Riparian Buffer

Assessing Potential Water Quality Improvements for the Miyun Reservoir in Beijing, China
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A Technical Primer on Quantifying Benefits of Watershed Interventions

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The China Mega-City Water Fund (CMWF) was launched in August of 2015 in cooperation with the Beijing Forestry Society (BFS), China Biodiversity Conservation and Green Development Foundation (CBCGDF), International Union for Conservation of Nature (IUCN), and Forest Trends. Once fully operating, the CMWF will identify, fund, and help implement watershed improvement projects ("interventions") to benefit water quality and water quantity in the Miyun Reservoir. The City of Beijing relies in part on this reservoir as a critical drinking water supply. A notable challenge facing the CMWF, and other water funds throughout the world, is the ability to reasonably estimate water quality and/or water quantity benefits associated with specific interventions. Recent 2016 efforts have established an operating framework for the CMWF that will evaluate various watershed interventions in the context of relatively simple, established performance metrics for water quality and water quantity benefits. Coupled with projected costs for such interventions, the CMWF will be able to assess, compare and optimize benefits associated with its investments in watershed improvements with this framework.

This Technical Primer[1] represents an initial examination of quantification methods that the CMWF and others may use to reliably estimate water resource benefits derived from particular land management interventions in the watershed of the Miyun Reservoir. This approach relies upon existing studies from both the Miyun Reservoir watershed and other basins in China.

Proposed Intervention: Riparian Buffers

Riparian buffers are a vegetated interface between terrestrial and aquatic ecosystems capable of a variety of functions including erosion reduction and improved water quality.[2] The installation of riparian buffer vegetation is a best management practice (BMP) widely recognized for improving water quality in agricultural landscapes facing issues of nonpoint source pollution.[3] Vegetative buffers can: 1) reduce the velocity of overland flow; 2) reduce diffuse surface runoff before it reaches surface waters; and, 3)

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[1] This Technical Primer was prepared by Kieser & Associates, LLC for Forest Trends of Washington, D.C. in collaboration with BFS and IUCN. Funding was provided by the Swiss Agency for Development and Cooperation SDC.

[2] Dindaroglu, T., M. Reis, A. Akay, and F. Tongue. 2015. Hydroecological approach for determining the width of riparian buffer zones for providing soil conservation and water quality. International Journal of Environmental Science and Technology. 12: 275-284

[3] Momm, H., R. Bingner, Y. Yuan, M. Locke, R. Wells. 2014. Spatial characterization of riparian buffer effects on sediment loads from watershed systems. Journal of Environmental Quality. 43:1736-1753.

promote runoff infiltration. Velocity reduction and infiltration largely result in the interception and capture of particulate and dissolved pollutants such as sediments and nutrients including phosphorus (P) and nitrogen (N). Dissolved pollutants, particularly N, in shallow groundwater flowing through the root systems of riparian buffers can be taken up by plants and undergo other bio-physical processes in the soil matrix, resulting in nutrient load reductions into adjacent waterways.

Surface overland flow is typically associated with high volume precipitation events and may result in observable rills, gullies or sheet erosion, particularly on cultivated lands. Upgradient infiltration of precipitation, which may resurface in adjacent waterways, drives subsurface shallow groundwater flow beneath the buffers. Both overland and shallow groundwater flow are often potent transport mechanisms of pollutants within a watershed to streams, rivers, and lakes. A riparian buffer's ability to reduce nutrient loading of these transport pathways is correlated with various factors including soil type, vegetation, flow rates and buffer width, as well as the presence of concentrated flow paths.[4,5] Thus, when designing and installing a riparian buffer, site-specific considerations are necessary to quantify and maximize the benefits of this BMP.

The procedure proposed herein quantifies the nutrient reduction benefits of implementing riparian buffers between farm fields and adjacent waterbodies. Figure 1 conceptually illustrates riparian buffer hydrology. Water enters the system through precipitation and may leave the farm field via evapotranspiration, infiltration or surface runoff. Of most concern is runoff across the field surface that carries sediment and nutrients to a stream or infiltration that, through groundwater flow, delivers dissolved nutrients (principally, N) to a surface water.

