<u>Riparian Setbacks</u>
Technical Information for Decision Makers

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CRWP's primary support comes from its Members including *Auburn Township, City of Aurora, Bainbridge Township, Village of Bentleyville, Chagrin Falls Township, Village of Chagrin Falls, Chester Township, Claridon Township, Cleveland Metroparks, Cuyahoga County, City of Eastlake, Village of Gates Mills, Geauga County, Geauga Park District, Village of Hunting Valley, City of Kirtland, Village of Kirtland Hills, Lake County, Lake County Metroparks, City of Mayfield Heights, Mayfield Village, City of Mentor, Village of Moreland Hills, Munson Township, Newbury Township, Orange Village, City of Pepper Pike, Russell Township, City of Solon, Village of South Russell, Waite Hill Village, City of Wickliffe, City of Willoughby, City of Willoughby Hills, and Village of Woodmere.*

The Chagrin River Watershed Partners, Inc (CRWP)

CRWP was formed by 16 cities, villages, townships, counties, and park districts in 1996 in response to increasing concerns about flooding, erosion, and water quality problems. These founders understood the need to improve land use decisions and to limit the impacts of development and rising infrastructure costs due to increased storm water quantities. Today CRWP's 34 members represent 90% of the watershed. CRWP provides technical assistance to members and develops cost effective solutions to minimize new, and address current, water quality and quantity problems as communities grow. CRWP's accomplishments include the on-going collaboration of 34 local governments on watershed protection; the development of model natural resource management regulations; the successful adoption and implementation of these models by communities; the review and improvement of development proposals; successful grant applications for member storm water and stream restoration projects; and a variety of other member specific services. CRWP also developed a model National Pollutant Discharge Elimination System (NPDES) "Phase II" Storm Water Management Program in use by communities across the watershed and assists members with successful implementation and annual reporting of the Phase II program. CRWP and its member communities support the adoption and implementation of riparian setback zoning as one of the most cost-effective tools to minimize the impacts of land use change in developing communities.

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Further Investigation

The literature cited in this document was obtained through review of published work as well as personal communications. Sources of information included existing bibliographies, federal and state agencies, county soil and water conservation districts, and individuals. This report is intended as a "living document." Please contact the Chagrin River Watershed Partners, Inc. with any comments, questions, or recommendations.

Terms Defined

BMP, Best Management Practices
CRWP, Chagrin River Watershed Partners, Inc.
Corps, The U.S. Army Corps of Engineers
CWW, Cincinnati Water Works
DDT, Dichloro-diphenyl-trichloroethane
FEMA, Federal Emergency Management Agency
MRB, Multi-species riparian buffer
NAPA, National Agency of Public Administration
NFIP, National Flood Insurance Program
NPDES, National Pollutant Discharge Elimination System
ODNR, Ohio Department of Natural Resources
OHIO EPA, Ohio Environmental Protection Agency
PCB's, Polychlorinated biphenyls
SWCD, Soil and Water Conservation District
USDA, United Sates Department of Agriculture

Introduction to the Third Revision of
<u>Riparian Setbacks: Technical Information for Decision Makers</u>

This third revision of **<u>Riparian Setbacks: Technical Information for Decision Makers</u>** continues the commitment of the Chagrin River Watershed Partners to bring its members the best available science to support riparian setback regulations. The first edition of this work relied on scientific literature on riparian function [5-8] and seminal research on the function of riparian buffers as water quality best management practices in agriculture [9, 10] and forestry [11]. Reliance on this sound scientific literature represented the "first generation" of scientifically based riparian setback regulations.

First generation riparian setback regulations drew heavily on the analogous services reported in the scientific literature for riparian buffer function in agriculture and forestry, and proved to be an effective model that has been replicated, refined, and implemented around the country. Since the original publication of **<u>Riparian Setbacks</u>** by CRWP, more recent literature reviews with a broader scope have been independently assembled and continuously improved. Significant contributions include scientific review of the basis for riparian setback regulations for the Cities of Everett, Washington [12] and Renton, Washington [13], the Etowah River Habitat Conservation Plan [14] in Georgia, and a thorough widely cited literature review from the Institute of Ecology at the University of Georgia by Wenger [15]. In addition to updating results from more recent scientific research, these reviews incorporated scientific literature conveying new advances in understanding riparian processes, such as the importance of wood in streams (often referred to as large woody debris or coarse woody debris), and the far reaching influence of headwater streams on watershed hydrology and water quality.

This continually improved knowledge base validates the use of the scientific literature to support local government interests in the CRWP riparian setback regulations. The findings from the updated literature also validate the recommendations that balance riparian services and the beneficial use of private property, previously established in the CRWP setback model regulation. This revision of **<u>Riparian Setbacks</u>** updates our understanding of riparian function, continuing the established use of current scientific literature to support setback recommendations and provide the sound basis for local government interests and authority in promulgating riparian setback regulations in the Chagrin River watershed.

In reviewing the recent scientific literature, it is clear that the scientific understanding of riparian processes and the services they provide has undergone a dramatic transformation since this document was first published. A burgeoning literature has emerged reporting experimental site-specific effects of a wide variety of riparian management practices across a diverse array of physiographic, ecohydrologic, and hydroclimatic provinces. This growing literature reinforces the foundation for understanding the processes and factors influencing the benefits and services of riparian setbacks.
Yet, beyond richer site-specific results that offer further analogues for riparian setback function,

the synthesis of interdisciplinary research is rapidly reformulating our understanding of the far reaching extent and dynamic linkages through which robust interconnected riparian corridors affect the landscape.

This emerging scientific understanding has given rise to the second generation of integrated riparian management. We now understand that riparian services are far more pervasive and interdependent than any narrow investigations of, e.g., nitrogen removal or sedimentation in riparian buffers could have revealed. We now understand that the rich portfolio of riparian services flows directly from maintaining and enhancing the dynamic connections and exchanges between rivers and their riparian corridors. Viewed through the lens of this integrative understanding, the value of riparian setback guidelines originally advanced by CRWP in **Riparian Setbacks** are strongly validated as a simple cost-effective zoning tool to minimize encroachment and disturbance of the connected riparian corridor on which these services depend. Our current understanding reaffirms the value of the CRWP riparian setback model regulation as an effective means to maintain the vital connectivity of rivers and floodplains, while striking a prudent pragmatic balance between the valuable services derived from riparian protection, and the beneficial uses of private property by riparian landowners.

Synthesis

The scope and breadth of this second generation understanding of riparian function and services is incorporated in this revised version of **Riparian Setbacks** and reflects the synthesis of interdisciplinary research in the scientific literature, notably punctuated by:

- The American Fisheries Society's Monograph on the source, effects, and control of sediment in streams [16];

- Results from the International Workshop on Efficiency of Purification Processes in Riparian Buffer Zones, held in Hokkaido Japan in 2001, and the International Conference on Ecological Engineering for Landscape Services and Products, held in Christchurch, New Zealand in 2001, published in a special edition of the Journal *Ecological Engineering* [17];

- Research reports compiled from the International Conference on Wood in World Rivers [18];

- The National Academy of Sciences' report of the Committee on Riparian Zone Functioning and Strategies for Management [1];

As well as timely reviews and syntheses of the scientific understanding and recent research on:

- Buffers and pesticides [19, 20];
- Landuse effects on aquatic ecosystems [21, 22];
- Groundwater – surface water interactions [23-25];
- River bank filtration [26];

- Sedimentation effects on lotic food webs [27];
- Riparian nitrogen removal [28-31];
- Riparian management practices [32-34];
- Recognition of an "urban stream syndrome" affecting the world's developing watersheds [35, 36].

Implications for Riparian Management

The emerging science has not only refined our understanding of local factors that moderate specific riparian processes, but also provided a broader synthesis that guides us to far reaching conclusions on the importance of riparian protection. The implications of the current scientific literature for management are that a stream buffer, riparian setback, or forested buffer should be viewed as not only a parcel-specific best management practice, such as a stormwater management pond or a bioretention structure, but also as a watershed-scale management system.

We now recognize that the essential value of riparian services derives from maintaining the connectivity and dynamic exchanges and processes throughout the riparian system. The superposition of political boundaries and individual property rights presents the challenge of effectively managing the functional integrity and the valuable resulting services provided by this dynamic interconnected system, through the collective efforts of individual decisions by riparian landowners. It is precisely this joint coordinated management of the riparian resource that riparian setback regulations attempt to institutionalize in simple easily implemented zoning instruments.

Perhaps the most important guiding principles to emerge from the current scientific literature are the importance of contiguity in riparian protection, and the great value and importance of protecting the remaining least disturbed riparian corridors.

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EXECUTIVE SUMMARY

Riparian areas adjoin rivers and streams, connecting aquatic and terrestrial systems across unique ecological, biogeochemical, and hydrologic gradients. If properly maintained and sized, riparian areas provide services to communities, including flood control, erosion control, and water quality protection, at little cost.

Riparian setbacks are a zoning tool local governments can use to maintain riparian functions as communities grow and land is developed. In the Chagrin River watershed and nationwide, communities recognize the need for riparian setbacks as a preventive tool to minimize encroachment on stream channels while providing a cost-effective alternative that minimizes the need for storm water infrastructure and engineered solutions to flooding, erosion, and water quality problems.

> *Riparian areas are the lands adjacent to rivers and streams.*
>
> ***Riparian areas stabilize streambanks, limit erosion, reduce flood size flows, and filter and settle out runoff pollutants.***
>
> *A riparian setback is a local zoning tool that uniformly limits soil disturbing activities in riparian areas to protect public health and safety.*
>
> ***Riparian setbacks protect public health and safety by maintaining the flood control, erosion control, and water quality protection services of riparian areas.***

Riparian setback regulations facilitate a uniform approach to riparian management in a community. An ordinance or resolution establishing a riparian setback must be justifiable in terms of its protection of public health and safety; designed with an awareness of the impacts on individual properties; and implemented with public support and understanding of what the regulation does, and more importantly what it does not, accomplish.

This report focuses on introducing riparian areas and discussing the functions, services, and benefits they provide local governments and landowners. The report is designed for local decision makers – county commissioners, mayors, township trustees, council members, and planning and zoning commission members – as well as their engineers, law directors, and other professional advisors. The report provides the technical information necessary for these decision makers to adopt and implement riparian setback zoning as it relates to the authority of Ohio local governments to protect public health and safety.

The report also discusses the economics of riparian setbacks and the implementation of riparian setbacks through zoning regulations in Northeast Ohio. Through its review of setback programs nationwide and the current research on riparian area functions and widths, the report concludes that CRWP's recommended minimum setback widths are accurate and pragmatic compromises between the various setback widths reported in the literature as necessary to maintain the services of riparian areas and the development patterns of the Chagrin River watershed.

RIPARIAN SETBACKS: TECHNICAL INFORMATION FOR DECISION MAKERS

Within the Chagrin River watershed and across the country, communities are protecting vegetated riparian areas along their rivers and streams with riparian setback regulations. If appropriately sized, these areas benefit communities by controlling flooding, erosion, and water quality as well as by protecting a community's groundwater and quality of life. Vegetated riparian areas provide these services at little cost to taxpayers. A community may protect riparian areas through a variety of mechanisms including land purchases and conservation easements. One of the most effective methods is through the adoption of local regulations establishing riparian setbacks, a zoning tool similar to front and side yard setbacks that excludes development and related soil disturbing activities within a prescribed distance from a watercourse.

To implement riparian setback regulations local officials need technical information linking riparian setbacks to the protection of public health and safety. Further, officials must have the information to design setback regulations that are reasonable and sensitive to local conditions. This report provides the technical support decision makers need to meet these challenges. The report introduces riparian setbacks; discusses their functions, benefits and economics; and explores the technical issues related to the successful implementation of a riparian setback regulation.

THE RIPARIAN CORRIDOR

Riparian refers to the organisms and their environment adjacent to or near flowing water. Riparian corridors include the stream channel and its adjacent land where vegetation may be influenced by high water tables, flooding or the ability of soils to hold water [7]. Because these corridors link terrestrial and aquatic ecosystems, their importance is far greater than their minor proportion of the land base would suggest [37]. Riparian areas extensively influence and are influenced by other areas of the landscape. It is this aspect of riparian corridors that makes their protection a useful natural resource management tool. With their unique position in the landscape, riparian areas can mitigate the impacts of one land use on another [8].

The geologic and hydrologic processes at work in a riparian corridor form its three typical components: stream channel, wetlands, and floodplain [38]. The stream channel meanders through the landscape carving through terrain, depositing and remobilizing sediments as it flows. In the Chagrin River watershed the stream's constant reworking of the channel and floodplain may result in steeply sloped areas within the stream valley. The sediments and depressions near the edge of the stream channel often intersect the water table supporting the formation of riparian wetlands. In addition to steep slopes and wetlands, most stream channels are surrounded by a broad level area known as the floodplain. Floodplains are periodically inundated by overbank flows, and occupy the unique position in the landscape between the active stream channel and the surrounding hillslopes [37]. This is the area on which flood waters spread during periods of high flow. Floodplains can be defined by the frequency and extent of inundation. For example the "100-year floodplain" designates the area having at least a 1 percent chance of flooding in any given year. The 100-year floodplain designation is perhaps best known due to the widespread preparation of 100-year floodplain maps by the Federal Emergency Management Agency (FEMA) in support of the National Flood Insurance Program (NFIP). It is important to note, however, that the absence of a FEMA map of the 100-year floodplain, should not be misinterpreted as the absence of flood risk; most streams overtop their banks during high flows.

The components of the riparian corridor function together to provide valuable natural resource services. The National Academy of Sciences [1] emphasized the importance of the gradients in environmental conditions and the connection between rivers and riparian areas in providing these services, and cautioned against the loss of ecological function in riparian areas that become hydrologically disconnected from their adjacent stream channels. A riparian setback regulation is a flexible zoning mechanism through which communities can preserve and enhance these natural resource services by maintaining the natural connectivity between streams and riparian corridors. For example, in the Chagrin River watershed riparian setbacks provide a transitional zone between streams and the streets, houses, parking lots, and open lands they drain. This drainage contributes water, nutrients, pesticides, and sediments to streams. The impact of nonpoint pollution on water quality can be diminished if this runoff first passes through a vegetated riparian setback. Riparian setbacks also lessen the impact of streams on land by slowing erosion and minimizing flood damage.

BENEFITS OF RIPARIAN AREAS AND SETBACKS

> ***Except for support of biodiversity, some of the environmental services of riparian areas can be provided by technologies, such as reservoirs for flood control and treatment plants for pollutant removal. However, these substitutions are directed at single functions rather than the multiple functions that riparian areas carry out simultaneously and with little direct costs to society.***
> ***- National Research Council [2]***

Historically public health and safety problems associated with growth and land development, such as water quality degradation and increased flooding and erosion, have been addressed through engineered structural solutions such as dams, rip rap, channelization, and water treatment plants. Typically implemented after a problem has developed, each of these engineered infrastructure responses has associated capital, operation, and maintenance costs. The need for these costly solutions can be reduced or avoided by preserving and enhancing the natural functions and services provided by a healthy connected riparian corridor. Riparian setbacks offer a low-cost proactive approach to maintain these valuable riparian services. By minimizing encroachment, a riparian setback maintains the connectivity between rivers and floodplains that moderates flood peaks, traps sediments and sustains the dynamic biogeochemical processes that enable riparian corridors to function as living filters. The details of these, and other, benefits of riparian setbacks are discussed below.

