Midwestern Journal
of Undergraduate Sciences

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Vol. 3 Iss. 1. 2024 https://journals.ku.edu/MJUSc

Integrative Review of Riparian Buffers Benefits in Urbanized Watersheds

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Riparian buffers or riparian corridors are areas of vegetation in the floodplains and areas surrounding a stream. By the early 2000s, numerous national reports and studies of riparian buffer benefits established that vegetation near streams is helpful in protecting the stream from increasing urban runoff, minimizing bank erosion, reducing flooding, and improving overall water quality. However, influential studies concluded that buffer benefits dwindle as urbanization increases, eventually becoming ineffective. This study evaluates recent research that suggests riparian buffers are more effective at countering urbanization impacts than previously understood and considers the extent to which we can quantify these benefits and identify the factors that maximize their effectiveness (i.e. greater efficiency based on buffer distance from the stream, extent of stream setbacks, and percentage of impervious cover in the area). Much of the research has been conducted in the Kansas City area in the Blue River Watershed, which begins in Kansas and flows into the Missouri River east of downtown Kansas City, Missouri. About 800,000 residents live in the watershed, which includes some of the region's fastest-growing areas. It is critical to protect this major resource, and other regional rivers and streams, for residents of the Kansas City Metropolitan area and the ecosystems that depend on them. It is also critical to provide the latest and best information to the community-of-practice currently updating regional stormwater management planning and design guidance.

Introduction

The Mid-America Regional Council (MARC), the Kansas City Metropolitan Chapter of the American Public Works Association (APWA), and its member communities and consultants have worked to define and quantify the benefits of riparian corridors for 30 years to develop more effective regional policies and design criteria. The work was undertaken with assistance from the Center for Watershed Protection, state and Federal agencies, regional and national not-for-profit environmental organizations, and academic researchers. The efforts are built upon fundamental research from pioneers in the field and early stream protection and restoration practitioners.

The purpose of this review is to integrate available resources including multiple peer-reviewed and other published studies, watershed plans, and modeling over the last twenty years to define and update our understanding of riparian buffer benefits. The emphasis of this paper will be how riparian corridors help reduce bank erosion, minimize flooding, protect the area from urban runoff, and overall improve stream health and quality. Furthermore, this analysis will evaluate distinct types of riparian corridors and where they can be most effective (i.e., woody vegetation vs. partially vegetated corridors). The conclusion of the paper will also provide a few recommendations for how riparian buffers can be utilized along the Blue River.

To understand riparian buffer benefits and potential protection strategies for urbanizing watersheds, it is also important to understand the Impervious Cover Model, stream setback ordinances, and how the negative effects of urbanization can be countered by riparian zones. Based on this analysis, the paper will present updated conclusions about how stream buffers protect urban streams, what factors improve their benefits, and how communities might incorporate this knowledge into policies.

Urbanization's Impact on Streams

Urbanization converts rural land and increases impervious cover that degrades stream quality in many ways. "Contaminants, habitat destruction, and increasing streamflow flashiness resulting from urban development have been associated with the disruption of biological communities."[1] Reduced stormwater infiltration as vegetation is replaced by buildings and pavements increases flooding, bank erosion, and loss of biodiversity in surrounding streams. Increasing pollution impacts all urban streams. From 2001-2003, Jeffery Deacon studied water quality in New Hampshire to correlate concentrations of different chemicals and organisms in streams as well as the overall water quality/habitat scores in areas with various levels of urbanization and buffer coverage. Deacon found that areas with higher impervious cover and urbanization had higher concentrations of E. Coli, nitrite and nitrate yields, pesticide detection, etc.[2]

Impervious Cover and the Impervious Cover Model

Impervious cover includes human-caused structures that do not allow for water infiltration in the surrounding area. Impervious cover has been widely known to affect stream quality in many ways: the urbanization of land causes urban runoff, loss of biodiversity, bank erosion, and increased flooding. However, it has been found that stream buffers may be able to combat the negative impacts that impervious cover has on water/stream quality.