The primary pathways of water flow through the riparian buffer are an important consideration for calculating benefits. Separate methods of quantification are used for surface flow (or surface runoff) and subsurface flow (also referred to as groundwater flow). Surface runoff can be observed in an agricultural field by the presence of rills, gullies, top soil depletion, or direct evidence during a precipitation event. Riparian vegetation slows the velocity of surface runoff principally allowing sediments and sediment-attached nutrients to settle out before reaching the stream. If indications of surface flow do not exist, this report assumes that the primary pathway of water flow is subsurface in shallow or deep groundwater. The root zone of a riparian buffer is capable of removing dissolved nitrogen in the form of nitrates.

For the Miyun Reservoir application, this Technical Primer focuses on quantifying nutrient removal from surface runoff and shallow groundwater by riparian buffers. A separate technical memorandum prepared for Forest Trends by K&A discusses buffer design and monitoring.[6]

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[4] Dillaha, T., J. Sherrard, and D. Lee. 1989. Long-term effectiveness of vegetative filter strips. Water Environmental Society. 1:419-421.

[5] Liu, X., X. Zhang and M. Zhang. 2008. Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis. Journal of Environmental Quality. 37: 1667-1674.

[6] Kieser & Associates, LLC. 2015. Buffer design and monitoring for IUCN and BFU pilot. Technical Memorandum prepared for Jan Cassin, Forest Trends, November, 2015.

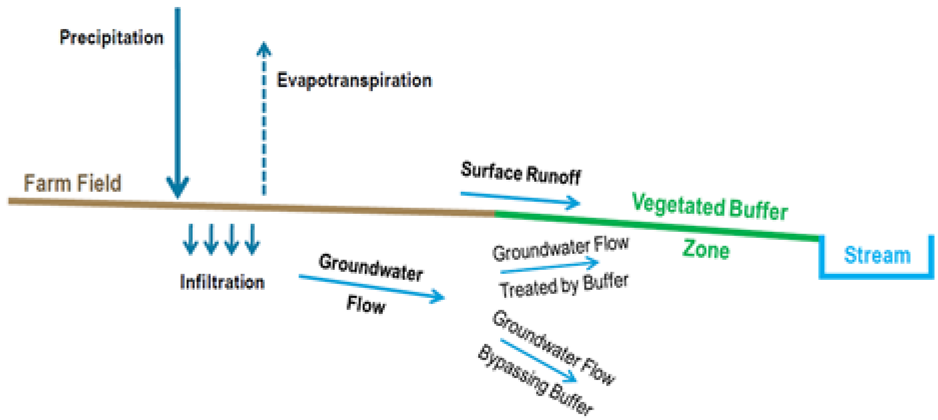

Figure 1: Schematic of Riparian Buffer Hydrology

Source: Kieser & Associates

Calculating Water Quantity Benefits

Riparian buffers can treat both surface runoff and groundwater depending on design. For surface runoff, riparian buffers may improve water quality by trapping sediments and nutrients in particulate forms migrating from upgradient agricultural operations. Vegetation reduces the velocity of overland flow thus trapping nutrient-laden sediment and promotes water infiltration. In addition to treating surface runoff, riparian buffers may function to treat shallow groundwater through nitrate removal.[7] Interactions between vegetation root zones and the soil matrix remove nitrate from groundwater. Dissolved P interacts similarly and is adsorbed within the soil matrix during infiltration. Generally the removal of nitrate and dissolved P from shallow groundwater is an accepted function of riparian buffers. However, the effectiveness of this removal is variable and highly dependent on site-specific hydrogeological conditions.[8]

The approach for quantifying nutrient reduction benefits associated with implementing riparian buffers was determined using available information from a planned buffer site in Dazhazi Village in Xiaowopu, Fengning County, Hebei Province. Beijing Forestry University (BFU) assisted in the construction of the buffer at Dazhazi in partnership with IUCN.

The quantification methods presented herein assume a simplified approach for determining nutrient load reductions resulting from buffers, given the general lack of site-specific information at the Dazhazi Village site, most notably in regards to local hydrology. The following provides a framework to conservatively estimate nutrient load reductions using riparian buffers absent local hydrologic information. Attachment A of this Technical Primer assumes hypothetical site-specific values to illustrate

[7] Correll, D. 2005. Principles of planning and establishment of buffer zones. Journal of Ecological Engineering. 24: 433-439.
[8] Hill, A. 1996. Nitrate removal in stream riparian zones. Journal of Environmental Quality. 25(4): 743-755.

use of this nutrient load reduction calculation strategy.

