

**The Functions of Riparian Buffers in Urban Watersheds**

by

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A report submitted in partial fulfillment of the degree of

Master of Science

University of Washington

1998

University of Washington

Abstract

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There are numerous functions that the riparian zone provides for the streams in undisturbed watersheds in the Pacific Northwest. In general the vegetation in this zone influences the water quality, hydrology, and biology of the streams. This paper will briefly look at how the riparian buffer interacts with the stream to moderate temperature, reduce sediment and nutrient loads, attenuate peak flows, and maintain the biological integrity of the stream. Once the functions provided by riparian areas in undisturbed watersheds have been evaluated, this paper will then focus on the ability of a riparian buffer to provide the same functions in urban watersheds.

Urban watersheds have many unique characteristics, and the associated streams have altered water quality, hydrology and biology. To address this problem, government agencies enforce riparian buffer widths in an attempt to minimize the impacts of development on the stream. However, in urban watersheds, the buffer may not be an effective method to reduce the degradation of urban streams due to the increased volume of stormwater, which is often channelized through the buffer. The buffer is by-passed, and therefore it is not effective at reducing peak flows or the sediment and nutrients carried by the stormwater.

An evaluation of the effectiveness of a riparian buffer in moderating stream temperatures was done using data collected in two watersheds, Rock and Richardson Creeks, in the Portland, Oregon, Metro area. Portland Metro, the regional government, is interested in the condition of these watersheds because they both lie within the urban growth boundary and therefore the amount of development in these watersheds is expected to double over the next 50 years. The establishment of riparian buffers is one methods of regulation that will be implemented in these watersheds to protect the streams from urbanization. In an attempt to evaluate the effectiveness of these methods, the function of temperature attenuation was examined in each of the watersheds. The percent of the riparian buffer that was intact upstream of each sampling site was correlated with the maximum, minimum, and daily fluctuation observed throughout the summer of 1996. The general trend observed was an increase of all three measures of temperature as the percent of intact buffer decreased, which supports the hypothesis that at least some of the conditions of the stream are related to the condition of the riparian buffer.

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## **Introduction to Riparian Buffers**

Riparian areas occupy a unique ecological niche between upland and stream ecosystems. Historically, the riparian area has only been studied in relationship to other habitats and has therefore been defined by a variety of different scientific disciplines (Swanson et al., 1982). Yet to understand the riparian buffer as a separate ecosystem related but independent from both upland and stream ecosystems, all of the definitions must be combined. The most comprehensive definition states that a riparian buffer is the land adjacent to any stream or wetland and acts as a transition from the stream to the upland ecosystem.

Riparian buffers, in general, have many common characteristics. They must have surface water present all or at least part of the year, a complex and diverse vegetation community, a high edge-to-area ratio, and recurring disturbance (Riparian Committee, 1985). However, these characteristics are broad and do not reveal information about the important functions or unique characteristics of riparian buffers. Instead, a combination of more specific definitions can better illuminate both the unique characteristics of riparian areas and their importance for stream ecosystems. For example, the soils that underlie the riparian area are periodically inundated with water and support vegetation tolerant of saturated soils (Beschta, 1991). The vegetation of the riparian buffer is important because of the role it plays in fixing nitrogen (Triska et al., 1993). Therefore, the riparian area can be considered as a unique ecosystem, which interacts with the stream and upland ecosystems in several important ways. The integrity of each of these ecosystems is closely dependent on the existence and function of each other.

Riparian buffers are commonly used as a regulatory tool to moderate the impact of land use in the watershed. They have been used in this fashion because there are many examples of how the stream system interacts with, and is apparently influenced by, the riparian buffer. The buffer can influence the water quality of the stream by moderating the temperature and the loading of nutrients and sediment. Additionally, it influences the hydrology by the interception of rainfall and the storage and infiltration of overland runoff. The morphology of the stream is affected as the stream interacts with the vegetation in the riparian zone during high and low flow periods. Finally, the riparian buffer significantly influences many components of the biology of the stream.

Stream ecosystems and the adjacent riparian area are closely interrelated. The vegetation and species diversity of the riparian area are a function of the hydrology and water quality of the stream. Similarly, the characteristics of the stream such as water quality, hydrology, and biology also depend on the riparian area. More specifically the riparian vegetation has a significant influence on the flow regime, geomorphology, temperature, nutrients, and sediment load in streams. Additionally, the buffer also provides numerous biological functions related to instream species and shoreline habitat. The riparian buffer also protects the stream ecosystem from human encroachment.

Despite these interactions, the ability of buffers to moderate the impacts of human development in the upland portion of the watershed is unclear. This paper specifically addresses whether the buffer can provide the water quality, hydrologic, and biologic functions in an urban watershed that it affords on a natural undisturbed system.

## **Purpose**

Under natural conditions, an intact riparian buffer serves numerous functions that maintain the integrity of the stream ecosystem. As a result, protection of a buffer is commonly equated with the protection of stream integrity. However, an alternative hypothesis is that an intact buffer in an urban watershed cannot provide the same functions as a buffer in a forested watershed, and that as a result the stream ecosystem is not completely protected from urban upland development even if a substantial buffer is maintained. Although the decision to maintain riparian buffers in urban watersheds can be justified on the basis of numerous studies, the riparian buffer may not in fact be adequate to reduce all of the impacts of upland development. The expectations of full restoration of stream function is largely a consequence of having a majority of buffer studies being done in forested and agricultural watersheds, both of which have characteristics distinctly different from those of urban watersheds. Additionally, most of these studies are very site specific and therefore the conclusions about the width of buffer adequate to protect the stream have a high degree of variability when applied elsewhere.