Flood Control Services

Flooding is a natural process, essential for the maintenance of floodplain plant and animal communities and soil fertility. However, flood waters can significantly damage public and private property and threaten human life, especially where vulnerable structures remain in the flood plain as a result of historic development. Communities along the Chagrin River have experienced significant flooding. This has included large flood events in the City of Eastlake as well as small floods throughout the watershed. Years of attempts to control floods have shown that traditional structural solutions alone are not sufficient to minimize the impacts of flooding. According to the Federal Interagency Task Force on Floodplain Management:

> *…the most sensible, least costly approach to flood hazard protection may have less to do with dams and disaster relief, and more to do with land-use patterns within floodplains. [38].*

Flooding is a natural restorative process for riparian systems that maintains the form, function, and connectivity of stream channels and their floodplains. Riparian setbacks maintain the natural connection between rivers and their adjacent floodplains and protect the floodplain's natural functions in storing and attenuating flood flows. These floodplain services offer low maintenance cost-effective solutions to community flooding. The National Park Service's review of the economic impacts from protecting rivers describes local and county government experiences with the benefits of landuse-based non-structural flood policies [39]. For example:

> *Johnson County, Kansas expected to spend $120 million on stormwater control projects. Instead, voters passed a $600,000 levy to develop a county-wide streamway park system. Development of a greenways network along streambeds will address some of the County's flooding problems, as well as provide a valuable recreation resource.*

This review similarly documented the justification of greenways as a cost-effective means to address county level flood damage by Dutchess County, New York [40]:

> *Floodplains function well as emergency drainage systems - for free - when they are left undisturbed. The public pays a high price when misplaced or poorly designed development interferes with this function. Human encroachment on the natural flood corridors often increases the risk to downstream homes and businesses by increasing the volume of runoff and altering the flood path. The resulting demands for costly drainage improvements, flood control projects, flood insurance, and disaster relief are all, ironically, preventable by conserving and respecting the floodplains from the outset.*

Rockland County's greenways acquisition program was inspired by the County's dismay over the costs of coping with drainage problems caused by encroachment into floodplain systems.

The value of non-structural flood control management from connected riparian corridors entered national flood control policy as part of a planned channel improvement project in Littleton, Colorado in 1971. The U.S. Army Corps of Engineers' (Corps) plan to channelize part of the South Platte River was challenged by the citizens of Littleton, who organized to preserve the river's scenic natural floodplain. Congress, through the Water Resources Act of 1974, enabled the Corps to contribute federal funds for the acquisition of land in the floodplain for flood protection in lieu of the traditional structural channel improvements. Searns [41] describes the events in Littleton that ultimately resulted in land acquisitions and the creation of a floodplain park, as the precedent-setting legislation that required the Corps to consider the value of non-structural alternatives in all Federal flood protection projects.

Stream disconnected from its adjacent floodplain. Only at very high flows would water reach the floodplain, removing the potential for flood attenuation for the majority of storms.

The City of Soldiers Grove, Wisconsin realized the direct benefits from restoring floodplain function choosing to relocate the entire business district out of the floodplain of the Kickapoo River at a cost of $1 million. The conventional structural alternative of a levee system proposed by the Corps would have cost $3.5 million, and imposed an annual maintenance cost that was more than twice the City's entire real estate tax base. Along with the creation of a floodplain park, the relocation is credited with annual savings of $127,000 in avoided flood damages. Similar benefits from maintaining floodplain connectivity on the Charles River in Massachusetts were realized by the purchase of full title or easements to 8,500 acres of floodplain wetlands in the upper Charles River at a cost of $10 million, as an alternative to the estimated $100 million cost for upstream levees and flood control reservoirs that had been proposed. The ***annual*** flood damages that would have resulted from the loss of flood control services provide by these wetlands has been estimated at $27 million [42].

This stream is connected to its adjacent floodplain.

Flood Control Services: *Bank storage*

In addition to the temporary storage and gradual drainage of floodwaters from inundated floodplains, rising streamflow also recharges alluvial aquifers through the bed and banks of rivers and streams. This recharge of alluvial groundwater occurs whenever river levels rise above the elevation of the water table – not just during periods of overbank flow. Bank storage reduces flood peaks by recharging surface runoff into the pore spaces of riverbank sediments and helps maintain higher baseflow through the slow release of groundwater back to the stream as river levels decline. The joint services of flood attenuation and baseflow augmentation provided by bank storage also provide favorable soil moisture conditions for riparian vegetation, and the biogeochemical processing of contaminants in riparian soils.

Stream at base flow with active stream and land connection

In a detailed study of bank storage on the Cedar River in Iowa [43] a 6.6 foot (2 m) rise in river stage induced substantial groundwater recharge of the connected alluvial aquifer. Observation wells in the floodplain clearly showed that river water, uniquely identified by its lower concentration of dissolved solids, recharged more than 98 feet (30 meters) into the stream bank, to a depth of over 13 feet (4 meters). The "new" groundwater, with the distinctive chemical signature of river water, slowly discharged back to the river over a period of five weeks as river levels fell. Bank storage thus provides flood peak reduction and incremental baseflow maintenance for relatively frequent high flow events that do not result in overbank flows. Even higher recharge of bank storage can be expected to occur with overbank flooding. The result is stable river flow and a reduction in dramatic shifts in water levels [5]. Bank storage moderates the development of high flows as well as the frequency and duration of extremely low flows. Preserving the connection and natural exchanges between rivers and floodplains provides flood attenuation services naturally, along the entire length of the stream system.

Whiting and Pomeranets [44] modeled the groundwater hydraulics of bank storage and showed that the volume of bank storage is nearly proportional to the floodplain width and bank height. Both the volume and duration of bank storage discharge increase with floodplain width. Moreover the rate and volume of bank recharge are nearly directly proportional to the hydraulic conductivity of the bank material. Drainage from bank storage may last for weeks to a few years in sandy banks, with longer drainage times and lower drainage rates for silt or clay banks.

Flood Control Services: Riparian Vegetation

Traditional flood control strategies for large waterways have promoted the clearing of vegetation from river channels. More recent investigations question whether the removal of riparian vegetation from riverbanks has increased the vulnerability of adjacent lands to erosion [45]. The active removal of riparian corridor vegetation to maintain conveyance of the floodway creates ongoing labor intensive maintenance demands and degrades the habitat and aesthetic amenities of the riparian resource [46]. Removing riparian vegetation reduces bank strength and hydraulic roughness, and can lead to increased near-bank flow velocities, accelerated bank erosion, [45] and can increase flood damages.

Standard hydraulic analysis of riparian floodways usually considers the effect of riparian vegetation on hydraulic roughness as it affects flood heights and inundation areas. A more inclusive consideration of connected riparian corridors also accounts for the value of floodplain vegetation in protecting upland terraces and hillslopes from flood waters. Woody floodplain vegetation dissipates stream energy, reducing scour and resulting flood damage. The value of the riparian corridor and its associated vegetation is strikingly demonstrated by the flood damages following the Great Flood in the Mississippi River Basin in 1993. In Central Kansas, Geyer et al. [47] found the greatest lateral streambank erosion during the 1993 flood occurred on sandy streambanks adjoining cropland, while streambank erosion was negligible along forested streambanks. In the Missouri Basin, Allen et al.'s [48] analysis of levee failures along a 353 mile section of the Missouri River found compelling evidence of the flood protection services provided by wooded riparian corridors. The absence of woody riparian vegetation in the floodplain was consistently associated with a greater likelihood of levee failure and longer lengths of levee failure. Over 40% of the 1993 levee failures on the Missouri River occurred in areas where woody vegetation was absent from the riparian corridor and nearly 75% of the failures were associated with areas in which the width of the woody riparian corridor was less than 300 feet. Moreover, discontinuities in woody corridors were associated with more than 27% of the observed failures, reinforcing the importance of the *contiguity* of the riparian corridor as well as its width. It is particularly notable that engineered levees, designed to resist damaging flood waters, were themselves afforded flood protection by woody riparian floodplain vegetation.

Floodplain vegetation also diffuses concentrated overland flow and resists the formation of erosive rills, rivulets, channels, and gullies. Complex shallow flow paths on vegetated riparian areas encourage sedimentation and infiltration of overland flows [6]. The combined effect of these floodplain functions is reduced flow velocity, increased storage of water, and the attenuation of downstream flood impacts [38].

Riparian setbacks are an essential component of land-use management to reduce flood hazards and maintain the flood control services of floodplains. Through the implementation of a riparian setback program, a community protects its floodplain and the services floodplains provide. During high flows, floodwaters are temporarily stored as they spread across the floodplain, dissipating much of the energy of flood flows [37] and reducing downstream flood heights. Floodplain vegetation also presents a barrier to flood flow and runoff, encouraging water to move slowly and infiltrate soils reducing the contribution to downstream flood peaks.
A riparian setback program protecting floodplains also reduces potential property damage from flooding by setting development back from the stream channel and out of the floodplain area. FEMA divides the 100-year floodplain into two areas based on water velocity: the floodway and

the flood fringe. To participate in the NFIP, communities must prohibit development in the floodway and place restrictions on development in the flood fringe. While this minimizes the blockage to the free flow of flood waters downstream, it does not fully protect the storage capacity of the floodplain. A riparian protection program that prohibits development in both the floodway and the flood fringe preserves natural areas for temporarily storing flood flows and protects structures from flood damage [8]. An example of a riparian setback regulation designed with its highest priority on flood protection services is found in Garner, North Carolina, which established setbacks of 50 to 100 feet from the limits of the 100-year floodplain [49].

Riparian setbacks reduce flood hazards and contribute flood protection services by limiting development within floodplains, restoring the natural flood protection services provided by riparian floodplains, and fostering riparian vegetation that reduces erosion. Hancock [24] concludes that limiting human disruption of riparian corridors is an important cost-effective component of strategies to prevent the degradation of these essential linkages and riparian functions. Riparian setbacks provide a cost-effective zoning tool to achieve these outcomes.

Riparian Setbacks Protect Floodplains and:
- *Reduce flood flow velocity.*
- *Facilitate infiltration.*
- *Provide temporary storage and slow drainage of floodwaters.*
- *Reduce property damage.*
- *Maintain stream baseflow and recharge alluvial aquifers.*

Erosion Control Services
In addition to reducing flooding and associated property damage, riparian setbacks counteract the erosive forces of water. Stream bank erosion is a significant concern to Chagrin River watershed communities. Residents lose both land and structures as stream banks slump and soils are washed downstream. Once in streams, sediments destroy aquatic habitat and degrade water quality. Eroded sediment can also block storm water conveyance structures and is costly to remove through dredging.

Erosion at any particular point along a stream may be caused by the erosive effects of surface runoff and the erosive force of flowing water in the stream channel. Setbacks address both sources of erosion [50]. By presenting a physical barrier to overland flow, riparian vegetation slows surface runoff and disrupts concentrated flow paths, enhancing infiltration and diminishing runoff's erosive potential. The root systems of riparian vegetation, particularly trees, hold bank soils in place against the erosive force of high velocity waters [37] maintaining soil structure and bank stability [6]. The stronger the rooting system, the greater this benefit. According to the Ohio Environmental Protection Agency [51], vegetated stream banks are up to 20,000 times more resistant to erosion than bare stream banks.

In addition to altering channel hydraulics and dissipating erosive shear stresses, riparian vegetation increases the strength of streambanks through both mechanical effects of roots [52, 53] and hydrologic effects on the pore water pressure in the soil matrix [54]. Using the U.S. Department of Agriculture Agricultural Research Service's Bank Stability and Toe Erosion Model [55], the effect of riparian vegetation on the resistive forces in a streambank can be quantified. As an example, model calculations estimate that a 30 year old stand of ash can roughly double the factor of safety (the ratio of resistive forces to driving forces in bank failure) for a prototypical 16.4 foot (5 meter) streambank with an alluvial soil profile. Abernathy and Rutherford [56] similarly quantified the geotechnical reinforcement of soil strength by the roots of native riparian tree species along the Latrobe River in Australia. They found root reinforcement could raise the factor of safety for an otherwise unstable bank section by 60%.

The long-term contribution of riparian vegetation to stream bank stability is strikingly displayed on the Sacramento River in California. From the careful evaluation of 100 years of maps and aerial photography, Micheli et al. [45] compared river meander rates between forested and agricultural floodplains below Shasta Dam. They estimated that agricultural floodplains have been 80% to 150% more erodible than forested floodplains during the latter half of the 20th century. Even the control of flood flows provided by the construction of Shasta Dam could not offset the increase in observed erodibility that accompanied the conversion of forested floodplains to agriculture.

Micheli et al. [57] also analyzed channel migration rates from 40 years of aerial photographs on California's Kern River and found migration rates for streambanks with wet meadow vegetation were 10 times lower than streambanks without wet meadow vegetation. Their results also emphasize the importance of maintaining the hydrologic connection of the riparian corridor to bank stability. They note that channel incision may reduce bank stability through both the increase in the bank height and the loss of wet meadow vegetation as channel downcutting alters the local water tables that support riparian vegetation.

Following severe flooding in British Columbia, Beeson and Doyle [58] surveyed more than 700 stream reaches using aerial photography to identify post-storm channel erosion. They found that stream bends without riparian vegetation were 30 times more likely to show some evidence of channel erosion and major channel erosion was nearly 5 times more likely on unvegetated streambanks. The greater stability of forested streambanks stems, in part, from their ability to resist the initiation of bank erosion. Along a 62 mile (100km) section of the Upper Illinois River in Oklahoma, Harmel et al [59] estimated short-term and long-term bank erosion rates using a combination of aerial photography and field measurements from erosion pins. Short-term erosion rates on banks with forested, grassed, and mixed vegetation were not significantly different. However, 20 years of aerial photography showed that significant erosion (greater than 2m) occurred along 66% of the grassed banks compared to only 16% of the forested bank length.

The dominant contribution of stream bank erosion to excess sedimentation in urbanizing watersheds has been carefully documented by Trimble [60] in Southern California. Over the 10 year period from 1983 to 1993, Trimble [61] found channel erosion contributed two-thirds of the annual sediment load of San Diego Creek and concluded bank stabilization should be a priority in managing sediment yield. The role of riparian vegetation in reducing sedimentation and bank erosion has generated varying management recommendations concerning the short-term and long-term value of different types of riparian vegetation on streambank erosion [3, 56, 61-63].

Severe stream bank erosion

Erosion Control Services: Riparian Vegetation

Vegetation in the riparian corridor affects the width and geometry of streams by stabilizing stream banks against bank erosion and bank failure, and trapping sediment in overland and overbank flow. The relationship between riparian vegetation and channel form is dynamic and changes with the size and scale of the watershed [64]. For small streams draining less than 4-40 square miles (10-100 km^2), forested streams tend to be wider than grassed streams; in larger watersheds streams with forested banks tends to be narrower than similarly sized watersheds with grassed banks. On the well studied Coon Creek watershed in Wisconsin, Trimble [61] estimated the stream's grassed banks were storing up to 16,800 cubic yards of sediment per mile of streambank (8,000 cubic meters per km). Based on this observation, Lyons et al. [63] suggested sediment loads in Midwest streams might be cost-effectively managed by actively converting stream bank vegetation from forest to grasses in order to store more sediment.

