Watershed Conservation Screening Tool: Methodology

This document is a short summary of the methodology that was used to create the values displayed by the Watershed Conservation Screening Tool. In general, the methodology is similar to that used in the Urban Water Blueprint, and the entire report is worth reading for context about how source watershed conservation can help maintain water quality.

Note however that a few methodological details have changed from the Urban Water Blueprint, most notably the calculation of sediment and nutrient deliver ratios, as well as the definition of contributing upstream areas. For this reason, results are not directly comparable between the Urban Water Blueprint and the Watershed Conservation Screening Tool, although in practice the two estimates are highly correlated for most watersheds.

Key caveats for the use of the Screening Tool

What it does: This tool will quickly measure the potential for five common watershed conservation activities to reduce sediment and nutrient pollution in a source watershed.

Values returned: This tool will describe for each source watershed its land cover and estimate its pollutant loading. It will also return for each watershed the amount of conservation effort (in area or cost) needed to achieve a 1%, 5%, 10%, and 20% reduction in pollution.

Surface water only: This tool is intended for bulk surface water users that know the location of their water intakes. Groundwater sustainability is not analyzed.

Non-point source pollution only: This tool focuses on how watershed conservation activity can reduce sediment and nutrient pollution from non-point sources. Watersheds that have significant sources of pollution from point sources may not find the results returned meaningful.

Municipal water users: Water users that draw water from a municipal supply must know where that municipal water supply comes from. Users can look up this information for some large cities in the Urban Water Blueprint. If your city isn't listed there, but you know where you city gets its water from, then you can should enter that information yourself.

Inter-basin transfers: If a larger inter-basin transfer of water into your watershed occurs upstream of your water intake, you must input into the tool both the location of your intake and the location of where the transferred water comes from (the donor basin).

Defining contributing areas

The minimum mapping unit for our analysis was the HydroBASIN product (Lehner and Grill 2013). These are a set of polygon layers that describe watershed boundaries and sub-basin delineations. The smallest polygons are tens of km^2, but are nested hierarchically within other sub-basins and within the overall watershed boundary. When a user clicks on an intake point in the Tool, we first locate the smallest HydroBASIN polygon in which the point lies. Once the ID of this polygon is known, we can quickly and easily extract the boundaries of the overall contributing area upstream.

HydroBASINS are derived from a global high resolution (15 arc-second) hydrographic dataset HydroSHEDS (Lehner et al. 2008). The HydroSHEDS digital elevation model was created from NASA's Shuttle Radar Topographic Mission (SRTM) (Farr et al. 2007) and further processed to ensure correct hydrographic flow paths. Specifically, we used the HydroBASINS "Format 2" product, which has lakes (mostly following the Global Lands and Water Database (Lehner and Döll 2004)) incorporated into the HydroBASINS typology. This correction allows the watershed of the lake to be correctly calculated: If a user clicks to put an intake point on a lake, the upstream contributing watershed of the entire lake is calculated.

The HydroBASIN dataset, as well as some of the other datasets underlying our model, are limited in their distribution. If a user clicks outside of the area for which the Screening Tool can supply data (e.g., in the ocean, or in the high latitudes of Canada or Siberia), an error message will be returned.

We urge all users of the Screening Tool to check carefully the contributing areas upstream from their intake points. If these do not seem reasonable for a particular intake point, you can try clicking a nearby point (e.g., in the same lake or reservoir, but at a different point in the water body) and seeing what is contributing area is. If the boundaries of a contributing area do not seem reasonable, we urge users to use the results of the Screening Tool with caution.

The Screening Tool is designed to return information from medium to large sized source watersheds. If the source watershed of your intake point is small (less than ~ 100 km^2) the information that is returned by the Screening Tool will not be very meaningful.

Water quality

We focused our analysis of surface water quality on three types of pollutants often of concern to water utility managers: sediment, nitrogen (N), and phosphorus (P). While other types of pollutants are also quite important for water managers (e.g., fecal coliform contamination), these three are the pollutants that are most often targeted by the kinds of conservation activities considered in this report. In practice, estimate loadings of N and P are highly correlated, so in the Tool we only report values for P. Our results would look similar if we reported values for N.