To explore these issues, a case study of two watersheds in the Portland Metro area was used for both qualitative and quantitative analyses. Using these examples, this paper will address the question of whether the current criteria for the establishment of riparian buffer width are adequate to maintain the stream condition. Instead of taking the often-repeated approach of evaluating current required buffer widths to determine if they are adequate based on other studies, this paper will focus on the unique characteristics of urban watersheds in an effort to determine if maintenance of a riparian buffer alone is enough to protect the stream ecosystem from urban upland development.

## **Functions of Riparian Buffers**

### *Water Quality*

The riparian buffer moderates three particularly important components of water quality: temperature, nutrients, and sediment loads. Temperature in small streams is a combination of groundwater influence, upstream condition, and the amount of incoming solar radiation reaching the surface of the water. In forested watersheds, solar radiation is the primary agent for temperature change in the summer (Beschta et al., 1987), and on average a large percent of the upstream banks must be forested before temperatures are reduced (Barton et al., 1985). The vegetation in the riparian buffer shades the stream and decreases the summer temperature. It also traps back-radiation in the winter resulting in increased winter temperatures. Karr and Schlosser (1977) concluded that the removal of streamside vegetation results in a temperature increase of 6 to 9 degrees Centigrade. The vegetation also decreases evaporation and convection in the near stream area. As a result, the riparian vegetation creates a microclimate which moderates the stream temperature by preventing extremely low or high temperatures, and which reduces the daily and seasonal fluctuations in stream temperature (Beschta et al., 1987).

Vegetation in the riparian buffer is also a key component of the nutrient cycle. As groundwater and surface water from the uplands run through the riparian area, the dissolved nutrients they contain are removed through both the uptake by vegetation and adsorption to soil particles. The vegetation in the riparian buffer is a sink for dissolved nutrients and a source of complex organic material, which falls into the stream and decomposes. One study demonstrated that riparian vegetation demands high levels of dissolved nutrients, such as nitrate (Gregory et al., 1991). The results from other studies,



done in agricultural watersheds, support this theory by demonstrating that forested streamside buffers can remove 65 % to 100% of the nitrogen and 30 % of the phosphorus from the surface and groundwater (Lowrance et al., 1984; Petersen et al., 1992; Osbourne and Kovacic, 1993). Nitrogen is removed by the riparian buffer primarily through the process of denitrification in small patches of anoxic conditions (Triska et al., 1993). This function of the riparian buffer directly affects the stream condition because it removes the dissolved nutrients, which could be detrimental to stream biota. An additional function of the riparian vegetation, particularly important in headwater streams, is the input of leaves and pine needles which slowly decay and become and become a valuable food source for invertebrates and therefore the fish populations (Karr and Schlosser, 1977).

The removal of sediment from upland erosion is another important function related to water quality that is provided by the buffer. The quantity of sediment that can be removed is related to the slope of the adjacent bank, the flow characteristics of the stream, and the roughness of the vegetation. There are two main mechanisms by which the riparian buffer removes sediment transported by the stream. During large discharges and overbank flows, sediment carried by the instream flow is trapped by the increased hydraulic roughness, which causes slower flow rates and sediment deposition (Leopold, 1964). Sediment in surface runoff from adjacent hillslopes can also be removed because the vegetation will slow the flow, increase infiltration, and so reduce surface flow. Both mechanisms of sediment removal are only effective, however, if channelized flow is prevented.

## *Hydrology*

Geology, geographic location, long-term weather patterns, and land use in the watershed determine the hydrological characteristics of a stream. Although land use in the entire watershed has been shown to alter the hydrology, the condition of the riparian buffer, because of its direct linkage to the stream, is particularly important to hydrology. One study showed that the riparian buffer, if extensive, could prevent unnaturally large fluctuations in discharge (Barton et al., 1985). Riparian buffers interact with the stream and influence hydrology through several different mechanisms. It is important to divide the hydrological functions of the riparian buffer into two categories. The mechanisms in the first category are those that will continue to influence the hydrology even if the buffer is partially destroyed by land use practices. The second mechanisms are those that are not provided by the riparian buffer even if it is partially intact because the buffer is bypassed by channelized flow.

In the first category, the functions will be impaired as the buffer is destroyed but there will still be some influence. Vegetation growth in the buffer reduces the amount of water that will reach the channel, both by the interception and evapotranspiration of precipitation and by the uptake of water by roots. This is significant in watersheds, such as those in the Pacific Northwest, that are dominated by subsurface flow and where the majority of precipitation never reaches the channel as streamflow in the undeveloped state (Booth, 1991). The high surface area of vegetation and forest duff in land adjacent to the stream partially maintains this subsurface flow regime by increasing the infiltration rate and the volume of water stored. It also allows stormwater to be released slowly, over a period of days or months, to the stream after a storm event (Booth, 1991).

The vegetation in the buffer also interacts with the stream during high flows. It increases the roughness of the channel above bankfull depth, which slows peak flows and also enhances storage and infiltration. The riparian buffer can also influence the hydrology of the stream by dissipating the additional water from stormwater runoff before it enters the channel.

The increased number of channelized stormwater inputs, which by-pass the buffer, greatly reduce the ability of the buffer to reduce peak flows in an urban watershed. In small watersheds the stream system will be most influenced by the rate at which water reaches the stream and is transported to the mouth and less influenced by the increase in the volume of water that reaches the channel (Dunne and Leopold, 1978). With the increased number of stormwater channels connecting impervious surfaces to the channel network the response time to a storm event greatly decreases. This in turn leads to degradation of the stream from greater frequency and magnitude of high flows, which become progressively more important as the effects accumulate downstream (Vannote, 1980).