Gully erosion from storm water runoff

Davies-Colley [65] made similar observations comparing forested streams to streams with grass banks adjoining pasture land in New Zealand. Like Trimble, Davies-Colley[65] raised concerns about development of downstream sedimentation problems as the natural return of forest vegetation shaded out the grasses and remobilized the substantial sediment stored in the vegetated banks of narrower pasture streams. He also noted, however, that the sediment *currently* stored in the vegetated banks of these narrow pasture streams represents encroachment that followed earlier land clearance, as forest land was actively converted to managed pastures.

The empirical relationship between stream width and bank vegetation is not a static "endpoint" but represents a dynamic balance between the processes that mobilize and deposit sediment moving through stream systems. Allmendinger et al. [66] found grass cover resulted in up to 3 times greater sediment deposition compared to wider forested streams, but the erosion of cut banks in grassed streams was up to 5 times greater than forested streams. On balance, although grassed streams are less wide and store more sediment in their banks, they are also less stable than wider forested streams. Wider more stable forested streams also store sediment, associated with stable wood (sometimes referred to as coarse woody debris), which also provides habitat, structure, and refuges for aquatic biota. Hart [67] similarly considered stream width and bank vegetation in headwater streams in the Great Smoky Mountains. He also found that wider forested streams store sediment instream in deposits associated with stable wood, and the stored sediment in forested streams was up to 3 times greater than the sediment remobilized by channel widening as forest cover replaced grassed banks.

Consistent with the greater stability of vegetated streams, Zaimes et al. [68] found streams with streamside forest cover were more stable with lower erosion rates than streams adjoining either row crop or grazed agriculture land uses. They estimated that the presence of riparian forest buffers along the entire length of the roughly 7 mile (11 km) reach they studied would have reduced stream bank erosion by approximately 78% in a single year. Similar results have been reported in urban streams by Hession et al. [69]. For streams in Missouri's glacial till plain Burckhardt and Todd [70] compared bank erosion between pairs of similar streams for which the primary difference was the presence or absence of riparian forest on the streambanks. They too found that rates of lateral bank migration were 3 times greater along unforested concave banks.

The active removal of riparian vegetation can have dramatic effects on streambank erosion. Montgomery [2] describes the extensive channel widening that occurred on the Tolt River in Washington's Cascade Range following the clearing of forest vegetation down to the streambank. This widening, along with the pulse of mobilized sediment that led to filling of the channel downstream, was attributed to the loss of bank-stabilizing tree roots. Even more dramatic stream channel adjustments have been observed on the Cann River in Victoria, Australia, where Brooks et al. [71] estimated that rates of lateral channel migration have increased 150 fold, with an 860 fold increase in annual sediment yield and a 45 fold increase in bankfull discharge since European settlement. Most of these dramatic channel adjustments are estimated to have occurred in the last 40 years, in response to the removal of riparian vegetation and stable wood in the stream channel.

Riparian Setbacks Protect Streambanks and:
- *Minimize erosion from overland flow*
- *Reduce erosion from instream flow.*
- *Reduce property damage.*

- *Minimize sedimentation on streams and storm water conveyance.*

Water Quality Protection Services

Vegetated riparian areas are a cost effective best management practice (BMP) to address nonpoint source pollution and their use in this capacity is widespread [8, 72]. The term BMP refers to a practice or combination of practices that a State determines to be practical and effective in preventing or reducing the amount of pollution generated by diffuse sources to levels compatible with water quality goals [73]. The Ohio EPA and ODNR have, for example, recommended specific BMPs to meet Ohio water quality goals as established in the National Pollutant Discharge Elimination System (NPDES) General Construction Site Permit. These recommended BMPs include riparian setbacks and other non-structural planning techniques.

Connected riparian corridors function as filters that protect adjoining streams and downstream receiving waters [30]. By minimizing disturbance and encroachment, riparian setbacks protect and enhance the filtering functions through which riparian corridors sequester and remove sediments, nutrients, and a range of contaminants. These water quality services result from filtration and adsorption, uptake by riparian vegetation, and biogeochemical and microbial processes that immobilize, assimilate, and degrade dissolved contaminants. Vegetated riparian setbacks disperse concentrated or channelized runoff, increasing infiltration, slowing surface runoff, and enhancing the deposition of sediment and sediment associated contaminants from both overland flows and overbank floodwaters. Vegetative uptake and assimilation can remove nutrients, soluble ions, and some organic contaminants from shallow groundwater, incorporating these contaminants in plant biomass [74, 75]. The microbial and biogeochemical processes at work in saturated sediments, leaf litter on the forest floor, and in the thatch layer of riparian grasses, immobilize and transform dissolved nutrients, metals, and many organic contaminants.

Riparian setbacks maintain the connectivity and exchange of surface water and groundwater between rivers and uplands. The exchange of surface water and groundwater links riparian processes with the metabolism and productivity of streams through microbial processing in biofilms on the streambed and the surfaces of sediments in channels, bars, riffles, and streambanks [29, 76]. These living biofilms are dynamic ecosystems that adapt to changing conditions of flow, nutrient loading, water chemistry, temperature, etc. [3, 28, 77, 78]. The surface of sediments at the riparian interface where surface water and groundwater mix is now understood to play a central role in maintaining the chemical and microbial transformations that naturally maintain and regulate water quality [23, 24, 79]. Maintaining riparian zones and effective land use practices are widely recognized as two valuable strategies to prevent the degradation of water quality services provided by these essential riparian processes [24].

The intimate physical association between streams and their riparian corridor is self evident, but we now understand that the influence of riparian corridors on water quality is proportionately much greater than the relatively small area in the landscape they occupy. This is especially true on small first order streams that generate most of the runoff in watersheds. As a result of the strong topographic controls on runoff, riparian areas in headwater and first order streams may intercept most of the runoff that reaches the stream system, producing water quality services that extend far downstream and enhance water quality throughout the watershed. Using topographic indexes of wetness, sediment transport, and discharge Burkhart et al. [80] mapped hydrologically-based locations for effective stream buffer placement in the Deep Loess Region of Iowa, Missouri, and Nebraska. Watershed-scale analysis demonstrated that riparian areas in small first order streams exhibited much greater potential to intercept larger fractions of runoff and affect basin-wide water quality than larger streams. Moreover, discharge through riparian areas in the smallest stream catchments was dominated by groundwater, creating very high potential for riparian processes to remove nitrate, some pathogens, and most pesticides in the region.

Water Quality Protection Services: Infiltration and Sedimentation

Vegetated riparian setbacks create complex flowpaths that slow the velocity and decrease the turbulence in overland flow. Shallow distributed flow enhances sedimentation and the removal of sediment-associated contaminants while increasing infiltration and reducing surface runoff. The effectiveness of riparian setbacks can be severely compromised by the development of concentrated flow paths that bypass the riparian zone [81, 82]. Stiff, tufted grasses have proven very effective in disrupting channelized flows and increasing infiltration rates in riparian buffer systems [83, 84]. Significant increases in infiltration rates are consistently observed in vegetated riparian buffers [85] contributing to sediment removal and carrying dissolved constituents into shallow groundwater where they may be further immobilized and metabolized by geochemical and microbial processes [86, 87]. Bharati et al. [88] found cumulative infiltration rates in a multispecies riparian buffer were five times greater than in adjoining cropland and grazed pastures. In Schmitt et al.'s [89] experimental investigations fescue filter strips infiltrated 36% - 82% of runoff and cumulative infiltration doubled as the width of the filter strip was doubled from 25 to 50 feet (7.5 m to 15 m).

On experimental plots Blanco-Canqui et al. [90] found that a dense 2.3 foot (0.7 m) switchgrass barrier was sufficient to disrupt and distribute concentrated flow into more uniformly distributed sheet flow, significantly enhancing the performance of vegetated filter strips. With a switchgrass barrier, a 24 foot (7.3 m) fescue filter strip achieved 90% removal of sediment. By interrupting and temporarily pooling concentrated flow the switchgrass barrier also increased the particulate phosphorous removal by nearly a factor of 4 and removed 2 to 5 times more nitrogen compared to fescue filter strips with no vegetated barrier.

Water Quality Protection Services: Pesticides and Organic Chemicals

With significant variability in reported results, vegetated buffers and filter strips have also proven effective in reducing the runoff of herbicides and pesticides [91-94]. The greater complexity of the processes and chemical properties that influence pesticide and herbicide fate and transport accounts for the high variability in reported results and points to the need for a process-based understanding of riparian area effects on contaminant fate and transport [20]. Nevertheless the extent to which riparian areas trap organic compounds and prevent them from entering the stream system offers long-term preventive water quality benefits especially in urban and urbanizing streams.

Parker et al. [95] found significant concentrations of organochlorine compounds in urban stream sediments in Phoenix, Arizona even though many of these compounds are no longer in use. Despite the ban on some pesticides nearly 30 years ago, Chlordane, DDT and its decay products, dieldrin, toxaphen, and PCBs were ubiquitous in the sediments in Phoenix's urban stream channels. The persistence of these compounds, which pose very costly remediation challenges, highlights the long-term value of preventing contaminants in non-point runoff from entering streams. Riparian setbacks offer a last barrier to intercept and prevent persistent organic contaminants from entering the stream system.

An example of process-based determination of buffer widths to protect surface waters from multiple pollutants is described by Lin et al. [96] and Lin et al. [97]. To meet targeted water quality goals in the Shei Pa National Park in Taiwan, individual buffer widths were derived for over 50 different contaminants. Buffer widths for each contaminant uniquely account for the effects of slope and soil properties along the stream, as well as the specific attenuation and degradation processes affecting the fate and transport of each contaminant, such as denitrification, adsorption, and microbial degradation. From the analysis of 46 pesticides of interest, the pesticide Fenarimol required the widest buffer to protect water quality. Among the exchangeable ions of magnesium, potassium, sodium, and calcium; extractable metallic ions of copper, iron, manganese, and zinc; and soluble forms of nitrogen and phosphorous, the high mobility of potassium salts required the widest buffer width [97]. The largest buffer width was selected along each stream reach to provide protection from all the contaminants considered.

This process-based design of riparian buffers illustrates the explicit linkage between buffer width and the performance-based choice of riparian services. It also illustrates the substantial data needs required for site-specific performance-based design of varying buffer widths. The process analysis that supported these buffer calculations required site-specific data including slope, depth to water table, and the bulk density, saturated hydraulic conductivity, organic content, and saturated water content of each riparian soil along each stream segment. In addition to considering the specific services and tradeoffs provided by the choice of buffer width, consideration of site-specific setback widths creates pragmatic tradeoffs among the resources required for site assessment and data collection and the information needed for reliable setback implementation. As a result of the complexity and cost of developing site-specific setback widths, as well as the accuracy of CRWP's recommended widths as highlighted in this report, CRWP recommends fixed minimum setbacks of 25, 75, 120, or 300 feet depending on drainage area. This recommendation is discussed in more detail below.

Water Quality Protection Services: Denitrification and Nutrient Removal

The rapid growth of chemical fertilizer use and wastewater treatment discharges has dramatically accelerated the nitrogen inputs to rivers, lakes, and the coastal ocean. From Chesapeake Bay to the Mississippi River and the Gulf of Mexico, nitrogen enrichment of surface and groundwater resources has become an ubiquitous management challenge around the world [98, 99]. Nitrogen removal in the riparian zone is unequivocally recognized as one of the most cost-effective means to control excess nitrogen losses from intensively developed watersheds [9, 29-31, 100-102] and helps to guide our expectations and management of riparian setbacks.

Riparian areas reduce nitrogen pollution through nutrient uptake and assimilation by vegetation, and the transformation of dissolved nitrogen to nitrogen gas that is returned to the atmosphere through microbial *denitrification*. The nitrogen carried in flood flows and runoff becomes available to riparian vegetation as nitrogen rich surface water enters shallow groundwater. Nitrogen loss through denitrification takes place predominantly under anaerobic soil conditions - a circumstance in which no free oxygen is present in the soils. Such conditions are common in saturated or poorly drained floodplains.

Denitrification requires a population of denitrifying bacteria, a source of carbon, and sustained conditions with low dissolved oxygen concentrations. Shallow groundwater flow paths that maintain saturated conditions in riparian floodplains can sustain anoxic or reducing conditions, conducive for denitrification. Undisturbed riparian floodplains typically combine shallow water tables, a ready carbon source in rooted riparian vegetation, and the natural occurrence of denitrifying bacteria creating persistent zones of reducing conditions that support high rates of microbial nitrogen reduction. Denitrification rates vary with the position of the water table and variation in the geochemical environment along groundwater flow paths. Deep groundwater flow paths may bypass shallow reducing zones, as do tile drains and ditches that rapidly convey groundwater and dissolved nitrate to streams [103]. Nitrogen removal also varies with the seasonal variation in water tables and the residence time of groundwater flow. Nitrogen taken up by vegetation during the growing season may be released and recycled as plants lose their leaves in fall and winter. This transient uptake is nevertheless valuable for protecting groundwater from excess nitrogen inputs. The seasonal uptake of nitrogen by deep-rooted vegetation effects a net transfer of inorganic nitrogen in groundwater to organic nitrogen as leaf litter on floodplains and riparian forest floors where it can be re-mineralized and denitrified by soil microbes [104].

In contrast to seasonal uptake and recycling by riparian vegetation, denitrification can permanently remove nitrogen from riparian groundwater throughout the year as long as suitable biogeochemical conditions are maintained. Under appropriate conditions, denitrification rates remain high throughout the year [31, 105-107] and have been observed to increase as vegetation becomes dormant in fall and winter [105, 108]. The seasonal decline in vegetative uptake leaves more nitrogen in groundwater for microbial reduction. The accompanying seasonal decline in evapotranspiration leaves more soil water available to maintain saturated reducing conditions in the soil. Together these seasonal changes can support increased winter denitrification rates and sustain nitrogen removal throughout the year.

The spatial and temporal variability in factors affecting denitrification account for much of the site-specific variability reported in the riparian buffer literature and explain why setback width alone is insufficient to uniquely predict nitrogen removal rates. Highly permeable riparian sediments with high groundwater flow velocities require high rates of microbial transformation to achieve significant nitrogen removal. Long groundwater flow paths with residence times of 50 to 75 years have been observed to achieve nearly total nitrogen removal with very modest denitrification rates, due to the long effective reaction time [103]. Nitrogen removal efficiency reflects both the biogeochemical rate and the hydrogeologic contact time for nitrogen reducing chemical transformations. In glacial till and outwash soils in southern Ontario, Vidon and Hill [109] observed 90% removal of nitrogen in the first 50 feet (15 m) of riparian buffers in soils with sandy loam or loamy sand textures; in sand and cobble soils the distance to achieve a 90% removal of nitrogen ranged from 82 feet to over 574 feet (25 m to over 175 m) – reflecting the higher flow velocity, and therefore shorter contact times, in these more conductive soils. Groffman et al. [110] similarly suggested that gravel bars with low rates of denitrification may nevertheless be significant nitrogen sinks in urban streams due to the relatively long contact time of stream water flowing through the sediment matrix.