Sediment model

Global sediment loading was estimated using a modified version of the Universal Soil Loss Equation:

$$Sediment_{Load} = RKLSCP$$

The R-factor is rainfall erosivity, and a global map of this factor for current climate was obtained from the website climatewizard.org. The K-factor is soil erodibility, which was estimated by converting the soil texture values found in the Harmonized World Soils Database to K values using the methodology of Roose (Roose 1996). The LS-factor is the slope-length, and it was estimated using the HydroSHEDS 15-arc second DEM using a methodology similar to that of the Sediment Retention Model of the Natural Capital Project (Tallis et al. 2013). The crop and practice (CP) factors relate to land cover and land use practices, and average values for different land use types were taken from the STEPL model and the Water Treatment Model. Our global land cover map was the GlobCover 2009 dataset, reclassified into six categories: Agricultural, Grassland/Ranchland, Forest, Barren, Urban, and Water/Other.

In the Screening Tool, we accounted for the surface attenuation of sediment transport, as well as the in-stream attenuation.

Surface attenuation: Our estimated sediment loading for source watershed loadings in the United States was compared with the SPARROW dataset (Preston et al. 2011), which is an empirically based estimate of loading calculated from thousands of direct stream measurements in the United States. This comparison was done at the smallest watersheds for which SPARROW data were available, in effect accounting for attenuation of sediment transport along the land surface as well as the short stream segments within the SPARROW watersheds. Correlations between our loading estimates and those in the SPARROW dataset were generally strong (R ~0.8). We calibrated our results to the SPARROW estimates using a log-log linear regression.

In-stream attenuation: SPARROW data was used to calculate average in-stream attenuation rates for sediment, per km of stream mile. This average value was then applied to all streams in our global hydrologic network, allowing us to estimate the fraction of sediment that made it between two points in the hydrologic network.

Nitrogen and phosphorus model

Nitrogen and phosphorus loading were estimated using an export coefficient approach, where each land cover type exports a certain amount of N and P from the pixel. For forest, barren, urban, and water/other, the export coefficient was constant, using average values for different land cover types taken from the STEPL model and the Water Treatment Model. For Agriculture and Grassland/Ranchland, we based N and P export on the global grids of the Global Fertilizer and Manure (GFD), Version 1, dataset. Agricultural land was assumed to have both manure and fertilizer applied at the rates specified by the GFD, while grassland/ranchland was assumed to have only manure applied at the rates specified by the GFD. The nutrient utilization efficiency (the fraction uptaken by plants or soil, and not exported) was estimated using continent level data in NUE taken from Bouwman et al. (2009).

As with sediment, in the Screening Tool, we accounted for the surface attenuation of nutrient transport, as well as the in-stream attenuation.

Surface attenuation: Our estimated nutrient loading for source watershed loadings in the United States was compared with the SPARROW dataset (Preston et al. 2011), which is an empirically based estimate of loading calculated from thousands of direct stream measurements in the United States. This comparison was done at the smallest watersheds for which SPARROW data were available, in effect accounting for attenuation of nutrient transport along the land surface as well as the short stream segments within the SPARROW watersheds. Correlations between our loading estimates and those in the SPARROW dataset were generally strong (R ~0.8). We calibrated our results to the SPARROW estimates using a log-log linear regression.

In-stream attenuation: SPARROW data was used to calculate average in-stream attenuation rates for phosphorus, per km of stream mile. This average value was then applied to all streams in our global hydrologic network, allowing us to estimate the fraction of phosphorus that made it between two points in the hydrologic network.

Water quality risk metrics

Our metrics of surface water quality risk are sediment and P loading, in tonnes (sediment) or kilograms (P).

For our analysis of the opportunity of source watershed conservation to reduce pollutants, we use information on changes in pollutant load in our calculation. Pollutant concentration, which is what most often has economic impacts on the Operations and Maintenance (O&M) costs of water treatment plants (WTPs), is of course load divided by river flow. Note that in this study we are considering how changes in pollutant loading in one watershed will affect water quality. Assuming the effect of the conservation activity on flow is negligible, the proportional change in pollutant loading is the same as the proportional change in concentration, because the flow terms cancel out:

$$\Delta Concentration = \frac{Load_{after}}{Flow} \div \frac{Load_{before}}{Flow}$$

Water quality opportunity metrics

We developed five water quality opportunity metrics, each of which represents a commonly used source watershed conservation activity.