The riparian buffer also influences the geomorphology of the stream. In natural forested ecosystems, the buffer is a source of large woody debris (LWD) including rootwads and large branches (Bilby, 1988). The LWD changes the hydraulics of the channel by creating pools, bars, and stabilizing the channel (Leopold et al., 1964; Swanson et al., 1982). Although the input of LWD can increase lateral channel migration, the presence of LWD in small channels generally acts to stabilize the banks by dissipating energy. LWD also increases the volume available in the channel to store sediment (Bilby, 1988; Swanson, et al., 1982). This reduces the rate of sediment

transport in the stream, and it may influence the formation of terraces and increase the width of the channel (Bilby, 1988; Swanson, et al., 1982).

### *Biology*

Biology of the stream system depends on the condition of the riparian buffer. Salmon and macroinvertebrates are two main biologic entities that have been studied extensively to determine their response to the removal of riparian vegetation. The response of salmon and macroinvertebrates to the alteration of habitat has been used to characterize the response of the entire biological community of the stream.

In the Pacific Northwest, special concern is given to salmon populations. Numerous studies have evaluated how the changes in the riparian buffer have affected salmon populations. Paired studies, comparing streams in predominately unaffected watersheds, have found that the production of salmon biomass increases in the streams with no riparian buffer primarily because fish productivity of the streams was limited by cold temperatures until the removal of the vegetation caused the temperature of the stream to rise (Sedell et al., 1982; Newbold, 1980). However, the loss of riparian vegetation also leads to an increase in algae and fine sediment as well as the loss of habitat diversity and pools (Budd et al., 1987). As a result, there is an unnatural increase in the biomass of the stream, which is detrimental to the balance of the stream ecosystem. The increase in primary production leads to a shift in salmon species and age class structure. Populations that once dominated are outcompeted by other species (Sedell et al., 1982). Therefore, to ensure the integrity of the natural salmon populations, it is important to minimize the removal of riparian vegetation.

Other species, such as benthic macroinvertebrates, also interrelate with riparian vegetation. In watersheds with removed riparian vegetation, the general response is an increased density of the macroinvertebrates but a decreased diversity and loss of sensitive species (Newbold et al., 1980). The sensitive species, which are lost in streams without buffers, tend to be the species most important in the food chain. Many of these species are outcompeted by algae or worms, both of which cannot be used by fish as a food source. Therefore, changes in the benthic community are very important to the rest of the stream community because they form the base of the food chain (Budd et al., 1987). Benthic macroinvertebrates, because of their sensitivity and importance to the stream system, are therefore being used as an index to estimate the biotic integrity of the stream (Fore et al., 1996).

#### *Protection of Stream from Human Encroachment*

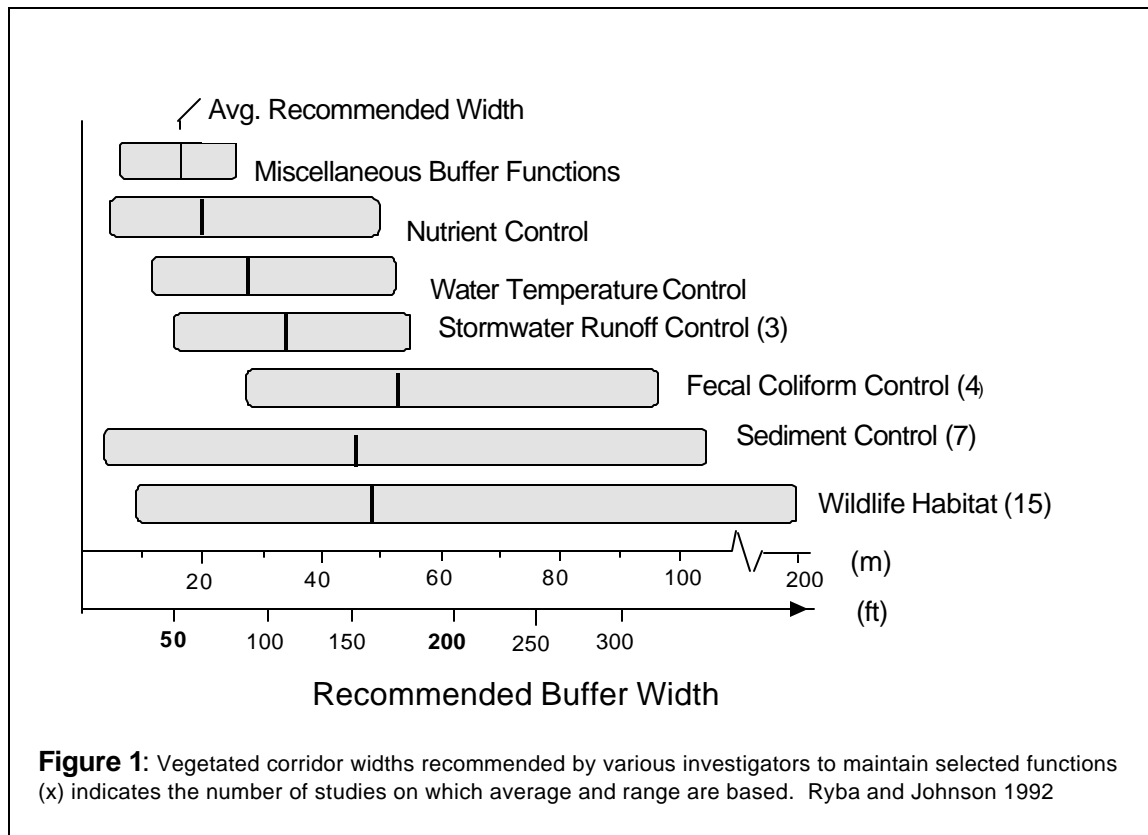
The most basic function of the buffer in populated watersheds is to reduce the direct encroachment of humans on the stream bank. An intact riparian buffer decreases bank erosion, the dumping of refuse, and visual degradation by preventing human intrusion. Another function of the buffer is to protect sensitive species from visual disturbances from human activities (Young, 1989).