Despite great variability in seasonal and site-specific denitrification rates, preserving riparian corridor functions is unequivocally recognized as one of the most effective means to manage excess nutrient losses from intensively used watersheds [100]. That is one of the reasons that the National Academy of Sciences [1] concluded that:

> *Future structural development on floodplains should occur as far away from streams, rivers, and other water bodies as possible to help reduce its impact on riparian areas…. Thus, preventing unnecessary structural development in near-stream areas should be a high priority at local, regional, and national levels [1].*

Water Quality Protection Services: Stream Productivity and Nutrient Removal

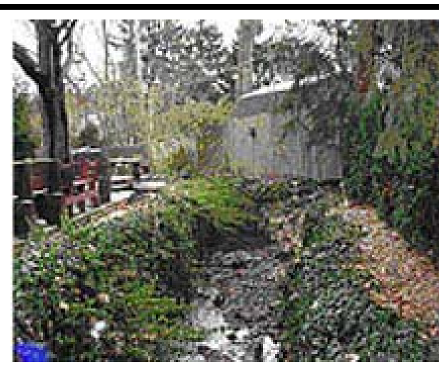
Beyond biogeochemical processes in the riparian floodplain, the riparian corridor is inextricably linked to the metabolism and productivity of streams. Streams do not just convey nutrients and contaminants delivered to them, but actively process nutrients and dissolved constituents on the active biofilms on the streambed [76] and on the surfaces of sediments in the channel and streambank [29]. The highest processing rates occur on headwater streams [3] that, together with their disproportionate contribution of watershed discharge, produce cumulative water quality services that extend far downstream.

> ***Not only do forest buffers prevent nonpoint source pollutants from entering small streams, they also enhance the in-stream processing of both nonpoint and point source pollutants, thereby reducing their impact on downstream rivers and estuaries.[3]***

We now understand that surface water does not just flow through the stream channel. At the head of riffles, streamflow enters stream gravels and flows into the streambank, reentering the channel in downstream pools and upwelling zones. The high surface area, intense mixing of surface water and ground water, and sharp chemical gradients in these mixing environments support some of the most important biogeochemical processing of nutrients, organics, and dissolved constituents in the landscape. For example, the low nutrient concentrations found in pristine headwater streams have traditionally been interpreted as merely the consequence of low nutrient inputs. We now understand that undisturbed headwater streams also have some of the highest rates of nutrient assimilation and stream metabolism in the landscape. Riparian areas are essential to maintain these highly productive interconnected systems and their integrity warrants protection. Using the radioisotope N^{15} as a tracer, Peterson et al. [111] found ammonium experimentally introduced to streams was completely assimilated over a downstream distance of only 33 to 330 feet (10m to 100m) in headwater streams, with distances typically 5 to 10 times longer for the uptake of nitrate. In contrast, ammonium uptake distances between roughly ½ to ¾ of a mile (766m to 1,349m) were observed in second order streams, in which nitrate uptake was undetectable [112]. The spatial pattern of human alteration of the landscape affects the status of rivers through variations in the length, width, and gaps of riparian buffers, all of which influence the effectiveness of buffers as nutrient sinks [113].

Elevated nutrient concentrations associated with urbanization are usually attributed to increased inputs from point and non-point sources; our results indicate that concentrations also may be elevated because of reduced rates of nutrient removal. Altered ecosystem function is another symptom of an urban stream syndrome. [4]

Streams in suburban/urban areas are impacted by pollutants from activities such as construction, road maintenance, and lawn care, as well as by streambank erosion. These pollutants, including sediments, nutrients, pesticides, and heavy metals, reduce water quality in a variety of ways. Elevated nutrient levels in urban streams reflect increased nutrient loads as well as the lower productivity and reduced capacity to assimilate nutrients. Nutrient processing of streams decreases with urbanization, characterized by an "urban stream syndrome" [4, 36] of increased nutrient and contaminant loading, increased stream flashiness, and altered biotic assemblages [4].



Urban Stream Syndrome

Riparian Setbacks Protect Water Quality and:

- *Provide for the uptake and storage of nitrogen.*
- *Facilitate the gaseous loss of nitrogen.*
- *Minimize sedimentation by controlling streambank erosion.*
- *Trap sediments, phosphorus, and some pesticides.*
- *Maintain the riparian biogeochemical processes that regulate stream water quality.*

Groundwater Purification Services

Riparian vegetation can remove certain nutrients and some metals from groundwater. Research shows that significant pollutant removal can occur if groundwater is available to root systems and to denitrifying microbes. Desbonnet et al. [8] reported 84% to 87% removal of nitrate from groundwater in a forested riparian area. This method of groundwater purification is generally not effective at removing oils, pesticides, and the majority of metals. Groundwater purification in the riparian corridor is enhanced by the convergence of runoff and the shallow depth of the water table near the root zone of riparian vegetation [114]. Connected riparian areas play a crucial role in the purification of groundwater in alluvial aquifers. Groundwater pumping from alluvial aquifers can induce recharge along the length of hydraulically connected rivers and streambanks. Groundwater flow through alluvial aquifers results in substantial removal of dissolved particulate materials, bacteria, pathogenic parasites such as *Giardia* and *Cryptosporidium*, and a variety of reactive contaminants. In central Europe bank filtration is a widely used component of drinking water purification [26].

The passage of river water through a stream's bed and banks into adjoining alluvial aquifers provides filtration and attenuation of suspended sediment and turbidity, microbial pathogens, and a variety of constituents ranging from fecal coliform bacteria to forms of organic carbon that can form potentially carcinogenic compounds when exposed to common drinking water disinfectants such as chlorine. The water treatment value of natural riverbank filtration has long been recognized. In Germany and central Europe river bank filtration via active pumping from alluvial aquifers has been used as an integral component of the water treatment process for public water supply for decades [26]. The natural hydraulic connection between surface water and alluvial groundwater systems in healthy riparian corridors is a necessity for sustained riverbank filtration. Under the Safe Drinking Water Act, the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) requires water suppliers to meet effective removal criteria for the microscopic intestinal parasite, *Cryptosporidium*. Riverbank filtration may provide removal credits toward compliance with the LT2ESWTR at very modest cost. Bank filtration requires no chemical costs and has low maintenance costs. Moreover the diverse removal processes operating along groundwater flow paths can effectively remove a wide variety of drinking water contaminants [115].

In southwest Ohio, the Cincinnati Water Works (CWW) draws most of its water supply from the thick alluvial Great Miami Aquifer. CWW's C.M. Bolton wellfield produces about 40 million gallons per day (mgd) from a field of ten wells located within approximately 800 feet from the Great Miami River, which recharges the aquifer. Extended monitoring data from the Bolton wellfield confirmed that riverbank filtration consistently provided greater than 3 log (i.e. 3 order of magnitude) removal of pathogen surrogates, such as aerobic and anaerobic spore-forming bacteria, and neither *Cryptosporidum* nor *Giardia* were detected in any groundwater samples [116]. Similar analysis from full scale riverbank filtration facilities along the Wabash, Missouri, and Ohio Rivers also found no detectable *Cryptosporidum* or *Giardia*, and only infrequent detection of any coliform bacteria, with 5-6 log reduction in average coliform concentrations relative to river water [117].

Partinoudi et al. [118] compared the filtration performance of full scale operating riverbank filtration systems in Pembroke, New Hampshire, Cedar Rapids, Iowa, and Louisville, Kentucky to conventional slow sand filtration. They concluded that riverbank filtration had similar performance to slow sand filtration for the removal of pathogens and turbidity, and superior performance in the removal of dissolved organic carbon and other precursors of disinfection byproducts.

Riparian Setbacks Purify Groundwater and:

- *Remove nutrients and some metals.*
- *Maintain the hydraulic connection between rivers and alluvial aquifers supporting riverbank filtration of groundwater.*

Ecosystem Protection Services

People are attracted to the Chagrin River watershed for the quality of life it provides. A critical component of this quality of life is the watershed's ecosystem features including its wildlife, streams, and open spaces. Riparian setbacks protect these ecosystem features. Setbacks are a component of a community's overall open space and support plant and animal populations in streams and throughout the watershed in a variety of ways.

Ecosystem Protection Services: Aquatic Systems and Stream Temperature

Riparian vegetation that shades streams, such as trees and large shrubs, stabilizes water temperatures and light levels [7]. Shading also minimizes the presence of aquatic nuisance species such as blue-green algae [119]. These species thrive in direct sunlight and may replace some of a stream's native food sources if riparian vegetation is removed. Stream temperature exerts important controls over chemical reaction rates in stream systems as well as the metabolism and development rates of fish eggs, fry, and macroinvertebrates [120]. Stream warming has direct effects on mortality rates, body morphology, disease resistance, and metabolic rates in fish. Changes in stream temperatures can cause eggs of spawning species, such as walleye, to mature early and disrupt the delicate synchronization between thermal and hydrologic regimes that has evolved in their reproductive behavior. The solubility of dissolved oxygen is strongly dependent on water temperature and key aspects of the life cycle of spawning fish are synchronized by stream temperatures [22].

Land transformation affects stream temperatures by removing shading from tree canopies, increasing heat inputs through direct runoff from roofs, roads, and parking lots, and increasing ambient air temperatures following the loss of shading and evaporative cooling. Changes in the inputs and connectivity to groundwater systems can also disrupt cooler groundwater inputs from alluvial aquifers, seeps, and springs that provide valuable thermal refuges for aquatic organisms under summer low flow conditions [121].

The influence of the riparian corridor on stream temperatures is not always easily quantified due to the variety of factors that contribute to the stream energy balance, the diversity of hydrologic settings in the landscape, and the limited data often available to elucidate these influences. Variation in average stream temperatures throughout the year is closely correlated with air temperature as well as the annual cycle of streamflow and vegetative cover [122]. The empirical correlation between air temperature and stream temperatures can provide significant skill in predicting average stream temperatures [123] and has led some to conclude that air temperature exerts a greater control on stream temperature than the inputs of solar radiation and shading by riparian vegetation [124]. These issues have assumed great significance in the Pacific Northwest where temperature effects from clearcutting directly threaten salmon, and both the width and length of forested riparian buffers required to protect stream temperatures have direct economic impacts in constraining timber harvest.

The effect of riparian shading is challenging to quantify due to the variability in the shading characteristics of leaf canopies of different riparian species and the change in shading as stream orientation to the sun varies along its course. For example, in reviewing best management practices in riparian forest management Broadmeadow and Nisbet [33] describe the results of a simple stream shading model that accounted for the different shadow lengths cast on north and south facing slopes and noted that buffer widths necessary to achieve stream shading goals will vary significantly with stream reach orientation.

Stream temperatures are determined by the energy balance of heat inputs from upstream runoff, incoming solar radiation, heat exchange with the atmosphere streambed and banks, and inputs from colder groundwater seeps and springs. The relative magnitude of each of these inputs is site specific and varies with season, geology, latitude, weather, and time of day. Direct solar radiation inputs vary along the course of a stream, as the meandering channel's orientation to the sun changes, and the channel's width to depth ratio exerts a strong influence on the rate of heat exchange. Wide shallow channels are easily heated by direct solar inputs, while narrow deep channels offer relatively little surface area to collect solar energy relative to the overall volume of water absorbing the heat. This complexity and variability, along with very limited data on all the terms in the heat balance, contributes to the challenge of quantifying the effects of any individual term in the heat balance.

Nevertheless the importance of stream temperature and its relationship to riparian vegetation has motivated research that provides clearer insights into the controls of stream temperature. Direct solar radiation has a relatively small effect on average stream temperature, but is most responsible for deviations of stream temperature above the mean. Moreover, of all the factors that influence stream temperature, incoming solar radiation is the main factor that can be influenced by management of the riparian corridor and streamside vegetation [125]. Danehy et al. [126] also determined that direct solar radiation exercised the predominant effect on maximum summer stream temperatures in mountain streams in Oregon and Idaho, observing significantly lower variability in minimum temperatures.

In southwest Wisconsin, Gaffield et al. [121] used a simple screening model based on heat transport to predict steady-state temperatures for whole reaches of coldwater streams. The simple heat balance elucidated the relative importance of meteorology, channel geometry, and stream shading on summer stream temperatures and quantified the importance of cold groundwater inputs, as well as channel width and stream shading, as the dominant variables controlling summer stream temperatures.

In one of the most carefully instrumented experimental studies of stream temperature effects, Johnson [127] developed detailed heat budgets from a shading experiment on stream reaches in the H.J. Andrews experimental forest in Oregon. Following two weeks of monitoring air and water temperature and solar radiation, a 492 foot (150 m) stream reach was experimentally shaded and monitored for two weeks. Maximum water temperatures were significantly lower with shading, with no significant change in mean or minimum daily temperature. The detailed heat budget constructed from this data clearly identified the dominant role of direct solar radiation on maximum daily stream temperature; stream shading exerted a much stronger influence on maximum stream temperature than ambient air temperature. An inferential model-based analysis of the relative effects of stream shading, wind sheltering, and hydrologic heat sources similarly concluded that the effect of stream shading was stronger than stream sheltering in a broad analysis of temperature data from 596 stream gauging stations in the eastern and central U.S. [128].

The vegetated riparian corridor provides a buffering effect on stream temperatures by moderating air temperatures, but primarily through the shading of streams. The effectiveness of vegetative shading varies with the height, density, and configuration of vegetation and tree crowns, as well as the latitude, the orientation, and width of the stream reach, the slope of the adjoining riparian lands, and the degree of canopy closure. Variation in tree canopy form, slope, and solar declination all influence the buffer width required for effective stream shading. The heat budget for a stream reach is affected by upstream stream temperatures. For this reason the *length* of the riparian area also affects stream temperatures, by influencing this significant upstream heat source. Moreover the relative importance of upstream temperature inputs and direct solar inputs result in a tradeoff between the width and the upstream length of riparian area required to maintain a specified temperature target. Broadmeadow and Nisbet [33] describe results from Barton at al.'s [129] analysis of these tradeoffs for streams in southern Ontario. The results suggest that a 459-foot (140 m) riparian area 3,281 feet (1 km) in length would be expected to keep maximum water temperatures at 22 degrees C. If the riparian area length was increased to 6,562 feet (2 km), the width necessary to maintain a 22 degree C maximum daily temperature would only need to be 164 feet (50 m) in width. This echoes Correll's [130] recommendation on the importance of continuous riparian areas and minimizing variances to riparian setback regulations in order to sustain resilient riparian function.

Ecosystem Protection Services: Aquatic Systems and Sedimentation

Perhaps the most pervasive ecological effects from riparian disruption may result from increased sedimentation and turbidity. In his review of the effects of sediment on fish, Waters [16] concluded:

> *After a half-century of the most rigorous research, it is now apparent that fine sediment, originating in a broad array of human activities (including mining) overwhelmingly*

> *constitutes one of the major environmental factors – perhaps the principal factor in the degradation of stream fisheries.*

In documenting the effects of sedimentation on fish communities, Rabeni and Smale [131] identify the control of sedimentation dynamics as one of the most beneficial services provided by riparian areas, and conclude that proper riparian management can mitigate the undesirable effects of sedimentation.