Thomas Schueler revisited the impervious cover model (ICM) in 2018. The ICM model was first introduced in 1994 and has been amended since then. The ICM documented a direct correlation between the percentage

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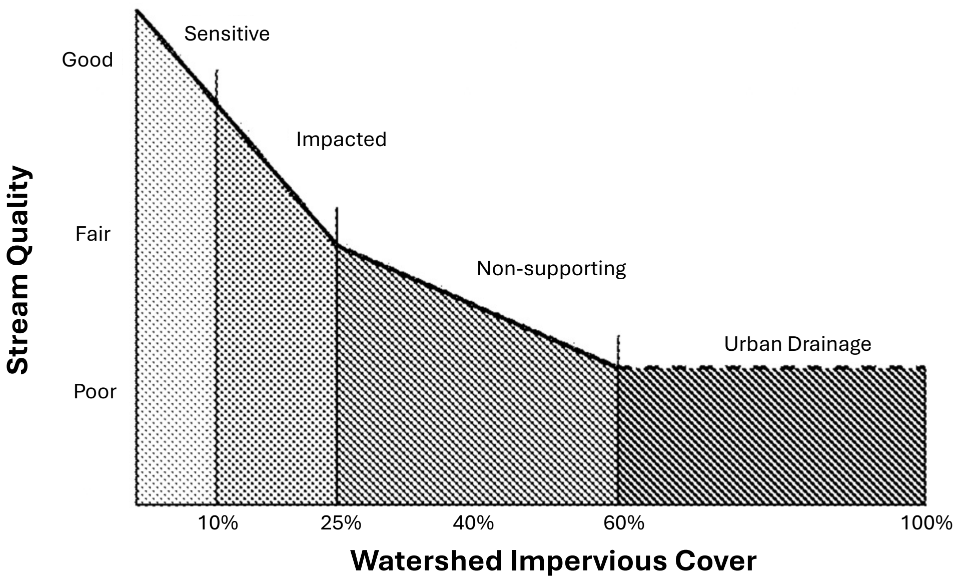

Figure 1 | Stream quality v. impervious coverage.[3]

of impervious coverage and stream quality and is still used today to provide insight into how much it can affect urban watersheds.[3]

Riparian Buffer Benefits for Urbanization

As it is clear that impervious cover impacts receiving streams, research has shifted to how to mitigate these negative effects – and riparian buffers may be the answer. Schueler (2018, p. 97) noted significant stream degradation "... reported in watersheds that had less than 10% IC, with eight notable outliers. These outliers had greater IC (25 to 35%) but similar B-IBI scores. These outliers are unique in that they had a large upstream wetland and/ or a large, intact riparian corridor upstream (i.e., >70% of stream corridor had buffer width >100 feet)". The Index of Biotic Integrity scores (B-IBI scores) assess the effects of human disturbance (i.e., impervious cover) on stream health and quality in wetlands.[4]

Riparian buffers provide resisting forces against urbanization impacts that contribute to stream health and quality in several ways. The vegetated zones slow runoff as the stems create friction that reduces the velocity of urban runoff entering the stream, which helps prevent bank erosion and reduces flooding as the roots absorb and infiltrate water that is flowing more slowly.[5] Riparian vegetation further protects streambank structure as greater amounts of vegetation and native plant roots fortify the bank and lessen the likelihood of bank erosion.[1]

When riparian vegetation is present, soil loss decreases exponentially (see **Figure 2**). The soil loss in the figure is due to canopy coverage. When more vegetation is present, "Some precipitation is intercepted by plant foliage and evaporated back to the atmosphere, but most of it reaches the soil."[5] Vegetation also builds healthy soil that allows for better infiltration of this water into the ground, further curbing the flow of urban runoff into the stream. Riparian zones contribute organic material (such as leaf litter and debris) to the streams and nutrients and the aquatic organisms they support, and deposit organic material in the riparian corridor, increasing soil health. Soil health is important because healthy soil can absorb more water, pollutants, and sediment, which protects streams from these harmful pollutants. But in an area without vegetation, the soil is degraded and water cannot infiltrate, making it even more likely to erode into the nearby streams.[5]

Several national and regional sources have offered important insights on riparian buffers' effectiveness in combatting the negative effects of impervious cover on stream quality. A 2001 study by Horner and May illustrated a correlation between the Habitat Quality Index (HQI) score and the presence of riparian buffers, even in watersheds with total impervious areas (TIA) approaching 40%. Riparian integrity was defined as buffer widths wider than 30 meters (m) over at least 70% of the corridor, less than 10% of the corridor with buffers under 10 m in width, riparian continuity (fewer than two breaks in the corridor per kilometer of stream), and riparian quality (more than 80% of the corridor as forest or wetland cover)."[6] The results are shown in **Figure 3**.