### **Historic Approaches for Protecting Riparian Buffers**

Numerous studies have evaluated the buffer widths needed for the protection of the stream ecosystem from upland land use. However, instead of analyzing the consequences on stream function of the natural variation in the width of riparian areas, the buffer widths are artificially specified and their effectiveness is evaluated. Although these studies recommend a buffer width deemed sufficient to protect the stream, they are

narrowly focused on both the type and intensity of land use as well as the single parameter of stream function they are trying to protect.

The buffer widths recommended to protect stream integrity vary depending on which measure of integrity has been used. A summary of recommended buffer widths, based on an extensive literature review, is given in Figure 1 (Johnson and Ryba, 1992). There is a wide range of variability even within each category, illustrating how the results of each study depend on the site conditions and function. Additionally, the majority of studies on the riparian buffer are conducted in watersheds with forestry or agricultural land uses, and therefore those studies do not address the numerous and different characteristics of urban land use. The variability in recommended riparian buffer widths increases the difficulty of establishing buffer-width regulations that are adequate to protect the stream.



## Buffers in the Urban Landscape

### *Unique Characteristics of Urban Watersheds*

Urban watersheds have many characteristics that differ from undisturbed, forested, or agricultural watersheds in the same geological setting. The principle difference is the intensity of land use and the increased amount of impervious surface area in the surrounding watershed. As a result of urban land development in these watersheds, streams characteristically have altered hydrology, increased sediment loads and new sources of pollutants. Numerous studies have documented the relationship between degraded stream ecosystems and urban upland development (Horner et al., 1996).

Hydrology is one of the most important determinants of stream condition in any watersheds, and therefore any change in the hydrologic regime of the watershed can significantly alter the natural ecology of the stream system (Poff et al., 1997). Both the volume of water reaching the stream as surface flow and the rate at which it travels are significantly increased in urban watersheds because increases in impervious surface are accompanied by increases in the drainage density and the number of channelized inputs (Hollis, 1975). The changes in the timing and predictability of these flows is also important to the biology of the stream which have evolved life histories, such as dispersal, egg incubation period, migration, and recruitment, that are related to natural hydrologic conditions (Poff et al., 1997).

The channelization or piping of runoff eliminates the urban buffer's ability to attenuate peak flows, infiltrate stormwater, or filter sediment and nutrients. The result is a changed stream ecosystem. Schuler (1995:155) found that:

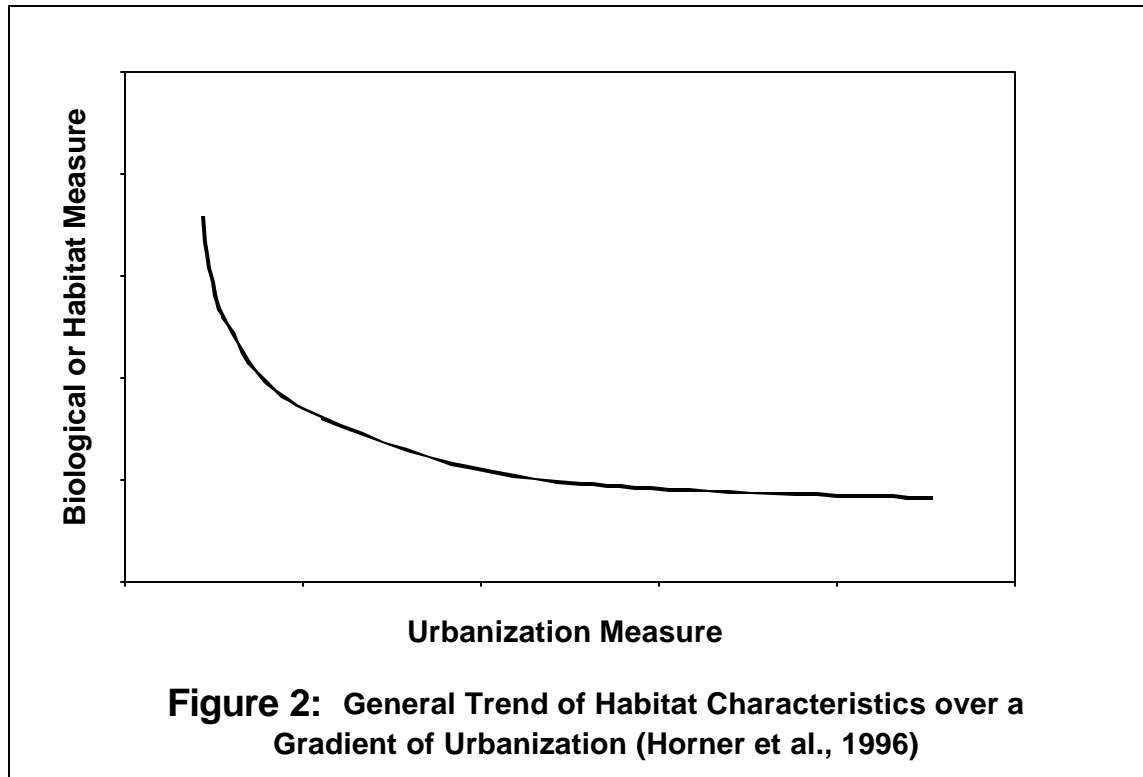
“as much as 90% of the surface runoff generated in an urban watershed concentrates before it reaches the buffer, and ultimately crosses it in an open flow channel or enclosed storm drain pipe.”