The generalized steps used to estimate the water quantity benefits using this approach include:

A. Gathering necessary information

1. Percipitation rates (annual and the 2-year 24-hour event[9])
2. Evapotranspiration rate
3. Soil and vegetation conditions

B. Calculate intervention benefits

1. Calculate runoff depth of overland surface flow
2. Calculate water depth of shallow groundwater
3. Calculate N and P load reductions from surface runoff
4. Calculate N and P load reductions from shallow groundwater
5. Estimate the unit costs of total N and P load reductions based on the cost of establishing a riparian buffer

The following equations define this quantification approach for nutrient load reductions resulting from riparian buffers. The water mass balance for each site (as conceptually depicted in Figure 1) is represented by the following equation:

$$P_a = Q_T + ET + I \qquad \text{(Equation 1)}$$

Where:

P_a = annual precipitation (mm/yr)
Q_T = annual total surface runoff depth (mm/yr)
ET = evapotranspiration (mm/yr)
I = infiltration (mm/yr)

The infiltration term in Equation (1) reflects the portion of precipitation that eventually becomes groundwater. Of this, it is assumed that shallow groundwater will travel towards the stream where it will pass through the root zone of the buffer and be treated. The remaining groundwater is assumed lost to deep groundwater thereby bypassing buffer treatment.[10] A proportion term "*C*" is used as a correction factor to account for these two fractions of groundwater given what will typically be an unknown condition at each buffer site. This is applied in an effort to better estimate the fraction of shallow groundwater flowing through the effective treatment zone of the buffer. The use of this term is illustrated in Attachment A and shown here:

$$GW_s = I \times C \qquad \text{(Equation 2)}$$

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[9] This represents a 24-hr rain depth with a once every 2-year return frequency.

[10] Nutrient loss to deep groundwater may or may not re-enter to the stream at some distance downstream of the farm field. However, this analysis only quantifies benefits resulting from the shallow groundwater treated by the buffer zone. In addition, a small amount of soil moisture retention is implicitly incorporated in the deep groundwater term for this water mass balance.

Where:

GW_s = shallow groundwater depth treated by buffer (mm/yr)
C = proportion term

Absent site-specific hydrologic information, an accurate determination of "*C*" is difficult. For the purposes of this initial quantification approach, the Technical Primer proposes a value of 0.5 for saturated buffers adjacent to perennial streams and 0.0 for intermittent streams. Perennial streams and saturated conditions indicate upgradient recharge which suggests shallow groundwater flow occurs through the buffer.

From Equations (1) and (2), an equation to estimate surface runoff is derived based on the depth of shallow groundwater (GW_s):

$$GW_s = (P_a - Q_T - ET) \times C \quad \text{(Equation 3)}$$

Equation (3) is an initial method to begin quantifying surface runoff, Q_T, through the use of the "curve number" method. This approach is commonly applied throughout the United States and quantifies surface runoff based on precipitation and soil and vegetation characteristics.[11] As more appropriate local or regional methods for addressing infiltration are identified, this report recommends utilizing those methods as opposed to the curve number method. The derivation of the curve number equation in this application is as follows:

$$Q_r = \frac{(P-I_a)^2}{(P-l_a)+S_r} \qquad \text{(Equation 4)}$$

Where:

Q_r = surface runoff from the 2-year 24-hour rain event (mm: $Q_r = 0$ when $P \leq I_a$)
S_r = potential maximum retention after runoff beings (mm)
P = percipitaiton of the 2-year 24-hour rein event (mm)
I_a = initial abstraction (mm)

I_a and S_r are determined as:

$$I_a = 0.25_r \qquad \text{(Equation 5)}$$

$$S_r = \frac{25{,}400}{CN} - 254 \qquad \text{(Equation 6)}$$

Where:

[11] The curve number approach was developed by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). The method is described in the USDA's Technical Release 55 (TR-55), published in 1986 and available online at: http://www.cpesc.org/reference/tr55.pdf.