A more recent and extensive study conducted by the U.S. Geological Survey (USGS) collected water quality data in nine metropolitan areas: Portland, Oregon; Salt Lake City, Utah; Birmingham, Alabama; Atlanta, Georgia; Raleigh, North Carolina; Boston Massachusetts; Denver, Colorado; Dallas, Texas; and Milwaukee, Wisconsin. Multiple, extensive sampling events focused on the riparian buffer and impervious cover effects on water quality.[1] In **Figure 4**, the percentage of urban development correlates to the channel cross-sectional area per watershed unit area, as increased runoff volumes and velocities generally erode and widen channels. However, Milwaukee's data shows a much less channel widening, which was attributed to the resisting forces from much greater riparian vegetation, that increased the strength of the bank structure in the region's streams. This further supports that riparian vegetation can be useful against the negative effects of urbanization and impervious cover.

Kansas City Regional Studies

Much of the riparian buffer research conducted in the Kansas City region has been focused on the Blue River Watershed, which begins in Kansas and flows into the Missouri River east of downtown Kansas City, Missouri. About 800,000 residents live in its watershed, which includes some of the region's fastest-growing areas. It is critical to protect this major resource, and other regional rivers and streams, for residents of the Kansas City Metropolitan area and the ecosystems that depend on them. Numerous not-for-profit and governmental partners have developed watershed management and conservation plans for the Blue River, all of which recognize the need to protect riparian buffers.[7]

In 2005, Patti Banks Associates and Black

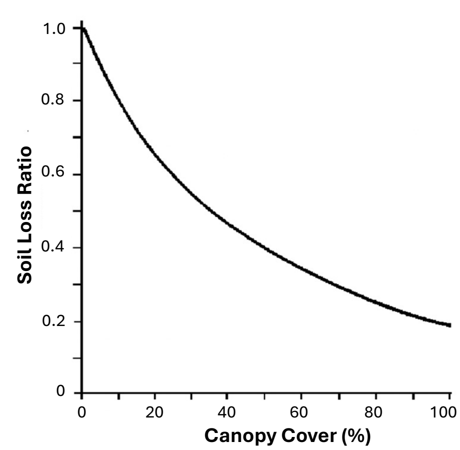

Figure 2 | Soil loss v. canopy cover ratio.[5]

& Veatch Corporation conducted a Stream Asset Inventory of 289 locations in Kansas City, Missouri, including many in the Blue River Watershed.[8] The SAI procedure was developed by practitioners in the Kansas City region to address a lack of urban stream assessment methods, using indicators of relative stream stability, terrestrial and aquatic habitat, and water quality. The results are presented in **Table 1**.

SAI stream types rank stream quality with Type I being the highest level of stream quality and Type V being the lowest, based on a statistical distribution of assessed streams; Type III streams represent the median streams. Type I and II streams are significantly higher quality, and Type IV and V streams are significantly lower. Type I and II streams are generally stable and correspond to the "sensitive" streams in the ICM, while the Type III streams correspond to the ICM's "impacted" streams. Type IV and V streams are "non-supporting" in ICM terms.[8]

However, the Blue River watershed stream types were not what the ICM predicted. "Type IV streams were found in the upper reaches of the Wolf Creek watershed, while Type II streams were identified in the Blue River main stem and Camp Branch sub-watersheds."[8] The Type II stream reaches along the Blue River main stem had drainage areas with about 8% imperviousness, while the Wolf Creek and Camp Branch sub-watersheds both exhibited impervious cover of 2 to 3%.[8] It was observed that more extensive and higher quality vegetation surrounded the Type II streams; and across the data set, the quality and quantity of riparian buffer vegetation correlated moderately to strongly with overall stream scores. Thus, it further supports that riparian corridors can negate the effects of impervious cover/urbanization.[8]