The consequence is seen in magnified peak discharges as well as an increase in the number of large runoff events that occur each year (Hollis, 1975; Booth, 1991; Horner et al., 1996). Conversely, the ability of a buffer to function properly depends on how effectively it resists channelization and maintains subsurface flow (Broderson, 1973; Karr and Schlosser, 1977). Yet in urban watersheds it is very difficult for channelization to be avoided, and therefore many of the natural functions of the buffer are difficult to maintain.



Changes in the geomorphology and biology of the stream system are directly related to altered hydrologic processes. Pederson and Perkins (1986) noted that as a result of the increased frequency of peak flows, there is a change in fluvial processes in urban streams. The common response to the changes in hydrology is an increase in the width of the channel and downcutting (Hammer, 1972). Booth and Jackson (1997) have also observed that channels are almost universally unstable in even moderately urbanized watersheds. The result is a loss of the complexity of the habitat and a reduction in the populations of invertebrates and vertebrates (Karr and Schlosser, 1977).

The benthic invertebrate community of urban streams is characterized by the relatively few species that can survive on unstable substratum (Pedersen and Perkins, 1986). Other studies also have noted a decline in the diversity of the benthic invertebrate community in urban watersheds (Whiting and Clifford, 1983; Horner et al., 1996). The study done by Horner et al. (1996) also measured a decrease in the Benthic Index of Biotic Integrity (B-IBI) scores of urban streams, with a particularly rapid decline at the earliest stages of urbanization (Figure 2; Horner et al., 1996). The combination of altered temperature, morphology, and hydrology can be linked to changes in all of the components of the stream biology (Fore et al., 1997).



## Evaluating the Riparian Buffer

There are several different methods for evaluating the effectiveness of the riparian buffer system for protecting the stream system from upland development. All of these methods rely on estimating the amount of development, either in the watershed or adjacent to the stream, and measuring the condition of the stream ecosystem. The purpose of each of these methods is to determine how well the amount of development within the watershed correlates with the chosen measure of integrity of the stream ecosystem.

Pederson and Perkins (1986) compared the variation in macroinvertebrate communities of urban and rural streams. They were particularly interested in the

influence changes in the physical characteristics of the stream had on the macroinvertebrate populations. Watersheds with greater than 75% of the land developed were classified as “urban” and those with less than 15% of the watershed developed were classified as “rural”. They found that although there was not a significant difference in the number of macroinvertebrates in the rural and urban streams, there was a difference in the composition of the macroinvertebrates. The macroinvertebrates in the urban watershed were tolerant of the flashy flow regime and unstable substrate that was associated with the urban stream. Therefore, Pederson and Perkins (1986) concluded that the difference in macroinvertebrates in rural and urban streams was a shift in the community composition to species tolerant of the changes in hydrology and geomorphology.

Horner et al. (1996) examined the relationship between the percent of impervious surface area in the watershed and several metrics of stream integrity: coho salmon to cutthroat trout ratio, ratio of 2-year peak flow rate to winter base flow rate, the quantity of large woody debris, the ratio of intragravel to water column dissolved oxygen, and a measure of benthic invertebrate community. Across a wide gradient of development, as the percentage impervious surface in the watershed increased both the number of cutthroat trout compared to the number of coho salmon and the frequency of predevelopment 2-year peak flows increased (Horner et al., 1996). Similarly, the amount of large woody debris in the channel, the concentration of intragravel dissolved oxygen, and the B-IBI scores all decreased (Horner et al., 1996).

Several other studies have specifically compared the stream condition with the condition of the adjacent riparian buffer. The purpose of these studies has been to

evaluate the effectiveness of various buffer widths at protecting the stream ecosystem adjacent to the buffer from upland development. Although these studies did not take into account upstream effects, nonetheless they do help determine the effectiveness of buffers at reducing the influence of land use along stream corridors.

In one example Whipple et al. (1981) classified buffer widths greater than 50 feet as “excellent,” between 10 and 50 feet as “medium,” and less than 10 feet as “poor” and then correlated these buffer widths with adjacent bed and bank erosion. The rates of erosion correlated well with the different classes of land development, and the presence of a buffer significantly reduced erosion. However, Whipple et al. (1981) noted that it was difficult to quantify the riparian condition for the stream corridor.

In a related example (Bingham et al. 1980), an engineered grass buffer was evaluated to determine its effectiveness at reducing polluted runoff from a poultry cage. In this study the buffer was quantified as an area and Bingham et al. (1980) determined the area of buffer required to remove the pollutants from the animal waste area. The study is important because it defines the buffer as an area and not a width. A similar study was done on the natural system, which looked at the relationship between weekly maximum temperature and the length and width of the buffer (Barton et al., 1985). To test the hypothesis that strong relationship between the stream temperature and the length and width of the upstream buffer exists, Barton et al. (1985) used a regression equation and found that it explained 90% of the observed variation in temperature.