CN = curve number (dimensionless)

After surface runoff depth is determined for the 2-year 24-hour event, the precipitation total (P_a) is divided by the 2-year 24-hour precipitation (P) to obtain the number of events that generate equivalent surface runoff:[12]

$$n = \frac{P_a}{P} \quad \text{(Equation 7)}$$

Where:

n = number of events in a year that generate surface runoff equivalent to the 2-year 24-hour event

Finally, total annual surface runoff (Q_T) is calculated as:

$$Q_T = n \times Q_r \quad \text{(Equation 8)}$$

Assuming precipitation data can be obtained from local weather stations, the curve number is the only parameter to be determined for the surface runoff calculation. The curve number is a function of soil, land cover, and vegetation management. Selection of a suitable CN for the farm field of interest is based on these factors and can be calibrated for observed runoff. Curve numbers typically range from 30 to 100, with higher values indicating greater runoff potential. An example calculation for Equations (1) to (8) with the application of the curve number approach is provided in Attachment A with site-specific assumptions under a hypothetical scenario.

The remaining steps for estimating nutrient load reductions by riparian buffers involve nutrient load calculations using flow depths calculated from Equations (3) and (8) and potential load reductions with measured or literature-based load reduction efficiency values associated with the buffer. These steps are outlined below with example calculations illustrated in Attachment A.

To calculate N load reduction by riparian buffers in shallow groundwater, the following equation is used:

$$R_{s-N} = GW_S \times A \times X_{s-N} \times E_{s-N} \times 0.000001 \quad \text{(Equation 9)}$$

Where:

R_{s-N} = N load reduction in shallow groundwater (kg/year)
A = area of draingage catchment to the buffer (m^2)
X_{s-N} = concentration of nitrate-N[13] in shallow groundwater (mg/L)
E_{s-N} = shallow groundwater N removal efficiency by the buffer (fraction)

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[12] The Pennsylvania Department of Environmental Protection (PA DEP) Chesapeake Bay Water Quality Trading Program. 2007, 2008. Nutrient and Phosphorus calculation spreadsheets. Accessed August 11, 2016; available at: http://www.dep.pa.gov/Business/Water/PointNonPointMgmt/NutrientTrading/Pages/Credit-Generation-Process.aspx.

[13] Nitrate-N is generally considered the main form of nitrogen in shallow groundwater.

0.000001 = unit conversion factor

Phosphorus is generally considered to be present in shallow groundwater only in a very small amount. However, if local data shows a substantial presence of P, Equation 10 can be adapted to calculate P load reduction in shallow groundwater ($R_{s\text{-}P}$) by changing the nitrogen concentration ($X_{s\text{-}N}$) and removal efficiency ($E_{s\text{-}N}$) terms to corresponding phosphorus terms ($X_{s\text{-}P}$ and $E_{s\text{-}P}$, respectively).

To calculate N and P load reductions in surface runoff by riparian buffers, the following equations are used:

$$R_{r-N} = Q_T \times A \times X_{r-N} \times E_{r-N} \times 0.000001 \qquad \text{(Equation 10)}$$

$$R_{r-P} = Q_T \times A \times X_{r-P} \times E_{r-P} \times 0.000001 \qquad \text{(Equation 11)}$$

Where:

$R_{r\text{-}N}$, $R_{r\text{-}P}$ = load reduction in surface runoff for total N or total P, respectively (kg/year)
$X_{r\text{-}N}$, $X_{r\text{-}P}$ = concentration of total N or total P in the surface runoff treated by the buffer, respectively (mg/L)
$E_{r\text{-}N}$, $E_{r\text{-}P}$ = surface runoff N or P removal efficiency by the buffer, respectively (fraction)
0.000001 = unit conversion factor

Nutrient removal efficiencies by a riparian buffer are a function of the vegetative composition of the buffer, buffer width, local soil, slope, hydrological conditions, and nutrient loading conditions from the upland field. The best source of removal efficiency information is site-specific long-term buffer monitoring data. Absent such site-specific information, regional values obtained from sites with similar biophysical conditions and buffer design can be used. However, such regional values are often not available. In those cases, literature values from a variety of field conditions and buffer designs would have to be used. Buffer efficiency has been a subject discussed by many studies (e.g., Zhang *et al.*, 2010[14] and Mayer *et al.*, 2007[15]). These studies generally provide a range of efficiency values based on various buffer characteristics such as width and vegetative composition. Making conservative assumptions and using best professional judgment in selecting efficiency values from these studies can provide reasonable initial estimations of load reduction by vegetated buffers.