Sediment effects on fish include direct effects, such as mortality and disease, and sublethal effects on reproduction, growth, behavior, and food supply. Elevated suspended sediment concentrations have been shown to depress growth, degrade the visual cues for fish reproduction and predation, and increase vulnerability of fish to disease and specific bacterial, viral, and protozoan pathogens. Experimental studies have documented the physiological symptoms of sediment-induced stress in fish [16]. Turbidity refers to the clarity of water, and even modest increases in turbidity lead to reduced primary productivity that can propagate through the food chain. For example, on the Colorado River Osmundson et al. [132] related the low abundance of the endangered Colorado pike minnow to the increased accumulation of fine sediments due to river regulation through withdrawals, impoundments and other reservoir control. The entire food chain was disrupted by these changes, as the accumulation of fine sediments reduced the populations of macroinvertebrates, algae, and microbes on the streambed that are, in turn, the primary food source for the Colorado pike minnow's prey species.

The reproductive cycle of spawning salmon and trout are particularly vulnerable to the effects of sedimentation and have been the focus of a large body of research on sediment effects on these highly prized fisheries [133]. With the exception of lake trout, all North American salmon and trout lay their eggs in gravel nests, called redds, whose structure alters local flow patterns to maintain the exchange of oxygenated waters over incubating eggs. Excess sediment results in high mortality by restricting the flow of oxygenated water over the eggs, smothering embryos and sac fry within the redd, and entombing emerging fry. The pervasive influence of sediment on fish is best understood by considering sediment effects throughout each stage of their life history. Fulfilling the different life history requirements for fish requires a complex mosaic of suitable aquatic and floodplain habitats [134]. Excess sedimentation can disrupt every life stage in salmonids [135] as well as the prey species that support them.

Riparian degradation and increased stream sedimentation go hand in hand. Jones at al. [136] analyzed the changes in fish communities at 12 sites with more than 85% forested land cover in the Little Tennessee watershed, at which the upstream riparian corridor had been deforested. Despite the very high levels of forested land use remaining in the contributing watersheds, one of the principal consequences of removing riparian forest was increased stream sedimentation; the longer the nonforested riparian patch, the greater the sedimentation of riffles and pools, with concomitant shifts in fish assemblages. They conclude that, in addition to width, the length and area of riparian buffers are key factors in riparian management to mitigate sedimentation and protect aquatic ecosystems.

Some of the earliest process-based guidelines for riparian setbacks were developed by Trimble and Sartz [137] to protect streams from sedimentation originating on logging roads in the Hubbard Brook Experimental Forest in New Hampshire. Their early setback guidelines were based on the observed distance sediment traveled across the forest floor and inherently accounted for the runoff volume, soil characteristics, and slope-dependent velocity of runoff. To ease implementation, recommended widths were expressed as simple "rules of thumb" based on a minimum setback of 25 feet that increased 2 feet for every 1 percent of slope - to a maximum 165 foot width on 70% slopes. They also recommended doubling these widths to protect streams that served as water supply sources. This conservative margin of safety for critical or vulnerable uses illustrates the explicit risk-based judgment about the tradeoffs between acceptable risk and the beneficial use of lands inherent in any minimum setback recommendation.

Ecosystem Protection Services: Aquatic Systems and Invertebrates

The complex matrix of algae and microbes attached to submerged substrate in most aquatic ecosystems is referred to as periphyton. Periphyton is an important food source for many grazing invertebrates and some fish and can be an important sink for nutrients and contaminants. Broekhuizen et al. [138] studied the effect of sediment inputs on the ability of grazing macroinvertebrates to assimilate periphyton. Using the radioisotope C^{14} as a tracer, they found that carbon assimilation by periphyton grazers decreased in direct proportion to sediment increases. Kiffney et al. [139] compared the growth of periphyton in 13 clearcut headwater streams with riparian areas ranging from 0 feet to 98 feet (0m to 30m) in width. The periphyton biomass increased with narrower riparian widths, attributed to greater inputs of direct sunlight. As the periphyton biomass increased the inorganic content of the periphyton increased as well. These changes reflected a shift in algal composition from diatoms to filamentous algae that trapped more of the increased sediment load in the periphyton, decreasing its nutritional value and making it more difficult for grazing invertebrates to attach. The observed increase in sediment and periphyton inorganic content coincided with a decrease in mayflies and an increase in more pollution tolerant midges (chironomids). Kiffney et al. [139] concluded that retaining a forested buffer of at least 98 feet (30 m) was required to minimize the sediment effects of clearcut logging on these headwater streams.

Stream macroinvertebrates are sensitive indicators of aquatic ecosystem integrity. Changes in community structure are widely used as biological water quality indicators and the relative influence of key stressors on aquatic ecosystems, including stream corridor structure, siltation, and total suspended solids, can be inferred from the observed changes in the community structure of fish and benthic invertebrates [140]. Sedimentation and turbidity increase the natural drift of aquatic insects causing them to enter the flowing current to be carried downstream to less stressful conditions [141, 142]. This is especially true for the so-called EPT taxa – the mayflies (Ephemeroptera), stone flies (Plecoptera), and caddisflies (Trichoptera) that serve as the primary taxa available for fish. Through abrasion, turbidity, and the infilling of preferred habitat in the interstices of gravel and cobble substrates, sedimentation results in a benthic macroinvertebrate community characterized by higher densities of burrowing organisms, such as sediment tolerant midges (chironomids) and annelid worms (oligochaetes) in soft mucky sediments, offering lower food value for fish.

A remarkable natural "experiment" on the effect of siltation on stream invertebrates in northeast Ohio was reported by Dewalt and Olive [143] in Portage County, Ohio. Silver Creek, a small headwater tributary of the Mahoning River, drains glacial sediments and periodically erodes a layer of glacially deposited silts. During these erosional episodes the cool clear gravel-cobble stream takes on a milky color and a thin layer of fine silts and clays accumulates on the streambed downstream from the source of these eroding silts. Dewalt and Olive [143] sampled the macroinvertebrate fauna upstream and downstream of such an erosional event that lasted from March to October 1984. Following the introduction of silt and clay into the stream they found the species richness, number of taxa, and abundance in the depositional reach dramatically declined, compared to upstream reaches. Of interest as well is the rapid rate at which the impacted reach recovered once the eroding silt was exhausted. The ecological integrity of the impacted reach recovered within 7 months of the cessation of siltation and was attributed to recolonization by drift from upstream populations. This remarkable process of impact and recovery highlights both the sensitivity of stream ecosystems to sedimentation and the ability of stream communities to recover from transient stresses, *if* they maintain their connectivity and function as part of a dynamic resilient stream system.

In contrast to the rapid recovery reported by Dewalt and Olive [143], Zuellig et al. [144] reported a similarly episodic discharge of approximately 9,156 cubic yards (7,000 m^3) of sediment flushed from a reservoir on the North Fork of the Cache La Poudre River in Colorado during dam inspections. As the sediment pulse worked its way through the river system, macroinvertebrates rapidly recolonized the affected reaches below the dam. However, the recolonized stream fauna differed radically and represented a complete functional shift from the pre-flush macroinvertebrate community. The dramatic change in the recolonizing fauna was attributed by Zuellig et al. [144] to the *absence* of permanently flowing tributaries that could connect similar biological populations for recolonization through passive downstream drift.

Forested riparian areas can insulate aquatic ecosystems from many of the effects of upslope land transformation - even clearcut forest harvesting. Quinn et al. [145] found that forest sites that had been harvested leaving continuous forested riparian areas had macroinvertebrate communities similar to unimpacted reaches. Stream ecosystems in which discontinuous or patch riparian areas were retained suffered a loss of taxonomic and functional diversity, but were not impacted as severely as reaches without any riparian areas. Their results reiterate the need to encourage contiguity in riparian areas, and the importance of the length of setbacks as well as their widths.

More widespread degradation is observed in streams with sustained stresses such as the permanent transformation of landuse and hydrology that accompanies current land development practices. In Big Darby Creek on the Scioto River in Franklin County, Ohio biological monitoring data document the impairment of aquatic ecosystems, water quality, and habitat associated with suburban land transformation. Primary causes of ecosystem impairment were identified as riparian and habitat degradation and excess nitrate concentrations [146].

Using the State of Ohio's exceptional biological monitoring data, Miltner et al. [147] analyzed the effects of land transformation on aquatic ecosystems in three streams in Franklin County, Ohio. Analysis of 10 years of biological monitoring data show the degradation of fish communities associated with suburbanization - including local extirpation of pollution intolerant species such as silver shiners and hornyhead chubs, at sites where they had been historically abundant. Although a general storm water construction NPDES permit requiring best management practices to minimize sediment loads is applicable statewide in Ohio, the continuing loss of sensitive species with development led Miltner et al. [147] to question the adequacy and enforcement of required site-specific practices. Among the central Ohio streams analyzed, Miltner et al. [147] found the following:

> *The few sites in our data set where biological integrity was maintained despite high levels of urban land use occurred in streams where the floodplain and riparian buffer was relatively undeveloped. An aggressive stream protection policy that prescribes mandatory riparian buffer width, preserves sensitive areas and minimizes hydrologic alteration needs to be part of the larger planning and regulatory framework.*
>
> *And…*
>
> *Together these results suggest that aggressive regulations that protect riparian buffers and preserve much of the predisturbance hydrology may be effective at maintaining aquatic life uses consistent with basic clean Water Act goals in suburbanizing watersheds, at least up to a point.*

In Washington, D.C.'s rapidly developing Maryland suburbs Moore and Palmer [148] similarly analyzed the changes in ecosystem integrity across a gradient of agricultural to suburban landuse conversion. They similarly concluded that:

> *…maintenance of riparian forests even in highly urbanized watersheds may help alleviate ecological disturbances that might otherwise limit macroinvertebrate survival.*

Ecosystem Protection Services: Aquatic Systems and Stable Wood

Our understanding of the importance of naturally occurring wood in streams has grown dramatically to the point that stable wood, often referred to as large woody debris or coarse woody debris, is recognized as a crucial element of healthy stream function and stream restoration [134]. Following the recommendation of Gregory et al. [18], here and throughout this report we refer to "wood" in streams meaning "stable wood" that stores alluvial sediments, creates hydraulic variability, habitat diversity, and the overall complex characteristics of the most diverse and productive fluvial environments. This terminology is recommended to distinguish the variety of valuable functions associated with *stable* wood [149] from the nuisance, aesthetic, and public safety dis-amenities associated with pruning waste, tree slash, and other forms of trash or garbage often associated with the terms debris, coarse woody debris, or large woody debris. In contrast to highly mobile debris that readily clogs culverts and damages infrastructure, tree ring analysis has shown that wood in natural streams can remain in place, providing structure and complexity in the fluvial system for over a century [67, 150].

Wood in streams provides ecological benefits ranging from instream habitat and shelter for fish, to the supply and accumulation of organic material and habitat supporting invertebrates, bacteria, and insects. The diverse habitats created by wood in streams are associated with hydraulic environments that dissipate stream energy, fostering the deposition and storage of sediment, detritus, and organic debris, as well as flow resistance that stabilizes and protects streambanks. Rivers and streams continually adjust to the dynamic inputs of wood and the associated changes in flow paths, channel form, and water surface elevations due to obstructions or logjams can create backwater conditions that increase flood risks for homes and structures in the floodplain. The routine clearance and removal of wood has therefore become common practice in developed watersheds. This removal of wood from streams is also associated with simplified stream and river channels and impoverished fish communities [151].

Moreover the indiscriminant removal of stable wood from streams can trigger profound changes in channel form, sediment storage, and the character and function of the riparian corridor, potentially causing additional flooding and erosion problems downstream. Brooks and Brierley [152] have reported on extensive analysis of channel changes in Australia's Cann River attributed primarily to the removal of riparian vegetation and wood since European settlement. The loss of storage and rapid mobilization of stream sediments with the removal of stable wood has resulted in a 700% increase in channel capacity associated with a 150-fold increase in the rate of lateral channel migration, a 40-fold increase in bankfull discharge, and even more dramatic increases in the annual sediment load. Of perhaps greater significance is the observation that these rapid adjustments have crossed key physical thresholds affecting stream processes. For example, the hydraulic significance of wood in streams changes as stream width increases relative to the mean size of wood [153]. In the Cann River, the vast increase in channel capacity has so widened the channel that the hydraulic effects of pre-development wood have fundamentally changed so that the reintroduction of riparian vegetation and predevelopment wood will not achieve stream channel recovery [152, 153]. These potentially irreversible changes in riparian systems emphasize the paramount importance of efforts to protect and maintain *existing* riparian function.

Management of riparian areas should give first priority to protecting those areas in natural or nearly natural condition from future alterations. [1]

In developed watersheds, the potential costs of wood in streams, such as undesirable changes in flood heights and channel alignments, must be balanced against the range of benefits from sediment storage, storage and dissipation of flood flows, and the critical ecological functions supporting diverse foodwebs and habitats. Along with desirable services, the potential for locally increased flood risks must be considered and logjams that threaten safety should be cautiously removed. Wood in streams can have both beneficial and deleterious effects, but all wood should not be automatically removed. These dual functions are recognized by the Ohio Department of Natural Resources (ODNR) [149, 154]. The necessary balance between environmental services and flooding and erosion costs means that, pragmatically, the density and abundance of wood in developed streams will remain lower than in streams with minimal human impact. Though less abundant in developed watersheds, the biological value of wood that is found in developed streams is especially high - due in part to its relative scarcity. [151].

On balance, wood in streams and its dynamic replenishment from riparian corridors, provides enormous value in creating stable hydraulically diverse environments, critical habitat, and supporting the base of many aquatic food webs. The stable wood in resilient streams reduces erosion by protecting and stabilizing streambanks and creates pools that store sediment, dissipate flood flows, and reduce the hydraulic slope of individual stream reaches.

Boyer et al. [155] emphasize the critical importance of the linkages between riparian forests and floodplains in maintaining the processes that support their many diverse functions. They suggest that the conservation, enhancement, and restoration of these processes may be one of the most complex land management problems of the 21st century, and conclude that the conservation of intact riparian areas may prove to be the most cost-effective management approach for initial restoration of ecological functions to watersheds, including delivery of wood.

Ecosystem Protection Services: Terrestrial Systems

In addition to their value to aquatic systems, riparian areas are commonly recognized as corridors for animal movement and plant dispersal [37]. Floodplain plant species are adapted to the conditions created by the soil types, hydrologic variability, and disturbance regime characteristic of riparian areas. Riparian plants have evolved a variety of life histories that enable them to endure, resist, or avoid the extreme conditions of flooding, erosion, abrasion, and drought they regularly experience. For example, vascular plants that are periodically flooded have adapted to anoxic root conditions by developing air spaces, called aerenchyma, in their roots and stems that allow oxygen diffusion from the aerial portion of the plant to the roots. Anoxic conditions also mobilize ions such as manganese that can be toxic to plants. Riparian plants can create a thin oxygenated layer in the soil zone immediately surrounding the roots, called the rhizospere, to reduce this threat [156]. Similar adaptations are found in reproductive modes that synchronize seed dispersal with the seasonal disturbance and retreat of flood waters, and vegetative propagation via floating propagules that opportunistically disperse and colonize sand bars, streambanks, and terraces modulated by the frequency and elevation of flood waters.