Models and equations are frequently used methods for the determination of effective buffer widths. One example of this method is an equation developed to predict the needed buffer width for filtration of sediment based on the particle size, slope, and

roughness of the buffer vegetation (Wong and McCuan, 1982). Wong and McCuan (1982) concluded that small buffers filter a small amount of sediment, but that large buffers do not filter incrementally larger amounts of sediment. A 30 meter buffer may remove almost all of the sediment, however the remaining suspended sediment, which is generally smaller than the initial sediment, has a longer settling time and therefore must be retained in the system longer than the larger sediment before it settles out of the system. Models such as this are useful tools for understanding the natural processes; however, they are based on several simplifying assumptions such as uniform vegetation roughness and sheet flow. Models such as may be used as tools for making land use decisions when field testing is not practical, but their underlying assumptions need to match anticipated conditions.

These studies all demonstrate that a relationship between upland development, the riparian buffer, and the stream ecosystem exists. However, each of these studies is limited by the specific variables they evaluate and the specific watershed characteristics. It is also important to note that the studies summarized above were conducted largely in forested or agricultural watersheds. The hydrologic and sediment generating processes in agricultural watersheds are very different from the land use in urbanized watersheds. Therefore, the factors that influence the effectiveness of a riparian buffer are likely to be different in an urbanized watershed. Due to the characteristics of the urban watershed, its condition should be evaluated before a buffer is relied upon to protect the stream ecosystem.

## **Field Investigation of Urban Buffers**

### *Introduction*

The three counties that contain Portland, OR and its surrounding suburbs are becoming increasingly urbanized. To coordinate transportation and growth management in the area, the legislature created Portland Metro, a regional government. The purpose of this regional government is to plan for the future development of the Portland area. Included in its objectives is an underlying goal to provide greenspaces and to preserve important components of the natural ecosystem, including aquatic and upland ecosystems.

One of Metro's projects is to evaluate the condition of Rock Creek and Richardson Creek watersheds located to the east of Portland. Both of these watersheds have been included within their urban growth boundary, which is anticipated to result in urbanization of the area over the next fifty years as part of the region's "2040 Plan." As part of Metro's evaluation, I spent the summer evaluating the condition of the riparian buffer in each of these watersheds with the goal of trying to determine the effectiveness of the buffer for protecting the stream system. Since Portland Metro is currently implementing the riparian buffer strategy for protecting stream ecosystems, the information drawn from this study should be immediately applicable. The two goals of my project were to evaluate the current conditions of the watershed and to explore different methods needed to protect the stream quality as the watersheds are urbanized.

Historically, land use along stream corridors was regulated by several different government agencies. The U.S. Forest Service has developed regulations that only apply

to logging-related land use. Similarly, the U.S. Environmental Protection Agency has developed guidelines for watersheds where agriculture is the primary land use. In both cases, the use of riparian buffers has been implemented as an effective method of regulation after years of studies. However, it has been very difficult for local and county governments to mandate stream buffers in urban watersheds due to the combination of land use laws protecting private property, previously existing development, and the scarcity of scientific studies demonstrating the effectiveness of buffers in urban watersheds.

The local county governments that govern land use in urban and developing watersheds are faced with many unique problems and, unlike forested or agricultural watersheds, they have little data on which to base their regulations. Their existing regulations, therefore, are a compromise between development, conservation, and local environmental concern. Regulated widths are based on measurable physical properties of the stream corridor such as slope, soil type, and the size of the stream, instead of scientific studies. Many of the issues, which likely influence buffer effectiveness, such as the intensity of the adjacent land use and the overall amount of development in the watershed, are difficult to incorporate into buffer regulations. Therefore, instead of creating laws for variable buffer widths for individual cases, buffer-width regulations are designed as single fixed widths for all cases.

Portland Metro is an example of a regional government agency that regulates stream buffer widths (Table 1). The width of the buffer is closely determined by the area drained by the stream, with the largest streams protected by the widest buffers and the smallest streams by small or no buffers. Streams in this region that drain 40 hectares

have channel widths of approximately 1 meter (cross sectional areas approximately less than half a square meter) and depths less than approximately half a meter (Dunne and Leopold, 1978). In addition to the area the stream drains, the slope of the adjacent upland is a major determinant of buffer width. Steep slopes have to be protected by much greater buffer widths because of the increased risk of landslides if the vegetation is removed.

<b>Table 1: Portland METRO Water Quality and Floodplain Management Model Ordinance</b>			
<b>Water Feature</b>	<b>Drainage Area</b>	<b>Buffer Width</b>	
	(hectares)	< 25 % Slope (m)	> 25% Slope (m)
Primary	> 40	15	60
Secondary	> 20	5	15
Other	< 20	none	none

## Methods

Given the numerous unique characteristics of urban watersheds, any method used to estimate the effectiveness of buffers should include both an initial, qualitative evaluation and a quantitative evaluation of the buffer system. Each approach is based on the stream continuum concept, which states that the effects of degradation accumulate and therefore the condition of the stream in the lower reaches is closely dependant on the condition in the headwaters (Vannote et al., 1980). Therefore, the buffer conditions everywhere upstream of the sampling site are evaluated because of the significant influence it may have on the condition of the sampling site. A qualitative evaluation of



each potential buffer function can determine whether the function could be provided if the buffer is only partially intact or bypassed entirely by urban runoff. This qualitative evaluation of the potential functions of the riparian buffer guided by a literature review. Once all the potential functions of the buffer are determined and so evaluated a quantitative evaluation can be conducted of certain conditions of the riparian and one or more measures of the stream condition related to particular buffer function. In this investigation of Rock and Richardson creeks, the quantitative evaluation focused only on the function of temperature attenuation in comparison to the percent of intact riparian buffer.