The total load reductions by the buffer in both shallow groundwater and surface runoff are the summation of N or P reductions calculated from Equation 9, Equation 10, and Equation 11:

$$R_{T-N} = R_{s-N} + R_{r-N} \qquad \text{(Equation 12)}$$

$$R_{T-P} = R_{s-P} + R_{r-P} \qquad \text{(Equation 13)}$$

Where:

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[14] Zhang, X., X. Liu, M. Zhang, and R.A. Dahlgren. 2010. A Review of Vegetated Buffers and a Meta-analysis of Their Mitigation Efficacy in Reducing Nonpoint Source Pollution. J. Environ. Qual. 39:76–84.

[15] Mayer, P. M., S.K. Reynolds, Jr., M.D. McCutchen, and T.J. Canfield. 2007. Meta-Analysis of Nitrogen Removal in Riparian Buffers, J. Environ. Qual. 36:1172–1180.

$R_{T\text{-}N}$ = total N load reduction by the buffer (kg/yr)
$R_{T\text{-}P}$ = total P load reduction by the buffer (kg/yr)
$R_{s\text{-}P}$ = P load reduction in shallow groundwater, if present (kg/yr)

Future Methodological Improvements

The calculation methods proposed in this Technical Primer required several assumptions regarding estimated water quality benefits resulting from riparian buffer interventions. Discussions here focus on data gaps that are encountered in applying these calculations to actual riparian buffer sites. Future quantification of nutrient load reductions should consider addressing these assumptions in order to obtain more refined estimates.

Proportion of Groundwater Treated:
This primer assumes the buffer will not treat all groundwater that infiltrates from the farm field; some might go to deep groundwater and not enter the stream, the remainder could move laterally to the stream and be treated as shallow groundwater by the buffer root zone. Because of this, Equation 2 introduces a correction factor, *C*, to account for the shallow fraction of groundwater treated by a buffer. These calculation methods assume groundwater does not flow to surface waters that are intermittent and thus is lost to deep groundwater. For sites with perennial streams, the methods assume there is recharge from shallow groundwater and that this fraction is treated by the buffer. Hydrologically defining shallow and deep groundwater fractions will improve estimates of dissolved nutrient removal.

Pollutant Removal Efficiency:
Attachment A assumes two sets of removal efficiencies for riparian buffers; P and N reductions occurring in surface runoff and N reduction in shallow groundwater. These removal efficiencies are based on best available science and professional judgment on nutrient dynamics in buffer zones. For instance, methods utilize shallow groundwater removal efficiencies as reported by the United States Department of Agriculture (USDA). USDA reports a range of efficiencies, of which this primer assumes a conservative value.[16] For surface runoff reductions, this primer uses removal rates presented by BFU research. Additional discussion of these assumptions is contained in Attachment A. Buffer efficiency likely varies from these reported values and should be studied at representative pilot locations. Calculations provide an initial framework to begin assessing water quality improvements gained from riparian buffer interventions. Buffer monitoring may reveal different biomass and water yield is thus crucial to understanding the long term effect of forest thinning in BRW. Such monitoring could then be used to better justify equation applications.

Curve Number Method:
While widely used throughout the United States, the applicability of the curve number method is not fully understood for the Miyun Reservoir. Future methodology should consider several aspects of the curve number method noted as follows:

- The curve number method was designed for highly mechanized and precise agricultural practices

[16] Bentrup, G. 2008. Conservation buffers: Design guidelines for buffers, corridors, and greenways. General Technical Report SRS-109. Asheville, NC: Department of Agriculture, Forest Service, Southern Research Station.

in the United States. Use of manual tools in farming operations, as commonly observed during a March 2015 local site visit, likely reduces soil compaction relative to the United States farming operations. Reduced compaction may promote better functioning hydrologic soil dynamics (greater infiltration/less surface runoff) and consequently a different curve number.

- Soil texture, compaction, vegetation cover, and plant residue management all influence curve number determinations. A better understanding of these parameters, based on site-specific characteristics, would further refine the curve number.
- The slope of the contributing farm field affects depth to shallow groundwater. Determining site-specific field slopes will further refine the curve number.