The dynamic flux and exchange of surface water, groundwater, nutrients, sediment, and organic detritus enables riparian areas to support some of the highest levels of ecological diversity in the landscape. For example, Nilsson [157] reports 13% of the entire Swedish flora of vascular plants occurring along a single river corridor. Diversity in riparian corridors results from the abundance of nutrients, energy, and water as well as regular disturbances such as floods and landslides, characteristic of the riparian zone. It is important to note that the disturbance regime that makes the riparian zone a disproportionately diverse and productive component of the landscape, also renders riparian areas generally unsuitable for development.

These disturbances in the riparian zone reduce the potential for competitive exclusion through periodic population reductions and environmental fluctuations [7]. Diverse plant life supports diverse wildlife which is enhanced if trees and shrubs are available to offer protection to nesting and resting areas [38]. For example, nearly 70% of vertebrate species in an area will use riparian corridors in some significant way during their life time [158]. The diversity of biogeochemical cycles, life histories, and disturbance regimes led Naiman et al. [7] to the unequivocal conclusion that:

> *Natural riparian corridors are the most diverse, dynamic, and complex biophysical habitats on the terrestrial portion of the Earth.*

Our understanding of the importance of riparian corridors for terrestrial fauna including mammals and birds, as well as semiaquatic species such as reptiles and amphibians lags behind the emerging understanding of the intimate coupling of riparian and aquatic ecosystems. This limited understanding of the terrestrial environment is reflected implicitly in many riparian management measures that are primarily based on protecting water quality. To extend current understanding of riparian function for semiaquiatic species, Semlitsch and Bodie [159] reviewed the literature on amphibian and reptile use of terrestrial habitats associated with streams and wetlands to identify “core habitats” necessary to carry out essential life-history functions. They focused in particular on the distinction between habitat use and occurrence that is most commonly observed, and habitat needs for all essential life-history functions. They note, for example, that reptiles such as turtles and snakes, that migrate to upland habitats to nest or overwinter, commonly forage and live in aquatic habitats. Conversely, frogs and salamanders that spend most of the year foraging and overwintering in uplands, must return to aquatic habitats to breed and lay eggs during their short reproductive season.

From their review of distances traveled for *essential* life-history functions (i.e. excluding dispersal, out-migration, and other non-essential functions) in 25 states and 5 countries, Semlitsch and Bodie [159] concluded that setbacks of 49 to 98 feet (15m to 30m) are inadequate to protect amphibians and reptiles, which have maximum core habitat requirements extending between 466 to 948 feet (142m to 289m) from the core stream or wetland. Here, the *core habitat* used by amphibians and reptiles is not a buffer, but the minimum necessary habitat, leading to the further recommendation that an additional 164-foot (50m) buffer should be maintained beyond these distances to insulate the core habitat from adjacent land disturbance. This guidance, based on literature synthesis, indicates the fledgling state of understanding about riparian habitat needs of amphibians and reptiles, and underscores the authors’ conclusion that more research is needed to understand the effect of riparian management practices on the long-term sustainability of amphibians and reptiles. Recognizing the inherent balance between habitat protection and beneficial use of land, they conclude:

A sustainable balance between continuing economic development and protecting natural resources depends on knowing and responding to species' biological requirements and knowing how tradeoffs affect the maintenance of biodiversity.

Ecosystem Protection Services: Terrestrial Systems and Birds

Avian life histories are highly variable and a remarkable array of specialized ecological behaviors allows birds to partition a resource in both time and space. On Vancouver Island, Canada, Shirley and Smith [160] observed significant shifts in bird species richness, abundance, and composition with varying riparian buffer widths. The influence of edge effects on avian communities was significant and strongest in the narrowest buffers. They observed significant declines in abundance as buffer widths decreased from 410 feet (125 m) to 135 feet (41 m), and concluded that buffers greater than 328 feet (100 m) may be necessary to conserve forest interior species. Many studies provide similar observations of incremental shifts in species composition diversity and abundance of birds with land disturbance, particularly forest harvest, and various buffer treatments [161-165]. In spruce forests Hagvar et al. [162] found bird species richness increased with buffer width up to about 98 feet (30 m), and remained constant up to about 328 foot wide (100m) wide forested buffers. They also found that basal area, tree height, and visibility were additional habitat characteristics needed to understand the full ecological value of riparian corridors for breeding birds.

Considering the effects of forest buffers that ranged from 66 feet (20 m) to over ½ mile (800 m) in width, Hannon et al. [166] found that, while total bird abundance did not significantly decrease following forest harvest, the relative abundance of forest dependent birds declined as buffer widths decreased from 656 feet (200 m) to 328 feet (100 m). They concluded that 66 to 328 foot (20m to 100 m) buffers were inadequate to serve as reserves for forest songbirds. Pearson and Manuwal [165] found that buffer widths of at least 148 feet (45 m) were necessary to maintain the entire breeding bird population along second and third order streams in managed Douglas fir forests of the Pacific Northwest. Despite the growing empirical literature on short-term changes in avian abundance associated with forest harvest effects, understanding riparian influences on the sustainability of bird populations requires a more integrated understanding of avian ecological life histories.

For example Warkentin et al [167] studied behavior of water thrush, known as a riparian specialist, in forests 5 to 10 years after harvest. In these post-harvest study areas the riparian areas consistently had higher numbers and greater biomass of insects and other arthropod prey, as well as greater crowding of water thrushes. Nevertheless, water thrush had lower attack rates and longer flight distances to forage in riparian areas adjoining harvested areas. The observed increases in crowding and decreased feeding efficiency led Warenkin et al. [167] to question the long-term sustainability of conserving riparian habitat specialists with buffer strips alone. Riparian management nevertheless offers rich opportunities for joint services that enhance wildfowl habitat. In the Katy Prairie near Houston, Texas, agricultural floodplain lands have been purchased by a local land conservancy and leased to rice farmers. The leased lands are allowed to flood, generating seasonal flood control benefits which also provide critical habitat for migratory waterfowl and generate local recreational benefits for hunting and birdwatching [168].

The benefits of riparian areas to birds are evident in Ohio. The Ohio EPA [51] reports that more than 50% of the breeding bird species in the State use riparian wooded areas to nest and these areas are also critical migratory habitats. During Spring and Fall, migratory birds are 10 to 14 times more abundant in riparian habitats than surrounding upland habitats [51]. Riparian areas also serve as corridors connecting larger natural areas and can prevent the isolation of small, non-viable populations.

Riparian Setbacks Protect Ecosystems and:

- *Enhance aquatic habitat by moderating stream temperatures, controlling sedimentation, and other services.*
- *Provide highly productive terrestrial habitat.*
- *Create linkages between aquatic, floodplain, and upland habitats.*

ECONOMICS OF RIPARIAN SETBACKS

In addition to the flood control, erosion control, water quality protection, groundwater purification, and ecosystem protection services provided by riparian areas, decision makers should be aware of the economics of riparian protection. Efforts to quantify the economic impacts of limiting development and maintaining natural riparian functions along streams and their associated wetlands are discussed below.

Natural resource services refer to the benefits communities receive directly or indirectly from natural resource functions. This includes only renewable natural resource functions, excluding non-renewable fuels and minerals. The natural resource benefits provided by riparian setbacks include [169]:

- Flood control and disturbance regulation through the control of extremely high and low stream flows.

- Erosion control and sediment retention through streambank stabilization and slowing runoff.

- Surface and ground water quality protection through nutrient cycling by nitrogen fixation and the storage of sediment bound phosphorus.

- Ecosystem protection through refuge by providing habitats for resident and transient plant and animal populations.

- Recreational services including hiking, picnicking, and the protection of resources for sport fishing.

- Cultural services by providing opportunities for noncommercial uses such as aesthetic, artistic, educational, or scientific uses.

Riparian setbacks provide these natural resource benefits by minimizing encroachment on stream channels, thereby preserving the community services these areas provide. If natural systems are not protected to provide these services, there is an increased likelihood that engineering solutions, such as dams, streambank hardening, expanded storm water retention and treatment systems, and dredging may be necessary to prevent property damage and the loss of use of the resource. These engineering solutions have associated costs to communities that may not be offset by an increasing tax base or outside funds. Because riparian setbacks can minimize the need for these engineering solutions, the costs of these solutions provide approximate estimates of the value of the natural resource benefits of riparian setbacks.

Determining the value of the natural resource benefits riparian setbacks provide will help decision makers to more accurately balance community development goals with the need to protect public health and safety and spend tax dollars responsibly. Development brings significant economic benefits to communities including employment and tax revenues. It can also have significant costs as natural systems are altered and flooding, erosion, and impacts on water quality threaten property and a community's quality of life. Currently, the benefits of development are quantified while the benefits of natural systems are not fully captured in commercial markets [169]. As a result, the non-market benefits to a community from the services of riparian areas are often not considered in development decisions and taxpayers must absorb the potentially significant costs for remedial efforts to mitigate the negative impacts of development such as accelerated streambank erosion and increased flooding. By valuing these preventive natural resource services through the proxy of the cost to replace them with engineering solutions, local decision makers are better equipped to balance overall community development goals.

The cost of remedial engineering solutions is at best a rough proxy for the value of the natural resource benefits of riparian setbacks and does not capture the inherent recreational or cultural services provided by these areas of the landscape. Further research is needed to accurately capture the full value of riparian areas in economic terms. Until such information is available, however, experience supports the use of the remediation cost as a lower bound on future expenditures communities may face when natural systems are not factored into land use decisions. These costs may be quantified from experience in protecting drinking water supplies and remediating excess sedimentation, increased flood damages, and damage to infrastructure from debris. The following section presents salient examples of these costs.

Value of Natural Resource Services Estimated Through Remediation Costs

Water Quality Services

A lower bound on the water quality protection services provided by New York City's water supply watersheds in the Catskill Mountains can be inferred from the estimated costs of $6 to $8 billion in capital investment and $300 million annual operating and maintenance costs that would be needed for drinking water filtration facilities to replace the natural filtration of the City's water supply. To preserve these services, the City of New York is investing $1.5 billion in the Catskill Mountain watershed for stream setbacks, stream fencing, and a range of best management practices to preserve the natural water filtration services of the riparian landscape [170]. In taking this action, the City is recognizing that the value of these watershed filtration services is significant enough to invest in stream protection in upstate watersheds outside of New York City.

Erosion Control

Nationally, Osterkamp et al. [171] estimates the annual damages from sedimentation are at least $16 billion in 1990 dollars. The costs of sedimentation can be appreciated by considering the town of Gastonia, North Carolina which saved $250,000 in annual water treatment costs by moving its water supply intake to a lake with no surrounding development [168]. In the year 2000, $300,000 of the annual $4 million operating budget of the Cobb County-Marietta Water Authority in Georgia was spent on increased chemical costs to remove sediment from drinking water taken from Lake Altoona [172]. Warner and Collins-Camargo [173] cited property value losses for "degraded streams and ponds" of $100 million, and "ecological damage" exceeding $50 million due to erosion and sedimentation, as the primary drivers for the design of sediment control systems in Atlanta's watersheds.

For the rapidly growing Atlanta metropolitan area sedimentation is ubiquitous. Although "mud in water" has historically been accepted as the natural status quo, a regional effort to change the attitudes and practices towards excess sedimentation resulted in a multijurisdictional partnership in the Metropolitan Atlanta Area called Dirt 2. The regional partnership engaged broad expertise in land development practices, institutional and legal structures, and engineering expertise in sediment and erosion control. The regional partners enlisted the National Academy of Public Administration (NAPA) [172], which helped assess and summarize the estimated regional economic damages from erosion and sedimentation. Among the continuing damages cited were frequent lawsuits by private property owners seeking compensation from the offsite damages of excess sedimentation. Although the average damages in individual actions were typically in the range of $10,000 to $30,000, the cumulative annual awards were estimated to range between $500,000 and $1 million, providing an indication of the frequency of recurring damages severe enough to lead to legal actions each year.

Lakeside property owners in the metropolitan Atlanta area have incurred significant dredging costs due to excess sedimentation. The NAPA study reported that 5 property owners in Lake Lanier paid $100,000 to dredge lakeshore sediments reported to have come from nearby development in order to maintain access to their boats as water levels fell in 1999. Comparable dredging costs of up to $500,000 were reportedly authorized by the City Council of Roswell, Georgia towards a total estimated dredging cost of $2 million to remove sediments from Stanford Lake attributed to upstream development [172]. Regional damages from sedimentation identified by NAPA [172] are summarized as follows:

Excess Sedimentation
Estimated Damage Costs in the Atlanta Metropolitan Area

$0.5 to $1 million in annual damage awards to downstream property owners
$1 to $5 million in additional drinking water treatment costs
$1 to $10 million in annual dredging costs
$1 to $10 million in additional maintenance costs for hydroelectric generating stations
$25 to $50 million in replacement costs for lost hydroelectric capacity.

Along with detailed site design and revised engineering practices, the Dirt 2 initiative has resulted in a profound shift in acceptable site design and construction practices in the Atlanta area. Detailed design and analysis of modified construction costs concluded that, for typical sites, the cost of these new recommended practices were comparable to costs incurred for current sediment and erosion control practices [173]. Success of the so-called "transition to performance" hinged critically on the commitment of state, county and local jurisdictions to advancing low impact design practices throughout the development process from plan recommendations, site plan approvals, and site inspections during construction.

Flood Control

The City of Isaaquah, Washington has experienced increased flood damages of over $2 million between 1993 and 2000. Increasing flood damages are attributed to lost channel capacity due to sedimentation, partial clogging of culverts, filling of the floodplain, and increased runoff associated with more urban impervious area. The region has also experienced an increase in precipitation, apparently associated with a long term trend in weather cycles. Nevertheless hydrologic modeling conducted by Kings County estimated that current flood peaks in Isaaquah have increased by 8% due to urbanization alone, and could be expected to increase by 30% with buildout to current zoning [174].

Up to 90% of all natural disaster damages, excluding droughts, are caused by floods and associated natural debris flows [175]. Debris clogs of culverts and engineered structures in rivers create frequent maintenance problems for transportation and utility infrastructure and can result in significant damage when roads and culverts fail due to clogging, overtopping, and scour. The Washington State Department of Transportation reported substantial highway damage due to debris clogs during severe storms in October 2003. At just one site, a 6-foot culvert was clogged with debris and overtopped, resulting in the washout of 200 feet of State Route 20. This road section alone required repair costs of approximately $2 million, with total reimbursable damage costs from this single storm of $9 million.

Debris clogged the emergency spillway in Canyon Lake Dam resulting in its catastrophic failure during the Rapid City, South Dakota flood of 1972. The flooding also resulted in numerous debris clogs of road culverts leading to their overtopping and failure. Washouts during the flood resulted in $22 million in damages, in 1972 dollars. Following this devastating flood, a regional floodplain plan was developed, converting most of the floodplain to large parks, restoring the connectivity with the river, and removing the most vulnerable structures from the floodplain [176].

Value of Natural Resource Services: Costs to Local Governments

In addition to valuing the natural resource benefits of riparian setbacks in terms of remediation costs for flooding, erosion, and water quality problems, the impact of preserving open spaces, such as riparian areas, on local government tax revenues and property values has been explored. The traditional economic argument against the preservation of open space is that undeveloped land is not economically productive while developed land provides tax revenues. This argument has been questioned in a variety of studies as reported by Stephen Miller in his 1992 book **The Economic Benefits of Open Space.** Miller found that proximity to open space enhanced property values. Citing a Philadelphia study, he showed that values for properties near open space were 40% higher than for properties away from open space. Miller [177] also reviewed several studies that compared municipal tax revenues to municipal costs for specific communities in 3 categories of land use: open space, residential, and commercial. Each community reviewed in these studies received more in tax revenues from open space than it paid in services.