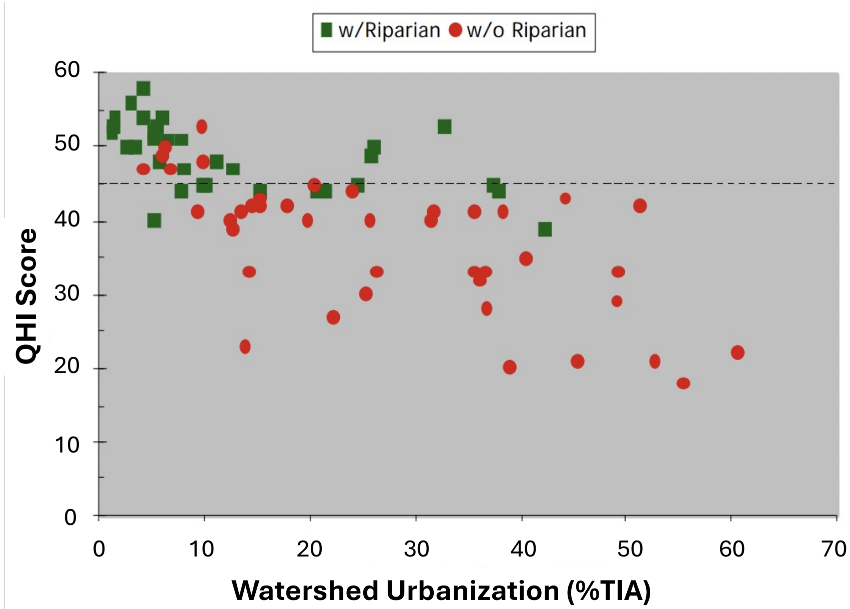

Figure 3 | QHI Score v. Watershed urbanization percentage[6]

Results and Discussion

The studies described above indicate that riparian buffers provide greater benefits for urban streams than the ICM predicts. Wherever present, buffer vegetation continues to protect streams from increased runoff volume, velocity, erosion, sedimentation, and contaminant loads, even as impervious cover increases. Given this result, riparian buffers should be protected and restored in the Kansas City region. The following sections suggest guidelines for prioritizing and designing effective riparian buffers.

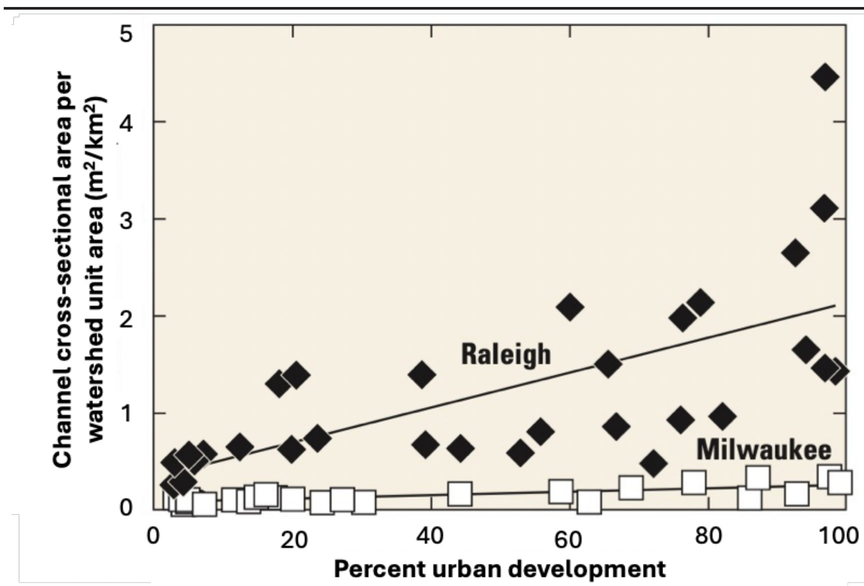

Figure 4 | Cross-sectional area v. percentage of urban development[1]

Prioritizing Areas of Concern

Areas, where urbanization is rapidly increasing, are in dire need of riparian corridor protection to prevent further stream degradation, and the data indicate that riparian buffer restoration may also help reverse negative impacts. Tools are needed to prioritize protection and restoration. Approaches like the two presented below may be complementary for assessing which riparian corridors need the most attention in places like the Blue River Watershed.

Watershed models can help quantify riparian buffer benefits for reducing flooding and erosion, and forecasting increases in impervious cover can help identify where riparian corridor protection is needed the most. Kansas State University developed a hydrologic and hydraulic model of the Blue River watershed and found that riparian buffers fully vegetated with native species reduced stream discharge by up to 20% for frequent storms (occurring on average every 1- to 2-years) that cause most stream erosion, and even some larger storms that cause flooding. Loss of native vegetation increased discharge while restoring native vegetation reduced it; however, turf grass provided no benefit. Kansas State then used future land use forecasts and Geographic Information System (GIS) mapping to estimate where impervious coverage would increase, and

Summary Distribution						
	KC-One Data (2005)		KC SAI Data (2002-03)		Overall	
Stream Type	**Count**	**% Total**	**Count**	**% Total**	**Count**	**% Total**
Type I	3	1.0%	0	0.0%	3	0.6%
Type II	39	13.5%	18	9.5%	57	11.9%
Type III	196	67.8%	141	74.2%	337	70.4%
Type IV	42	14.5%	28	14.7%	70	14.6%
Type V	9	3.1%	3	1.6%	12	2.5%
Total:	289	100.0%	190	100.0%	479	100.0%