Monitoring:
Given the potential biophysical variations between buffer locations (and consequent calculation variability between sites), this primer recommends implementers perform pre-and post-implementation data collection. This should focus on method verification, calibration or equation refinement for select sites, and laboratory-based analyses of water samples. Of particular importance is a better understanding and quantification of "water loss" terms (ET and deep groundwater) in the mass balance equation, as well as removal efficiencies for nutrients and sediment. Presently, these values are poorly understood for buffers in the Miyun Reservoir watershed. Calculation examples provided in Attachment A could be refined using new, more accurate removal rates.

To fully understand the site specificity and scalability of Equations 1, 2, 3, and 4 it would be necessary to conduct continuous hydrologic monitoring at a representative site for other riparian buffer interventions. The IUCN buffer at the Dazhazi village could be an appropriate site. Monitoring wells for groundwater and surface runoff collection pans have been installed at the site for the 2016 crop season. Extending the monitoring activities beyond 2016 would further benefit the refinement of the calculation procedures outlined in this primer.

Attachment A

Example Calculations

Forest Thinning Calculation Example

The following example illustrates the calculation approach for nutrient load reductions associated with vegetated buffers. Input values in the example reflect local information in the Dazhazi Village, Xiaowopu Administrative Village, Fengning County, Hebei Province, where a pilot riparian buffer has been established by IUCN and BFS. Lacking local data, the following calculations use a series of assumptions to account for these data gaps. Cost information is then applied to estimated nutrient load reductions to forecast unit costs based on US$/kg·yr^{-1}. Due to the multi-year benefit life span of riparian buffers, the unit cost calculations also include annualizing the initial investment over the estimated benefit life span, assumed here to be 20 years.

Calculate Depth of Annual Total Surface Runoff (Q_T)	
Equation:	$Q_r = \frac{(P - l_a)^2}{(\text{"}P - l_a) + S_r}; S_r = \frac{25{,}400}{CN} - 254; l_a = 0.2S_r; n = \frac{P_a}{P}; Q_T = n \times Q_r$
Input:	Precipitation (P) of 2-yr 24-hr rain event: 50 mm Curve number (CN) for sandy soils with vegetative cover: 65[17] Annual precipitation (P_a): 484.3 mm/yr[18] Q_r: surface runoff from 2-yr 24-hr rain event (mm) S_r: potential maximum retention after runoff begins (mm) I_a: initial abstraction (mm) n: number of events in a year that generate surface runoff equivalent to the 2-yr 24-hr event Q_T: annual total surface runoff (mm/yr)
Calculations:	S_r = 25,400/65 – 254 = 136.77 mm I_a = 0.2 × 136.77 = 27.35 mm Q_r = $(50 – 27.35)^2$ / (50 – 27.35 + 136.77) = 3.2 mm n = 484.3/50 Q_T = 9.69 × 3.2 = 31.0 mm/yr
Assumption:	The 2-yr 24-hr rainfall is assumed to be 50 mm.[19]
Data Gap:	Site-specific 2-yr 24-hr rainfall; Site-specific data on soil hydrologic properties and vegetation cover and management are needed for accurate curve number estimates.
Calculate Infiltration (I)	
Equation:	$I = P_a - Q_T - ET$
Input:	Annual precipitation (P_a): 484.3 mm/yr Evapotranspiration (ET): 430.1 mm/yr[20]

[17] Based on site observations, this curve number is assigned here to reflect the upgradient cultivated field that was under row crop (corn) with residue in a highly permeable soil in good hydrologic conditions.

[18] Represents annual average precipitation in the Bai River watershed (1973-1990), of which the pilot riparian site is a part; from Chapter 6 of the PhD dissertation by Jiangkun Zheng (2011. Dynamic response of eco-hydrological process to human activities and Climate change in Chaobai River Basin. Beijing Forestry University).

[19] The 2-yr 24-hr rainfall of 50 mm is assumed for three primary reasons: 1) when applied over time, 50 mm in a single event is representative of average annual rainfall intensity; 2) 2-yr 24-hr rainfall encourages streambank stabilization and; 3) if the rainfall event selected is too large, the top layers of soil will become super-saturated and infiltration will be inhibited, though if the rainfall event selected is too small, surface runoff may not occur.