The American Farmland Trust [178], in conjunction with Madison Village and Township in Lake County, Ohio, produced a study similar to the work reviewed by Miller [177]. This study examined the costs to communities to provide services to three land uses: residential; commercial/industrial; and farm, forest and open land. The study compared these costs to the tax revenues generated by each land use. On average, residential development required $1.54 in services for each $1.00 in revenue generated. In other words, for every dollar raised from residential revenues, the community spent an extra 54 cents on average to provide services such as education, health and human services, public safety and public works. By comparison, commercial/industrial development required $0.23 in services for each dollar it generated, and farm, forest and open land required $0.34 in services for each dollar it generated. A study done by the Portage County Regional Planning Commission in Shalersville Township, Ohio [179] had similar results.

The work in Madison and Shalersville shows that residential land use costs communities more than it provides in revenues and that other land uses help to offset this shortfall. The cost of providing new residents with services is greater than their gross contribution to the tax base. These studies also show the positive tax benefits of preserving land in agriculture and open space as well as having a balance of land uses in a community. Such a balance is necessary because while commercial/industrial development appears to provide the greatest economic gain, a disproportionate increase in commercial/industrial development may not help a community. If not properly planned, the tax revenues generated from such development may be negated by increased demand for services, such as new housing and roads, as well as increased costs associated with traffic congestion and pollution. From the Madison and Shalersville studies, a mix of land uses appears to be best for tax revenues. These studies also show that development, either residential or commercial/industrial, does have associated costs that must be balanced against expected revenues.

Value of Natural Resource Services: Impacts on Property Values

The economic effects of open space, riparian setbacks, and other forms of environmental zoning can be rigorously estimated from observed prices of property sales using *hedonic price* analysis. King and Mazzota [180] offer the following explanation of hedonic pricing:

> *The hedonic pricing method is most often used to value environmental amenities that affect the price of residential properties…. The hedonic pricing method is relatively straightforward and uncontroversial to apply, because it is based on actual market prices and fairly easily measured data…. In general, the price of a house is related to the characteristics of the house and property itself, the characteristics of the neighborhood and community, and environmental characteristics. Thus, if non-environmental factors are controlled for, then any remaining differences in price can be attributed to differences in environmental quality.*

The direct effect of ecosystem or environmental services on homes and property can be estimated from observed sales prices using hedonic pricing. Acharya and Bennett [181] used hedonic pricing to estimate the effects of development "form" on observed housing prices, separating the features of individual homes and lots from the price effects of surrounding land use patterns and the proximity effects of amenities such as open space. The interaction of various amenity effects is a critical component of hedonic analysis of home prices. For example the significant effect of "scenic views" on home prices is well established [182]. Any estimates of the effect of riparian setbacks or other environmental zoning regulations on property values must therefore account for the combined effects of features of the individual home, the neighborhood, and proximity to various amenities.

The effect of environmental zoning can be understood to induce both a favorable "amenity" effect through, for example, the preservation of valuable views and proximity to open space, as well as an unfavorable "development" effect that reduces individual property prices by constraining development. The development effect however may be negative or positive, as limiting development may limit the supply of developable area, thereby increasing the demand and prices for those remaining developable tracts.

Spalatro and Provencher [183] examined the effect of minimum frontage zoning on sale prices of lakefront lots in Wisconsin. They found the amenity effects from minimum frontage requirements increased the sales price of lakefront homes 18% to 21% with only a negligible decrease in home prices attributable to the development effect of the frontage requirement. Similarly, a 3-mile greenbelt around Lake Merritt, near Oakland's city center, was found to add $41 million to the surrounding property values [168]. In London, Ontario Shrubsole et al. [184] found that homeowners did not perceive Provincial floodplain regulations to have any significant effect on home prices; a perception that was validated by their analysis of observed sales price data.

Netusil's [185] recent hedonic price analysis of the effect of environmental overlay zoning in Portland, Oregon offers an insight into the range of effects environmental zoning may have on property values. Portland has two levels of environmental zoning with strong restrictions on development of parcels in the environmental protection zone (p-zone) and somewhat more accommodation of some development in the conservation zone. (c-zone). Some properties are in both a p-zone and a c-zone. Netusil [185] estimated home price effects for each of the 3 zoning combinations in each of 5 different areas of Portland. She found properties with a c-zone designation in North Portland sell for 35% more than homes without any environmental zoning, while c-zone designations are estimated to lower the sale price of properties in Southwest Portland by 2.6%. The mixed results highlight the importance of interaction effects from the full range of amenities affecting consumer perceptions and preferences in home purchases. Consider for example, the interactions among amenities associated with proximity to trails. Convenient trail access might offer a positive amenity effect for recreational use *or* a negative effect from the reduction of perceived privacy or, in Portland's case, the fact that many trails are railroad right-of-way conversions and are located in areas with other negative amenity values associated with the old industrial rail corridor.

Preservation of scenic views and open spaces and riparian proximity have generally been shown to provide consistent significant increases in individual property values….

We are currently aware of no study that specifically identifies the effect of riparian setback regulations on property values. To address this important information need, CRWP will initiate a rigorous hedonic price analysis of the effect of riparian setbacks on property values in the Chagrin watershed in 2006.

The effect of setback regulations on property values is uncertain. Setback regulations could create a development effect that either increases or decreases home and lot prices. While both river views and forest views are consistently shown to increase property values, Mooney and Eisgruber [186] estimated the effect of Oregon's voluntary riparian buffer rules, requiring a 50 foot *forested buffer* - not just a setback - reduced property values approximately 3%, attributed primarily to the loss of river view.

Setback regulations could also be expected to contribute positive amenity value from the preservation of scenic views and water quality protection, as seen in water clarity, in waterfront properties [187]. The statistical analysis of 7,658 sales transactions of single family homes located within 1.5 miles of Tanque Verde Wash in northeast Tucson, Arizona found proximity to riparian corridors had a very significant positive effect on home prices. Homes located within 0.1 mile (528 feet) of the riparian corridor commanded a 5.9% price premium compared to identical homes 1.5 miles away. For the 25,560 homes within 1.5 miles of the riparian corridor the cumulative increase in property values exceeds $103 million, of which 75% or $77.3 million is realized by homeowners within 0.5 miles of the riparian corridor [188]. The very tangible direct financial benefit realized by these homeowners is another component of the portfolio of goods and services resulting from riparian protection. Similar analysis of home prices in 3 California counties found urban stream restoration projects which decreased flooding, stabilized banks, and enhanced fisheries added between 3% and 13% to mean property values [189].

These results emphasize the importance of considering the full range and interaction of amenity effects at the parcel, neighborhood, and regional scales, including proximity to open space, transportation amenities, and convenience of services. Preservation of scenic views and open spaces and riparian proximity have generally been shown to provide consistent significant increases in individual property values. These amenity effects interact with development effects. We are currently aware of no study that specifically identifies the effect of riparian setback regulations on property values. To address this important information need, CRWP will initiate a rigorous hedonic price analysis of the effect of riparian setbacks on property values in the Chagrin watershed in 2006.

IMPLEMENTING RIPARIAN SETBACKS THROUGH ZONING REGULATIONS IN NORTHEAST OHIO

This report establishes the flood control, erosion control, water quality protection, ground water purification, and ecosystem protection services provided by the riparian area. In working with its member communities to minimize the impacts of land use change as communities develop, CRWP recommends that members adopt zoning regulations to prevent development and other soil disturbing activities in riparian areas and to maintain these low-cost storm water management services. The remainder of this report discusses the specifics of implementing setbacks and includes information on CRWP's model regulation for riparian setbacks, steps involved with implementation, and factors to consider in adoption.

CRWP Model Regulation for Riparian Setbacks

To maximize the low-cost benefits of riparian setbacks communities should protect riparian areas through local regulations. These regulations must be properly designed and implemented and insure long-term setback maintenance. A variety of organizations in Northeast Ohio are available to assist communities interested in riparian regulations. These include CRWP, the Cuyahoga, Lake, and Geauga County Soil and Water Conservation Districts, and the Geauga and Lake County Planning Commissions. Working with these and other watershed stakeholders, CRWP maintains a riparian setback model ordinance and model resolution.

The model ordinance and resolution are based on the public health and safety services of riparian areas including flood control, erosion control, and water quality protection. The models establish minimum setback widths to control the location of soil disturbance on a parcel. A key feature of the riparian setback model is the emphasis on providing flexibility in other setbacks, such as side, rear, and front yard setbacks, to enable landowners to place their development as far out of the riparian setback as possible while still developing their property. The recommended setback widths in the model range from 25 to 300 feet on either side of a watercourse as measured from the ordinary high water mark. These minimum setbacks are extended to the full extent of the 100-year floodplain and to encompass riparian wetlands in the minimum setback. The model also details suggested permitted and prohibited structures and uses and includes provisions to address non-conformities and to grant variances when necessary to permit buildability.

Steps to Implementing a Local Riparian Setback Regulation

Communities considering riparian setbacks should follow these steps:

- <u>Update community comprehensive or land use plan</u> to include documentation of the flood control, erosion control, and water quality protection services offered by local riparian areas. This could include mapping and other inventories of the community's streams, wetlands, and open spaces as well as documentation of past storm water problems related to loss of riparian functions through development.

- <u>Review models</u> available from CRWP and others as well as adopted regulations from communities such as the Cities of Kirtland and Aurora. It is important for communities in Northeast Ohio to note that while there are several models available for riparian setbacks, these models are essentially the same. Start with the model recommended by the organization assisting with your community process.

- <u>Tailor the model</u> to community norms. Throughout this process, follow community's standard practices for regulation review, public hearing, and adoption. Provide opportunities for public education on the need for riparian setback zoning at regularly scheduled Planning and Zoning Commission, Council, and/or Trustee meetings.

- <u>Work with CRWP and/or local SWCD</u> to provide technical support and to develop a guide riparian setback map. Having such a map of the potential setbacks in your community will enable Planning Commission to review the number and type of parcels covered and the extent of the proposed riparian setback.

- <u>Adopt riparian setback zoning</u> regulation with support of Planning and Zoning Commission, Council, and/or Trustees.

Factors to Consider When Adopting Riparian Setbacks

Factors to Consider When Adopting Riparian Setbacks: Minimum Setback Width

CRWP's riparian setback model recommends minimum setback widths of 25, 75, 120, or 300 feet on either side of a river or stream as measured from the ordinary high water mark. Communities across Northeast Ohio have followed these recommended minimum widths and they are supported by natural resource management professionals as effective minimum widths for riparian protection. As a result, Northeast Ohio has seen a consist and uniform approach to riparian setback implementation.

As this report highlights, there are a range of recommended widths based on the desired functions of riparian areas. However, beyond individual scientific studies that identify site-specific parameters for specific functions of setbacks and buffers, a number of literature reviews and federal, state, and municipal evaluations, provide general guidance supporting riparian setbacks widths. The CRWP minimum setbacks are consistent with setback widths adopted around the country as well as state and federal guidelines for riparian buffers and stream management zones. The recommended widths are consistent with the basic information required for their implementation, and represent a prudent balance between community values of maximizing riparian services and minimizing the restrictions on beneficial uses of property. Several reviews of setback widths are highlighted below to reiterate this point. These include:

- In a quantitative analysis of buffer widths from regulatory programs in Canada and the United States, Lee et al. [34] reported that mean buffer widths implemented in the surveyed programs ranged from 50 to 100 ft depending on waterbody type.

- In a comprehensive review of riparian literature, Scheuler and Holland [190] state that the typical minimum base width recommended to provide adequate stream protection is 100 ft, noting that buffers may be expanded beyond the minimum 100 ft to incorporate the following conditions:
  - The full extent of the 100-year floodplain.
  - Steep slopes greater than 25%.
  - Adjacent delineated wetlands or critical habitats.
  - Higher order or quality streams.

- Naiman and Decamps [156] suggest a multi-species riparian buffer (MRB) to provide protection of streams against agricultural impact. The MRB model employs 3 interactive zones in successive upslope order from the stream:
  - A permanent riparian forest about 33 ft wide,
  - A section of shrubs and trees up to 13 ft wide, and
  - An area supporting herbaceous vegetation such as forbs and grasses up to 21 ft wide.

- Depending on buffer function, Castelle et al. [6] noted that appropriate buffer widths vary widely. Considering the literature reviewed, buffers less than 17ft to 33ft appear to provide little protection for aquatic resources. In general, buffers designed to protect wetlands and streams should be at least 33ft to 100ft wide, with buffers at the low end of this range designed to manage the physical and chemical functions of the resource and buffers at the high end of the range designed to manage the biological functions of the riparian zone.

- Focusing on factors significant to the implementation of riparian buffer ordinances, Wenger [15] reviewed the riparian buffer literature to compile scientifically-based recommendations supporting effective municipal ordinance adoption. Recognizing that buffer widths vary with both the particular riparian services desired, and site-specific factors including slope, rainfall, soil condition, vegetation, land use, and size of drainage area, Wenger [15] nevertheless offered general width guidelines drawn from the scientific literature. For sediment trapping efficiency, a minimum 100 foot buffer with either grass or forest vegetation was generally recommended, while noting that forest vegetation provides additional benefits over grass buffers. For proper sediment trapping, riparian setbacks should also consider placing limits on upslope impervious areas, strictly enforcing upslope sediment controls, and ensuring continuous buffers along all streams to be protected. To emphasize nutrient removal services, buffer widths in the range of 50ft to 100ft were generally found effective, again dependent on local site characteristics and hydrology. To manage for aquatic habitat, buffers should consist of forest vegetation 33ft to 100 ft wide for most species, but may require at least 330ft to maintain particularly diverse species populations.

- The ODNR, in their **Ohio Stream Management Guide: Forested Buffer Strips, Guide No. 13**, recommends that buffer width be based on actual riparian areas that can be estimated using floodplains identified in Federal Flood Insurance Rate Maps or by using county soil survey identification of soils that are "subject to frequent flooding". When riparian areas are too small to function as adequate buffers, as occurs with highly entrenched stream channels, ODNR suggests basing setbacks on generic standards such as 2.5 times the dimension of the bankfull channel width or 50 ft, whichever is less.

- In the United States Department of Agriculture (USDA) Forest Service handbook for establishing and maintaining riparian forest buffers in the Chesapeake Bay watershed [191], criteria for determining riparian buffer width includes the value of the resource, the site and watershed traits, intensity of adjacent land uses, and desired buffer functions. The following minimum width ranges are recommended based on specific functions:
  - Bank stabilization and aquatic food web processes - 10ft to 40ft.
  - Water temperature stabilization - 10ft to 60ft.
  - Nitrogen removal - 30ft to 140ft.
  - Sediment removal - 50ft to 160ft.
  - Flood mitigation - 65ft to 225ft.
  - Wildlife habitat - 45ft to 255ft.

- In the Cuyahoga Valley National Park, the National Park Service has recommended that riparian setbacks range from 50ft to 120 ft depending on drainage area, plus an additional 2 ft for each 1% increase in slope [192].