Table 1 | Stream Types[8]

to identify which areas (**Figure 5a**) of the Blue River watershed would benefit the most from riparian corridor protection or would be negatively impacted by riparian vegetation loss.[9]

Another promising model from a study in northern central Texas helps predict water quality. A 2020 study of a public water supply reservoir's watershed in the Dallas-Fort Worth area utilized GIS mapping to assess 40-meter-wide corridors in 90 sub-watersheds.[10] The Water Quality Corridor Management for Restoration (WQCM-R) model is "a spatially explicit modeling and mapping technique"[10] used to "(1) utilize easily accessible data for the purpose of identifying and assessing potential water quality issues and (2) to classify stream segments in order of riparian quality in order to prioritize potential restoration activities as a component of an overall watershed management plan."[10] **Figure 5b** shows how the model sorted streams reached based on their relative protection and restoration opportunities.

Buffer Design Guidelines

Once priorities for protection and restoration are set, it's vital to optimize stream setback and corridor widths to improve stream health and achieve important goals, including minimizing bank erosion, reducing urban runoff volume and velocity, filtering pollutants, and minimizing flooding. Kansas State University's Blue River watershed modeling found that fully vegetated 100-year floodplains (and wide buffers on headwater streams) provided the greatest benefit with native vegetation.[9]

Gary Bentrup of the US Department of Agriculture (USDA) consulted a slew of research to develop more than 80 riparian corridor design models to help protect soil, alleviate bank erosion, improve water quality, reduce flooding, and increase biodiversity. These models help planners assess stream corridors and determine the minimum vegetation widths to provide the desired benefits; **Figure 8** illustrates how buffer width helps quantify the effectiveness of trapping pollutants.[11] One model specifically focuses on buffer widths to minimize urban runoff and can help planners assess stream corridors and development projects.[11]

After setting the buffer width, it is important to consider which types of vegetation can be most beneficial. A diverse mix of native plants is recommended for riparian corridors. Streamside plants include "herbaceous plants with fibrous root systems" and woody species.[11] In the Blue River, a variation of native streamside plants could include native grasses, willow trees, and other flood-tolerant woody species including Elm, Oak, and Dogwood.

Future Directions

As stated throughout this paper, riparian buffers can provide many benefits to the stream health of urban watersheds. It is critical to provide the latest and best information to planners, stormwater managers, consultants, developers, policymakers and elected officials. Preliminary results from this study have been provided to the community-of-practice currently updating regional stormwater management planning and design guidance, APWA 5600 (MARC, 2024), but more research is needed.

More work is needed to identify riparian buffer assessment and design models that optimize protection and restoration benefits based on stream and watershed characteristics. Understanding and using models like the Buffer Width Tool, proper vegetation selection, and watershed assessments like Kansas State's watershed model and the