[20] Derived from average annual precipitation (1973-1990) and annual average surface runoff (1978, 1988, 1998, and 2008) of the Bai River watershed, of which the pilot riparian site is a part; from Chapter 6 of the PhD dissertation by Jiangkun Zheng (2011. Dynamic response of eco-hydrological process to human activities and Climate change in Chaobai River Basin. Beijing Forestry University).

	Total surface runoff (Q_T): 31.0 mm/yr
Calculations:	I = 484.3 – 430.1 – 31.0 = 23.2 mm/yr
Assumption:	Only pathways for precipitation are infiltration, evapotranspiration and runoff.
Data Gap:	*ET* and P_a rates are not readily available for the pilot site
Calculate Depth of Shallow Groundwater Treated by Buffer (GW_s)	
Equation:	$GW_s = I \times C$
Inputs:	Infiltrated water (I): 23.2 mm/yr Proportion term (C): 0.5
Calculations:	GW_s = 23.2 × 0.5 = 11.6 mm/yr
Assumptions:	C is assumed to be 0.0 when intermittent stream is adjacent to buffer (i.e., buffer does not provide shallow groundwater treatment). C is assumed to be 0.5 when perennial stream is adjacent to buffer (buffer treats 50% of the shallow groundwater).
Data Gap:	C to be determined using field measurements.
Calculate Nitrate-Nitrogen (N)[21] Load Reduction in Shallow Groundwater (R_{s-N})	
Equation:	$R_{s-N} = GW_s \times A \times X_{s-N} \times E_{s-N} \times 0.000001$
Inputs:	Shallow groundwater depth (GW_s): 11.6 mm/yr Area (A) of drainage catchment: 13,340 m2 Concentration (X_{s-N}) of nitrate-N: 6.59 mg/L N removal efficiency (E_{s-N}): 0.75[22,23,24] Unit conversion factor: 0.000001
Calculations:	R_{s-N} = 11.6 mm/yr × 13,340 m^2 × 6.59 mg/L × 0.75 × 0.000001 = 0.76 kg/yr
Assumptions:	Area (A) of drainage catchment is based on 20 *mu* (1.334 ha or 13,340 m^2) of upgradient farm field. Nitrate-N concentration of 6.59 mg/L is assumed for shallow groundwater near farmland based on well survey data.[25] Removal efficiency of nitrate is conservatively assumed to be 75%. This value is based on a USDA reported range of 75 to 90% efficiency in a properly functioning buffer Phosphorus (P) is generally not present in groundwater or is found at a very low level.
Data Gap:	Nutrient concentrations are based on literature values. Removal efficiency from groundwater should be locally verified.
Calculate Load Reductions in Surface Runoff (R_{r-N} and R_{r-P})	
Equation:	$R_{r-N} = Q_T \times A \times X_{r-N} \times -0.000001; R_{r-P} = Q_T \times A \times X_{r-P} \times 0.000001$
Inputs:	Total annual surface runoff (Q_T): 31 mm/yr Area (A) of drainage catchment by the buffer: 13,340 m^2

[21] The main form of nitrogen in shallow groundwater around agricultural fields is nitrate.

[22] Range of 75-90% as reported in Bentrup, G., 2008. Conservation buffers: Design guidelines for buffers, corridors, and greenways. General Technical Report SRS-109. Asheville, NC: Department of Agriculture, Forest Service, Southern Research Station.

[23] Median value of 76.7% as reported in Mayer, P. M., et al. 2007. Meta-Analysis of Nitrogen Removal in Riparian Buffers, J. Environ. Qual. 36:1172–1180.

[24] A meta-analysis by Zhang et al. (2010. A Review of Vegetated Buffers and a Meta-analysis of Their Mitigation Efficacy in Reducing Nonpoint Source Pollution. J. Environ. Qual. 39:76–84) showed a median N mass removal efficiency of 68.3% from 61 studies and a modeled efficiency of 71% for a 10 m buffer. However, those median values did not take into account the various forms of nitrogen and flow paths of the nitrogen. Based on Mayer et al. (2007, see Footnote 24) buffers generally have a higher efficiency in removing N from subsurface flow than surface flow, which suggests the N removal efficiency for subsurface/shallow groundwater would be higher than the median value of 68.3% or the modeled value of 71% calculated by Zhang et al. (2010). Therefore, considering all three literature sources, it is believed that a removal efficiency value of 75% is suitable for use in this example calculation.