#### *Study Site Description*

Rock and Richardson creeks, two watersheds in the Portland Metro area, were used in this case study (Map 1). The watersheds have a combination of urban and agricultural land use. Portland Metro has recently placed both of these watersheds within the urban growth boundary, and consequently complete urbanization is anticipated over the next fifty years. Currently, the Rock Creek watershed is estimated to have 20% total impervious area (TIA) and the Richardson Creek to have 23% TIA using the method developed by the City of Olympia's Impervious Surface Reduction Study (1995) and land-use data from the Clackamas County Assessor's Office, mapped onto a GIS overlay (Table 2).

**Table 2      Total Impervious Surface Area**

Category of Landuse	TIA
Low intensity residential	20 %
Medium residential: 1-2 houses/acre	25 %
Medium/High residential: 2-4 houses/acre	30 %
High residential: 4+ houses/acre	35 %
Industrial and Commercial	90 %

As part of the planning and growth management process, Portland Metro is evaluating the current condition of each watershed. The goal for this study is to focus development onto the area with the least impact on the stream system (Map 2). Both the Rock and Richardson Creek watersheds display similar patterns of development. Agricultural and rural land uses are concentrated in the upper and middle area of the watersheds. The lower reaches were, at the time of sampling, generally less developed and, except for the Hwy 212 crossing, the riparian buffer system was intact.

The physical characteristics of both watersheds are also very similar. They are located in the Cascade Lowlands Ecoregion and drain into the Clackamas River just east of Portland, Oregon. Three classes of soil in these watersheds are identified (National Resource Conservation Service, 1991; Maps 3 and 4). A small fraction of the watershed, associated with the buttes, is covered by soils of hydrologic Class B, which are deep and moderately well drained. The majority of the upper watershed, including the riparian zone along Rock Creek, is composed of Class C soils. These soils have slow infiltration rates and usually contain an impervious layer close to the surface that prevents the

downward movement of water. The watershed along the major tributary to Rock Creek, as well as along the lower reaches of both creeks, is underlain by Class D soils. These soils consist mostly of clay and have low infiltration rates and a high runoff potential.

#### *Evaluation of the Riparian Buffer*

To evaluate the condition of the riparian buffer, a reference width equivalent to an “intact” buffer had to be chosen. Based on an extensive literature review, a buffer width of 30 meters was chosen as adequate to provide the desired functions of nutrient control, temperature moderation, and some sediment and stormwater control (Johnson and Ryba, 1992). Therefore, the reference condition was defined as an intact 30-meter wide buffer along the entire length of the stream.

The next step of the evaluation was to measure the actual width of the riparian buffer. This was done by estimating the width of the buffer, from the channel to the first disturbance, at 60-meter intervals along the entire length of the stream using GIS 1996 Orthophotogrametric Maps. These maps had an accuracy of about one meter and buffer widths in several locations were field-verified to ensure the accuracy of the GIS data.

Once the width of the buffer was measured it was converted to an area by multiplying the measured width with the length of the stream it represented, usually 60 meters. This process was done for both sides of the stream. The area of buffer upstream from each sampling site was then calculated by adding together the appropriate areas. The buffer condition was then evaluated by dividing the measured area of the buffer by the reference area. If the buffer was intact, meaning that it was 30 meters wide for the length of the stream, then the value would equal one. However, if the measured widths were less than 30 meters the value would be less than one and would represent the

fraction of the buffer area still intact. The final values were reported as a percent of the buffer destroyed.

Although this method includes a cumulative evaluation of the degradation of the buffer system upstream of each sampling site, it does not place any significance on the proximity of the degradation to the site of interest. For example, if the buffer system has been cleared or bypassed just upstream of a sampling site, it might influence the site more than this method would to reflect. Despite this limitation, this method appears adequate to evaluate the buffer system as a whole. It has several advantages for watershed planning over site-specific buffer measurements because it relates the overall amount of upland development to the stream ecosystem and therefore captures some of the cumulative effects of development.

The temperature of each stream was measured using continuous HOBO temperature gauges obtained from the U.S. Forest Service. The water temperature was automatically recorded every hour, with average, minimum and maximum values of temperature recorded daily from July 8, 1997 to September 24, 1997. Temperature was monitored at three sites in the Rock Creek watershed and one site in the Richardson Creek watershed (Maps 5 and 6). The first site temperature was monitored in Rock Creek was near the mouth by the crossing of Highway 224. The second monitoring site was located just upstream of the confluence with the tributary where Rock Creek flows under Trogg Road between Foster Rd and 172<sup>nd</sup>. The last site was just downstream of the tributary where Rock Creek flows under 172<sup>nd</sup> and Trogg Rd. The temperature of Richardson Creek was evaluated near the mouth. The condition of the riparian buffer

upstream of each monitoring site was calculated in order to relate the temperature regime to the condition of the riparian buffer.

## **Results**

The results from the calculations of the area of destroyed riparian buffer upstream of each sampling site show significant differences (Table 3). The condition of the riparian area upstream of each sampling site ranged from 41% to 58% of the buffer destroyed. To account for the degradation of the riparian buffer along the major tributary, these data was added to all of the sites below the confluence. This was done to represent the influence of upstream buffer conditions have on the water quality of the downstream reaches. The middle section of Rock Creek had the greatest percent of the buffer destroyed, which corresponds to the relatively intense land use in this portion of the watershed. The upper watershed, represented by Rock Creek Hi, also had more than 50% of the upstream buffer destroyed, also reflecting the land use in the upper watershed. The sampling site near the mouth of Rock Creek had the lowest fraction of the riparian buffer destroyed, due to the long section of stream corridor with a completely intact riparian buffer. However, it is important to note that the inclusion of the buffer data from the tributary increases the fraction of the upstream buffer destroyed by 3 %. Richardson Creek had the lowest fraction of destroyed buffer, again primarily due to the long reach of intact buffer near the mouth of the stream.