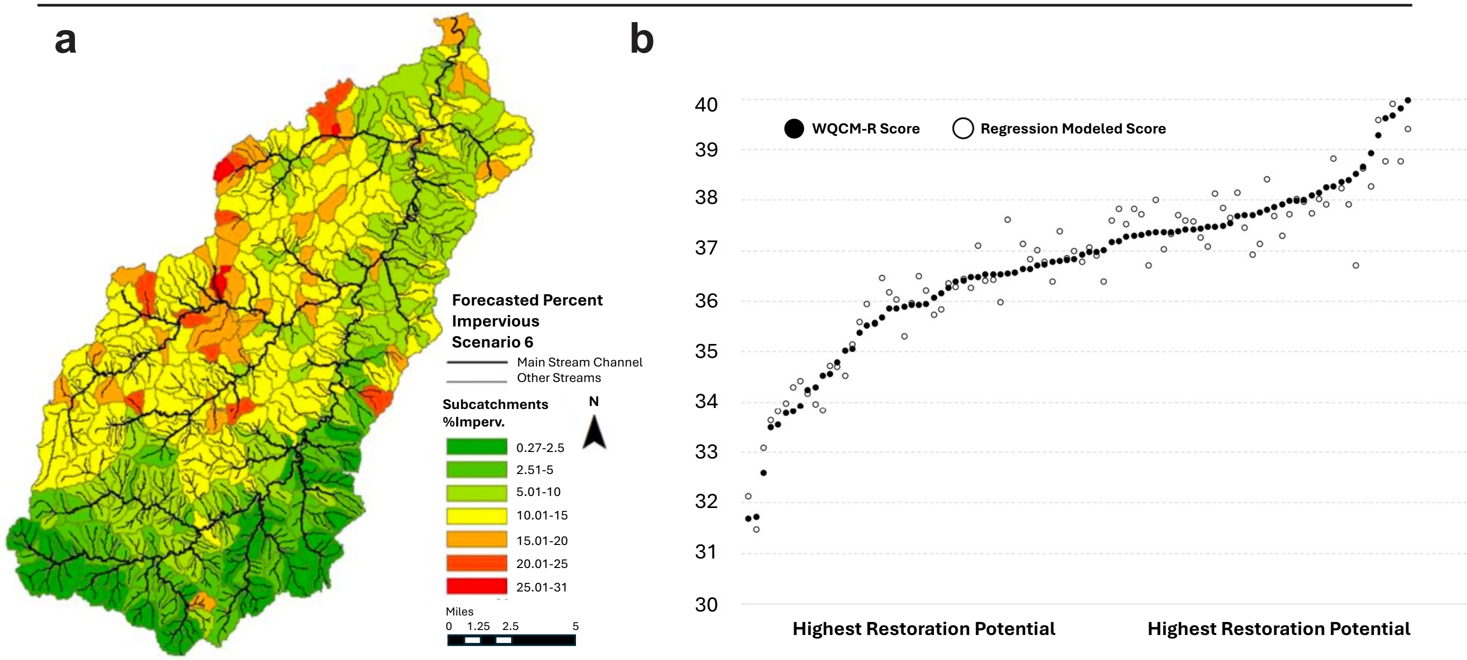

Figure 5 | (a) Forecasted impervious coverage percentages[9] & (b) Restoration potentials[10]

WQCM-R rating systems are crucial in improving riparian corridor spaces and their stream health. Ultimately, the region needs a quantitative model that can better predict and quantify the impacts of riparian corridor protection and restoration to help guide watershed managers, policymakers, elected officials, developers, and conservationists.

Author's Contributions

P.D. contributed to the experimental analysis, design, and writing of this work; S.S. contributed to the design and editing of this work.

Author's Biography

Paige Denning is a recent graduate from the University of Kansas with a Bachelor of Science degree in Environmental Studies. Throughout her final semester, she worked on a capstone project to understand the extent of benefits riparian corridors for stream quality as watersheds urbanize. The research supported updates to regional stormwater management planning and design guidance. Paige is currently pursuing work in water quality testing in the Kansas City region.

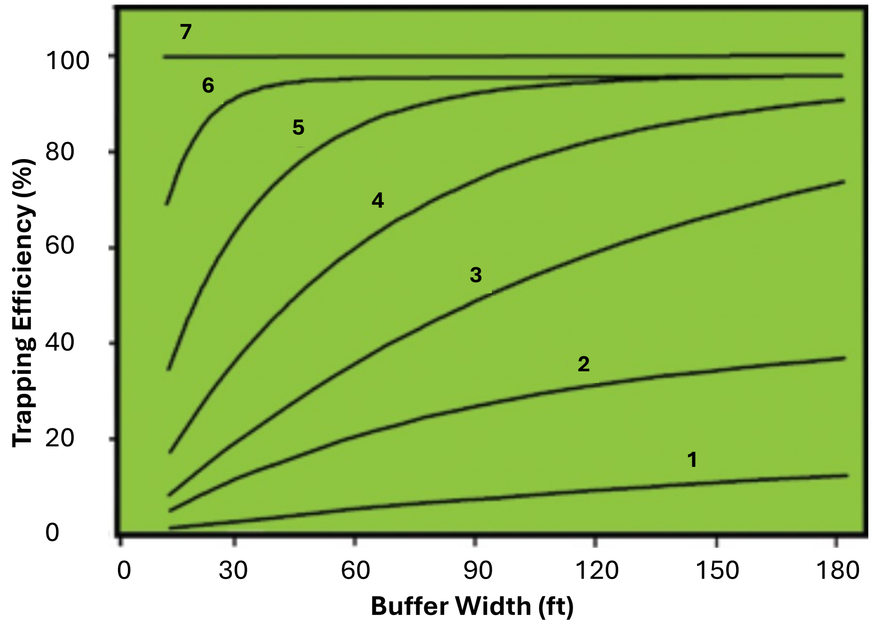

Figure 6 | : Trapping efficiency v. buffer width[11]

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