low order: 1,2; mid order: 3,4; high order: 5+)		hydrologic soil group (A,B,C,D)	**D**
drainage area in acres	**796.00**	wildlife function	**expanded**
Rosgen classification (A,B,C, etc)	**F**	*(minimal, expanded, optimum, specialized)*	
stream width at bankfull stage	**70.00**	specialized width, if applicable	
height of mature climax vegetation	**80.00**	primary land use of sub-watershed	**urban**
slope of riparian area (from soil survey)	**3.00**	*urban (urbanizing), rural (agricultural), natural (forest)*	
**** note: corridor widths per each side of stream. Multiply by 2 for total stream corridor width. ****			
Water Quality Function		**Bank Function**	
sediment removal	**100**	shade	**80**
nutrient removal	**125**	bank integrity	**80**
Corridor Function		**Wildlife Function**	
hyporheic zone	**145**	wildlife corridor *expanded*	**200**
edge effect/ blowdown	**160**		
meander zone	**145**		

Figure 2

Width Calcultion for Woodin Creek.

Variable Width Stream Corridor Model - width calculation			
Name of Watershed/ Sub-Watershed		*Woodin Creek*	
Required Data		*** note: fill all blank fields for "required data"*	
general stream order	**low**	soil permeability *(high, medium, low)*	**medium**
(intermittent; low order: 1,2; mid order: 3,4; high order: 5+)		hydrologic soil group *(A,B,C,D)*	**C**
drainage area in acres	**8757.00**	wildlife function	**minimal**
Rosgen classification (A,B,C, etc)	**G**	*(minimal, expanded, optimum, specialized)*	
stream width at bankfull stage	**15.00**	specialized width, if applicable	
height of mature climax vegetation	**150.00**	primary land use of sub-watershed	**urban**
slope of riparian area (from soil survey)	**13.00**	*urban (urbanizing), rural (agricultural), natural (forest)*	
**** note: corridor widths per each side of stream. Multiply by 2 for total stream corridor width. ****			
Water Quality Function		**Bank Function**	
sediment removal	**140**	shade	**150**
nutrient removal	**140**	bank integrity	**150**
Corridor Function		**Wildlife Function**	
hyporheic zone	**9**	wildlife corridor *minimal*	**50**
edge effect/ blowdown	**300**		
meander zone	**27**		

Figure 3

Width Calculation for Upper Salmon Creek.

Variable Width Stream Corridor Model - width calculation			
Name of Watershed/ Sub-Watershed		*Upper Salmon Creek*	
Required Data		*** note: fill all blank fields for "required data"*	
general stream order	**low**	soil permeability *(high, medium, low)*	**low**
(intermittent; low order: 1,2; mid order: 3,4; high order: 5+)		hydrologic soil group *(A,B,C,D)*	**D**
drainage area in acres	**6910.00**	wildlife function	**optimum**
Rosgen classification (A,B,C, etc)	**A**	*(minimal, expanded, optimum, specialized)*	
stream width at bankfull stage	**12.00**	specialized width, if applicable	
height of mature climax vegetation	**150.00**	primary land use of sub-watershed	**natural**
slope of riparian area (from soil survey)	**40.00**	*urban (urbanizing), rural (agricultural), natural (forest)*	
**** note: corridor widths per each side of stream. Multiply by 2 for total stream corridor width. ****			
Water Quality Function		**Bank Function**	
sediment removal	**235**	shade	**150**
nutrient removal	**275**	bank integrity	**150**
Corridor Function		**Wildlife Function**	
hyporheic zone	**7**	wildlife corridor *optimum*	**300**
edge effect/ blowdown	**300**		
meander zone	**21**		

Appendix

Table 1

Detailed description of calculations.

Variable	Calculation	Scientific sources considered when defining calculation method
Slope	For riparian slopes greater than 5%, increase corridor width by 5 feet for each 1% slope increment.	Brooks (1997), Metro (1997), Norman (1993), Palone (1998), Schueler (1995) Washington County Unified Sewer District (1999), Maryland Office of Planning (1993).
1. Water Quality Function		
Sediment	Base widths for sediment removal are divided into three categories. 60 feet will be used for streams with natural forest cover and a low probability of development, 80 feet will be used for streams with rural or agricultural development, and a base width of 100 feet will be used for streams within urban or urbanizing watersheds.	Washington State Department of Ecology (1992), Barten (1998), Palone (1998), Uusi Kamppa (1996), Metro (1997), Chesapeake Bay Program (1995), Dillaha (1997), Petts (1996), Budd (1987), Lynch (1985), Morning (1982), Newbold (1980).
Nutrient Removal	Base widths for nutrient removal are divided according to hydrologic soil groups as proposed by Welsch, including all Group D soils and the portions of Group C soils prone to flooding, provided that the combined width meets the recommended parameter for nutrient removal. If the combined width exceeds the minimum recommended parameter, width will be increased to include the recommended soil groups or 25% of the base width. For areas that do not include Group A and B soils, the following width parameters will be used: 75 feet minimum - rural/natural, 100 feet maximum - urban.	Metro (1997), Palone (1998), Lynch (1985), Chesapeake Bay Program (1995), Phillips (1989), Washington State Department of Ecology (1992), Schueler (1995), Uusi Kamppa (1996), Gilliam (1996), Lowrance (1992), Welsch (1991), Natural Resources Conservation Service (1986), Richman (1997).
2. Bank Function		
Shade and Temperature	Corridor shade width is equal to one mature tree height.	Bauer (1999), Binford (1993), Brazier (1973), Palone (1998), Metro (1997), Washington State Department of Ecology (2000).
Bank	Bank integrity width is equal to one mature tree height.	Barten (1998), Welsch (1991), Schueler (1995), Palone (1998), Petts (1996), Metro (1997),

Integrity		Bottom (1983), Oregon Department of Forestry (1994).
3. Corridor Function		
Hyporheic Zone	Probable extent of hyporheic zone is defined as A=2.7w^1.1, where A = amplitude or meander zone and w=stream width at bankfull stage.	Winter (1998), Hill (1996), Wentz et. al. (1998), Rosgen (1994).
Meander Zone	Width of the meander zone is defined as A=2.7w^1.1, where A=amplitude or meander zone and w=stream width at bankfull stage.	Ritter (1995), Washington State Department of Fish and Wildlife (2000), Rosgen (1994).
Edge Effect (Blowdown)	To manage for blowdown and edge effect, the corridor width is equal to two mature tree heights as measured on either side of the stream.	Noss (1993), Croonquist (1993), Forman (1997).
4. Wildlife Function		
Wildlife	To provide for a range of wildlife uses in vegetated stream corridors, established widths are: minimum corridor width, 50 feet; expanded corridor width, rural or natural, 100 feet; expanded corridor width, urban or urbanizing, 200 feet; optimum corridor width, 300 feet.	Schueler (1995), Washington State Department of Ecology (1992), Brown (1985), Barten (1998), Riparian Habitat Technical Committee (1985), US Department of Agriculture (1998), Forman (1997), Petts (1996), Noss (1993), Washington State Department of Fish and Wildlife (1992).