**Table 3            Condition of Riparian Buffer**

<b>Sampling Site</b>	<b>% Upstream Buffer Destroyed</b>
Rock Creek 1: Rock 224	38%
w/ tributary data	41%
Rock Creek 2: Rock mid	58%
w/ tributary data	58%
Rock Creek 3: Rock High	54%
Tributary	60%
Richardson Creek	30%

The temperature regime for the summer stream temperatures were compared among the four sites sampled. The general trend was an increase in the maximum daily, the minimum daily, and the daily fluctuation of temperature as the percent of the buffer that was destroyed increased. This trend represented the data for the highest value observed during the sampling period, the average of daily maximum temperatures, the highest value observed for daily temperature fluctuation, and the average daily fluctuation recorded at each of the four sites (Graph 4).

## **Discussion**

The general stream condition is related to both the amount of development in the watershed as well as the condition of the riparian buffer. The comparisons made in this study between temperature and the percent of the riparian buffer that is destroyed illustrates this relationship. The results showed that both the maximum and minimum summer temperatures were higher in the reaches with a higher percentage of destroyed buffer upstream from the sampling site. Although changes in hydrology are not taken into consideration in the approach used here, this study has shown that one stream parameter, the temperature regime, is linked to the condition of the buffer.

Other studies have examined the stream condition relative to the amount of development in the watershed. Horner et al. (1996) showed that the stream integrity declined as impervious surface area increased. However, there was considerable variation in this relationship and several streams had higher scores of B-IBI than expected for the amount of watershed development. They speculate that some of this variation can be explained by differences in the condition of the buffer. Therefore, the final assessment of watershed development should include measures of the form of urbanization and a measure of the intactness of the buffer.

#### *Functions Provided by Buffers in Urban Watersheds*

In urban catchments, unless the riparian buffer has been completely destroyed, it will still be able to provide moderation of temperature by blocking incoming solar radiation and trapping long wave radiation that is emitted from the stream. However, this function is related to the amount of shade provided by riparian forests and therefore the removal of large trees in the riparian zone particularly influences this function. This function is also more important in shallower streams than in deeper streams.

The function of providing a habitat component for stream ecosystems is also a function that can be provided by buffers in urban streams. The ability of the buffer to provide habitat is related to the condition of the buffer and presence of large trees, but an intact buffer can increase the quality of habitat by providing heterogeneous banks, by trapping and providing food, and by reducing human encroachment. However, this function also declines as the area within the natural riparian zone is encroached upon or destroyed.

### *Functions of Buffer Impaired in Urban Watersheds*

The remaining buffer functions-- flow attenuation, sediment and nutrient filtration -- are often not provided by vegetation in urban buffers. The main reason these functions are not provided is the numerous channelized sources of runoff in urban watersheds. The altered hydrology of the watershed may be the single most important agent of degradation in urban watersheds. In addition to the increased flows this stormwater also carries fine sediment from construction and pollutants from urban land uses. Therefore, even in reaches that have intact riparian buffers, the buffer does not attenuate peak flows or filter sediments and nutrients because it is bypassed. It is important to understand that the ability of the buffer to reduce hydrologic change is greatly reduced as a result of channelized stormwater and therefore the stream is not protected from these changes in hydrology, even in watersheds with relatively intact buffer systems.

### *Implications for Regulations*

Current regulations assume that if a riparian buffer is maintained it will provide all of the functions desired to protect the stream. However, this assumption may not be true. The riparian buffer might not provide the desired functions if it is fragmented along the length of the stream or if the regulated buffer width is not wide enough. Most importantly, certain conditions that bypass the buffer, such as a change in the hydrology, may not be controlled.

For the riparian buffer to function properly, as much of the stream corridor as possible should be protected. This would extend most current regulation to protect the upper reaches and small headwater portions of the stream, which are very important to the stream system. The riparian buffer has the most interaction and influence on smaller



streams, and because the small headwater streams can make up to 75 % of the stream network they greatly influence the condition of the downstream reaches (Leopold et al., 1964; Vannote et al., 1980). A clear consequence is that the entire stream network and its associated buffer should be protected by regulations to ensure the integrity of the functions of temperature moderation and habitat complexity.

The study also illustrates that the buffer cannot provide all of the necessary functions in an urban watershed due to the altered hydrologic processes of the system. Therefore, other actions beyond buffer protection should be taken to minimize the changes to the hydrology. These changes would include the reduction of surface water runoff, both by reducing the amount of impervious area and the detention and reinfiltration of any surface runoff generated.

## **Conclusions**

The protection of riparian buffers as a management technique to protect the integrity of streams in urban watersheds ensures that several functions of the riparian buffer will be provided. However, the protection of a riparian buffer alone is not adequate to ensure that the stream will not be degraded by upland development. Urban watersheds are characterized by altered biology, hydrology, and morphology in the upland riparian and stream ecosystems. Therefore, simple solutions such as the maintenance of a riparian buffer cannot alone be expected to protect the stream from upland development. The changes associated with hydrology and upland biology should also be addressed and impacts to these two components also minimized. The direct interaction of the stream ecosystem and the riparian buffer indicates the importance of the riparian buffer on the stream ecosystem. The integrity of the stream depends on an intact

buffer. However, having an intact buffer, especially in an urban watershed, does not ensure that the integrity of the stream ecosystem will be similarly protected.

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