[25] Wang, Q., D. Sun, W. Hao, Y. Gu, Y. Li, X. Mei, and Y. Zhang. 2011. Nitrate Concentration Distribution in Groundwater of the Miyun Reservoir Watershed. Acta Pedologica Sinica. 48(1): 142-150.

	Concentration of N (X_{r-N}) and P (X_{r-P}): 8.20 mg/L and 1.03mg/L, respectively[26] Removal efficiency for N (E_{r-N}) and P (E_{r-P}) : 0.51 and 0.75, respectively[27] Unit conversion factor: 0.000001
Calculations:	R_{r-N} = 31.0 mm/yr × 13,340 m^2 × 8.20 mg/L × 0.51 × 0.000001 = 1.74 kg/yr R_{r-P} = 31.0 mm/yr × 13,340 m^2 × 1.03 mg/L × 0.75 × 0.000001 = 0.32 kg/yr
Assumptions:	Buffer is properly designed and functioning. Removal efficiencies reported by BFU are consistent among sites.
Data Gap:	Nutrient concentrations in surface runoff should be locally verified. Removal efficiencies from surface runoff should be locally verified.
Calculate Total Load Reductions (R_{T-N} and R_{T-P})	
Equation:	$R_{T-N} = R_{s-N} + R_{r-N};\ R_{T-P} = R_{s-P} + R_{r-P}$
Inputs:	N and P load reductions from shallow groundwater R_{s-N} *and* R_{s-P}: 0.76 kg N/yr and 0 kg P/yr, respectively. N and P Load reductions from surface runoff R_{r-N} and R_{r-P}: 1.74 kg N/yr and 0.32 kg P/yr, respectively.
Calculations:	R_{T-N} = 0.76 kg/yr + 1.74 kg/yr = 2.50 kg/yr R_{T-P} = 0.0 kg/yr + 0.32 kg/yr = 0.32 kg/yr
Assumption:	P in the groundwater is completely retained by soil before reaching the buffer zone (no shallow groundwater P load reduction).
Data Gap:	Load reduction efficiencies should be locally verified.
Calculate Unit Cost of Load Reduction by Riparian Buffer	
Equation:	Total Cost = Buffer length × Unit length cost Annualized unit cost = annualized total cost (US$/yr) ÷ load reduction (kg/yr) = cost per kg load reduced (US$/kg)
Inputs:	Buffer length: 100 m Unit area cost: $27.56/m[28] Total cost annualized over 20 year buffer lifespan at a 4% interest rate[29] Load reduction: 2.50 kg N/yr or 0.32 kg P/yr (see above calculations for R_{T-N} and R_{T-P}, respectively)
Calculations:	Total Cost = 100 m × $27.56/m = $2,756 Annualized total cost = $202.78/yr (20-yr, 4%) Annualized unit cost (N) = $202.78/yr ÷ 2.50 kg/yr = $81.24/kg N Annualized unit cost (P) = $202.78/yr ÷ 0.32 kg/yr = $633.33/kg P
Assumptions:	Effective lifespan of riparian buffers is 20 years Interest rate is 4%
Data Gap:	Assumed lifespan and interest rate values should be verified

[26] Wang, Xiaoyan, Xiaofeng Wang, Qingping Wang, Zhengang Wang, and Xinguang Cai. 2004. Loss of Non-point Source Pollutants from Shixia Small Watershed, Miyun Reservoir, Beijing. Scientia Geographica Sinica. 24(2): 227-231.

[27] Efficiencies are based on research from Beijing Forestry University (BFU) for 10m buffers in the Miyun watershed. Removal efficiencies should be independently verified to confirm anticipated reductions. Quantification methods for BFU research can be found at: Song, S. 2012. Research on water purification effect and optimizing allocation technology of riparian buffer strips. M.S. Thesis, Beijing Forestry University.

[28] Cost provided by IUCN, 2015.

[29] Riparian buffer unit area cost is based on estimate provided by IUCN for a one-time investment of RMB ¥175/m; assuming a 100 m buffer length, 20-yr life span and 4% interest rate, the unit area cost comes at RMB ¥1,288/yr or $202.78/yr (1 US$ = RMB ¥6.35; October 2015).