- The City of Everett, Washington conducted a review of riparian literature [12] and, as applied to the riparian function requirements of their community, came up with the following buffer width recommendations:
  - Sediment Retention and Filtration – 100ft to 300 ft.
  - Bank Stability - 100ft to 125 ft.

  - Small Woody Debris - 250 ft.
  - Shade/Water Temperature – 35ft to 250ft.
  - Water Quality – 13ft to 600ft.
  - Wildlife Habitat – 30ft to 1000ft.

- The City of Renton, Washington conducted a similar review of riparian literature to provide the scientific support for their riparian buffer ordinance [13], and reported the following recommended minimum buffer widths for their community:
  - Pollutant Trapping – 50ft to 100 ft
  - Sediment Trapping – 50ft to 200 ft.
  - Provide Particulate Nutrients to Stream (detritus) – 50ft to 100 ft.
  - Microclimate Control – 100ft to 525 ft.
  - Shade and Temperature Control - 50ft to 250ft.
  - Human Disturbance Control – 25ft to 50ft.
  - Bank Stability- 40ft to 70ft.

Factors to Consider When Adopting Riparian Setbacks: Expansion of the Minimum Setbacks for Floodplains, Wetlands, and Steep Slopes

Floodplains and Wetlands

As components of the riparian corridor, wetlands and floodplains are critical for the flood storage and pollutant removal functions of a riparian setback [38]. Minimum setback widths should be expanded to include these components. Depending on fluvial geomorphology, floodplains can extend a great distance and several floodplains with successively higher surfaces can occur along a single transect across a river valley [37]. It may not be practical for a community to protect this entire floodplain. To ensure reasonableness of its riparian setback regulation, a community should focus protection on the 100-year floodplain.

Steep Slopes

The degree to which riparian setbacks can filter sediments and nutrients depends to a great extent on the slope of the riparian area [38]. A slope of less than 15 percent is reported to allow for a retention time long enough to remove pollutants from runoff and to absorb water [8]. A steep slope, generally considered greater than 25 percent, reduces a setback's potential to slow flow and minimizes its ability to filter nonpoint pollution [193]. Even if steep areas are thickly vegetated, their steepness may negate the velocity reducing effects of vegetation and may promote erosion and channelization [8]. As a result, setbacks areas containing steep slopes may not significantly impact runoff velocity and minimum setback widths must be increased to compensate for these steep areas.

Factors to Consider When Adopting Riparian Setbacks: Riparian Area Contiguity

We now recognize that an essential value of riparian services derives from maintaining the connectivity and dynamic exchanges and processes throughout the riparian system. The superposition of political boundaries and individual property rights presents the challenge of effectively managing the functional integrity and resulting services provided by this dynamic interconnected system, through the collective efforts of individual decisions by riparian landowners. It is precisely this joint coordinated management of the riparian resource that riparian setback regulations attempt to institutionalize in simple easily implemented zoning instruments.

Perhaps the most important guiding principles to emerge from the current scientific literature that should be considered when implementing riparian setback regulations are:

- The importance of contiguity in riparian protection and
- The great value and importance of protecting the remaining least disturbed riparian corridors in communities.

<u>Contiguity and aquatic biota</u>

We know that land use influences the diversity and integrity of aquatic ecosystems and stressors associated with land disturbance from agriculture, forestry, and urbanization are inexorably associated with a shift towards pollution tolerant ecological communities. Riparian setbacks that minimize the disturbance of the riparian corridor have consistently been associated with moderating these pervasive effects. These land use effects are clearly associated with not just the width of a setback at a particular location in the stream system, but are strongly related to the upstream extent or length of riparian areas, and the "zone of influence" of riparian disturbance propagates far downstream [136, 145, 147, 194, 195].

<u>Contiguity and stream temperature</u>

Stream shading has been well established as a significant influence on stream temperatures, along with air temperature, cool groundwater inputs, and other terms in the heat budget. The sensitivity of cold water fisheries such as salmon and trout has driven the retention of forested buffers in forestry practices to mitigate stream temperatures in cold water fisheries.

We now understand that direct solar radiation is one of the most important controls on maximum daily stream temperatures and its effect on stream temperature is affected by both the width and the upstream length of the riparian area. Moreover the shading effects of riparian corridor vegetation is the only factor affecting stream temperatures that can be controlled by managing riparian vegetation, and the forested buffer width required to realize temperature management goals increases as the upstream length of the forested buffer declines [121, 126, 127, 129, 196] .

<u>Contiguity and sedimentation</u>

Field scale evaluation of vegetated riparian filter strips and buffers in agriculture and harvested forests have demonstrated the influence of buffer width, along with site-specific factors such as slope, drainage area, and particle size distribution, in trapping eroded sediments before they enter the stream system. In addition to width, the contiguity of vegetated riparian areas critically influences the sediment inputs to stream systems. Even heavily forested watersheds with 85% to 90% forest cover, experience increased stream sedimentation when the riparian forest is removed; the greater the riparian disturbance, the greater the sediment stress [27, 136, 145].

Contiguity and flood protection

Maintaining stream-floodplain connections with riparian setbacks has long been recognized as an effective means to maintain floodplain storage for overbank flows and reduce downstream flood damages. These riparian flood protection services are also extended by woody vegetation in connected riparian corridors and bank storage in alluvial floodplain sediments. Woody floodplain vegetation dissipates the energy of damaging floodwaters, and flood damages can be concentrated in areas in which gaps or discontinuities in the woody riparian vegetation are allowed to develop [47, 48, 197]. Bank storage helps dissipate flood peaks and moderate low flows for smaller more frequent storm events. Bank storage is nearly directly proportional to the width of the floodplain and helps reduce the flashiness and extremes of runoff along the entire length of the connected riparian corridor.[43, 44]

Contiguity and streambank erosion

Vegetated riparian corridors strengthen stream banks and dissipate concentrated overland flow, reducing erosion and bank failure, and promoting floodplain sedimentation. Riparian vegetation increases bank stability through both the mechanical effects from root strengthening and the hydrologic effects on soil pore water pressures. Discontinuities in the vegetated riparian corridor present vulnerable locations at which bank erosion is much more likely to be initiated, and individual stream reaches or river bends are far more likely to experience severe erosion where the contiguity of the vegetated riparian corridor has been compromised [55, 58, 59, 68, 70].

Contiguity and water quality

The capacity of riparian areas to remove sediments, nutrients, and dissolved contaminants has been well established experimentally. The surface of sediments at the riparian interface where surface water and groundwater mix is now understood to play a central role in maintaining the chemical and microbial transformations that naturally maintain and regulate water quality [23, 24, 79]. Maintaining riparian zones and effective land use practices are widely recognized as two valuable strategies to prevent the degradation of water quality services provided by these essential riparian processes [24]. These processes generate a valuable portfolio of water quality services that, once lost, are costly and difficult to replace. As Correll [130] observed,

> *Natural resource managers, having realized the values of healthy riparian zones, now face the challenge of restoration or recreation of functional riparian zones in many different settings.*

That is one of the reasons that the restoration of continuous riparian areas is an essential cost-effective component of watershed-scale efforts to protect and restore water quality from New York City's water supply watersheds and Chesapeake Bay to the control of nitrogen in the Mississippi River Basin to reduce chronic anoxia in the Gulf of Mexico.

Contiguity and groundwater purification

The riparian zone's capacity to infiltrate runoff and floodwaters and immobilize and degrade contaminants has been recognized as part of the natural system through which landscape processes protect and replenish groundwater. The hydraulic connection between rivers and streams and their adjoining alluvial aquifers provides an extremely cost effective portfolio of water treatment services that is widely relied on in Europe, and increasingly relied on for public water supply in the United States in cities from Cincinnati, Ohio and Louisville, Kentucky, to Kansas City, Missouri [116-118, 198]. The value and effectiveness of these services is directly linked to maintaining the hydraulic connection between river banks and alluvial aquifers.

The importance of contiguity in riparian protection is now clear in providing flood control services, ecological integrity, moderating stream temperatures, mitigating bank erosion and sedimentation, and modulating the landscape-level hydrologic fluxes and material loadings to fluvial systems [130, 199] The emerging knowledge and experience in managing the portfolio of beneficial riparian services at the watershed scale is crystallized in Correll's [130] conclusion that buffers along small headwater streams are most important, and that a continuous buffer is more valuable for overall waterway protection than a wide, but intermittent buffer.

The valuable portfolio of riparian services derives from the maintenance and enhancement of natural functions of the connected riparian corridor. The reliability and resilience of these functions will be maximized when the contiguity of the riparian corridor is preserved to the greatest degree possible. Setback programs should therefore emphasize the preservation of existing riparian land uses and discourage setback variances for new construction.

> ***Single-recipe approaches provide a poor foundation for management of rivers and streams, in part because they often ignore connections between physical and biological processes. …. That leaves us with two distinct choices for ecologically orientated river management: either trust that 'natural is best' and promote restoration of riparian forests, or treat each river on a case-by-case basis. [2]***

Factors to Consider When Adopting Riparian Setbacks: Type of Setback Vegetation

The physical roughness, root depth, and metabolic capacity of riparian vegetation significantly influence a setback's ability to slow and filter runoff and to stabilize riverbanks. Streamside vegetation increases channel roughness during overbank flow, decreasing the erosive action of floods and retaining material in transport [37]. The greater a barrier vegetation presents to flow, the greater its ability to slow this flow.

Because the type of riparian setback vegetation is essential for setback functions, a setback regulation should have a vegetative target, or goal plant community. Riparian setback vegetation such as maintained lawns presents less resistance to flow and provides less support to stream banks than vegetation such as unmowed grasses, shrubs and forests with leaf litter. Desbonnet et al. [8] found that both unmowed grass and forested areas effectively removed pollutants, provided that the setback was of a proper width and not particularly steep. Within theses types of "rough" vegetation, setbacks dominated by shrubs and trees are preferable to unmowed grasses for several reasons. After high flows, storage of litter on streambanks in a prairie system in Kansas was greater in forested reaches than in unmowed grassland reaches [200]. Trees and large shrubs also shade watercourses and minimize bank erosion as their roots penetrate soils and form a tight interlaced structure to hold bank soils in place against stream flow.

The vegetative target for most suburban/urban stream setbacks is the predevelopment riparian plant community [193]. In most cases this will be mature forest, however, the predevelopment plant community can be determined from reference riparian communities within the watershed or elsewhere. The native plant community is preferable because the benefits of riparian setbacks are natural functions and it is likely that native floodplain vegetation is best suited to achieve these functions at the lowest cost.

Management of riparian areas should give first priority to protecting those areas in natural or nearly natural condition from future alterations. [1]

In many areas, the riparian setback may be far from the vegetative target. A community has several options for reaching this target. If left untouched, native plants may eventually return. This takes time and delays realization of the benefits of the setback. To speed the process, a setback can be actively managed through reforestation efforts or through the removal of invasive and exotic trees, grasses and shrubs. When the setback is on private land, property owners can be encouraged through educational materials and technical assistance to undertake such management. Local county soil and water conservation districts and state agencies such as ODNR are excellent sources of such technical information.

Factors to Consider When Adopting Riparian Setbacks: Permitted & Prohibited Activities

A successful setback regulation should make clear the structures and uses allowed in the setback area. Uses that allow native vegetation to flourish and do not disturb soils are highly suitable for riparian setbacks [38]. These uses include passive recreation such as hiking, fishing and picnicking; the removal of damaged and diseased trees; and revegetation and reforestation efforts. The goal in determining suitable uses for a setback area is to allow flexibility for people to enjoy the area while not compromising the desired setback services.

Generally construction and other uses that disturb soil and vegetation should be prohibited. Construction of garages, patios and other structures adds impervious cover to the setback, decreasing its ability to slow flow and filter pollutants. However, selective timber harvesting, crossings, and erosion control projects may be appropriate and necessary in the riparian corridor. According to Lowrance et al. [9], periodic selective tree harvesting is necessary to keep forests highly productive where net nutrient uptake is high. If harvesting is done with minimum soil disturbance during the dry season, it will have little detrimental effect on the pollution control by riparian systems [9]. Selective harvesting, crossings, and stream bank stabilization must be done under an approved plan to ensure that such requirements for minimal disruption are followed. A riparian setback regulation should detail the conditions under which harvesting, crossings, and stabilization will be allowed and should encourage erosion control projects using bioengineering techniques where appropriate.

Factors to Consider When Adopting Riparian Setbacks: Long-Term Setback Management

A long-term management plan is necessary to ensure the success of a riparian setback regulation. Based on a nationwide study by Heraty [201] of 36 local level setback programs, Schueler [193] presents several key areas necessary for successful long-term setback management. These include:

Identification

Riparian setbacks need to be delineated on all subdivision plans and construction plans. Without such delineation, encroachment on setback areas is likely during construction. It is also helpful to maintain the riparian setback map to ensure community zoning and building officials generally know which parcels have riparian setbacks.

Education

Identification of riparian setbacks is also necessary to ensure that property owners understand how they are affected by the regulation. Those living adjacent to a setback may also be interested in assistance from local officials to properly manage their portion. Desbonnet et al. [8] point out that most setbacks will require some form of maintenance to reduce channelization of flow and to increase the effectiveness of pollutant removal from runoff. This education can be done through pamphlets, stream walks, individual visits, and community presentations.

Staffing

While identification and education programs will minimize encroachment and deterioration of the setback area, staff is also necessary to assist landowners in understanding the implications of riparian setbacks during construction and other soil disturbing activities for which they may otherwise require some sort of zoning approval.

FINAL POINTS

This report presents technical information on the functions of riparian setbacks and the components necessary for the development of a successful setback regulation. This information is intended to assist decision makers in developing reasonable riparian setback regulations and highlights the strong association between riparian protection and a community's quality of life. Through riparian protection, a community preserves natural resource benefits at low cost and maintains the natural systems that make it an attractive place to live and work.

Before developing a setback regulation it is important to recognize that implementation of a riparian setback will require the commitment of community resources. Community staff will need time to delineate the setback and to provide on-going education, technical assistance, enforcement, and other long-term maintenance. In deciding to establish a riparian setback area, a community should consider issues such as the level of technical and administrative resources available; its current level of development; the specifics of affected properties; community river protection priorities; and desired services from a setback. With this self assessment, a community will be better equipped to develop a setback regulation tailored to its needs.

It is important to note that riparian setbacks are only one part of an overall watershed approach to natural resource management. When implemented in conjunction with other sound land use practices, such as storm water regulation that address both water quality and quantity, riparian setbacks can maintain riparian corridor functions such as flood control, erosion control, nonpoint pollution control and groundwater purification. Setbacks will not eliminate the need for engineered solutions to severe encroachment on riparian corridors. They are preventive steps essential to maintaining the benefits of natural resources and reducing reliance on expensive engineering solutions to protect structures and reduce property damage.

Finally, riparian setbacks are an approved best management practice by the Ohio Environmental Protection Agency (Ohio EPA) for compliance with the Agencies National Pollutant Discharge Elimination System (NPDES) Phase II permit for storm water. Local setback regulations are also not in conflict with, or preempted by, the Ohio EPA's or the U.S. Army Corps of Engineers responsibility to review and permit impacts below the ordinary high water mark of streams and the jurisdictional boundaries of wetlands.

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