	Strategy	Description
	Land Protection	Purchase of easements, land rental, conservation agreements, fencing and funding for park guards to maintain watershed service
	Reforestation	Restoration and planting of native trees, grasses, and shrubs in critical areas to reduce erosion and related sediment transport
	Riparian Restoration	River bank restoration and protection to reduce erosion and improve water quality
	Agricultural Best Practices	Implementation of cover crops, contour farming to prevent sediment and nutrient runoff
	Forest Fuel Reduction	Conducting controlled burns and/or mechanical treatment to reduce wildfire severity and related sediment and ash pollution

Each water quality opportunity metric had a similar structure. The average effectiveness of the practice at preventing sediment, nitrogen and phosphorus loading was quantified through a literature review. The literature also sheds light on where the practice can be effectively implemented. In a GIS system, we examined all GIS pixels where the practice could be implemented, quantifying the reduction in sediment, nitrogen and phosphorus from applying the practice on one hectare of land. Pollutant loading for a source watershed is just the sum of the individual loads from specific pixels.

Each source watershed contains multiple pixels, so there are multiple places where a practice could be performed. This can be seen as the opportunity curve for a watershed (Figure D-1). The median or average return on investment from a practice in a watershed may not be the most meaningful metric since conservation action will likely focus on sites where it will yield the greatest return. We calculated the amount of hectares that would need to be worked on to get to a 1%, 5%, 10%, and 20% percent reduction in the pollutant, assuming conservation action started at the pixels with the highest return.

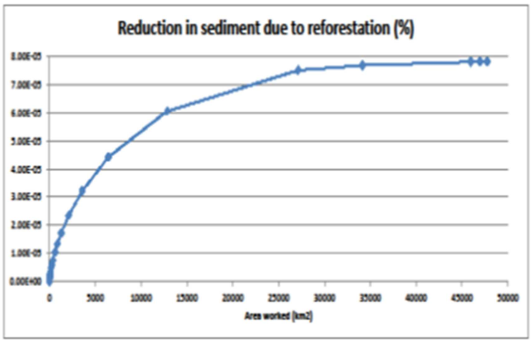

Figure D-1. Example curve of reduction in sediment load due to reforestation as a function of area worked.

Note that in some cases, it is not possible to get to a target percent reduction in a pollutant using a specific activity. For instance, if there is not much pastureland in a watershed where it is possible to do reforestation, then this conservation activity may be unable to reduce sediment load by 10 percent. We have marked these cases as “not possible” in the Screening Tool.

Note that forest protection and forest fuel reduction reduce a future risk of increased sediment or nutrient loading. For these two activities, we calculated the amount of land on which the activity would need to be conducted to reduce future pollutant loading by 10 percent, where future loading is defined as the current baseline pollutant load plus the expected future increase in loading.

We stress again that the Screening Tool only provides information on surface sources.

Table D-1. Effectiveness factors used in calculation of opportunity metrics.

Practice	Area where applicable	Percent reduction in sediment, nitrogen, and phosphorus	Citations

Pasture reforestation	Currently grassland/pasture pixels that are in natural forested area, as defined in WWF ecoregions	Sediment: Change in CP factor from grassland to forest. Nitrogen and phosphorus: Change in export from grassland to forest	See citations above for CP factors.
Agricultural BMPs	All agricultural pixels.	Sediment: 72 percent reduction Nitrogen: 61 percent reduction Phosphorus: 77 percent reduction	Based on average results for implementing cover crops (Kaspar et al. 2008).
Forest protection	Currently forest pixels that are in their natural area, as defined in WWF ecoregions	The expected increase in pollutant load, defined as the probability of habitat loss times the change in pollutant load if that occurs. Probability of natural habitat loss without action calculated as biome averages between GlobCover images. If that loss occurs, then changes calculated as follows: Sediment: Change in CP factor from natural land cover to agricultural or ranchland. Nitrogen and phosphorus: Change in export from natural land cover to agricultural or ranchland	See citations above for CP factors.

Forest fuel reduction	Current forest pixels that are in their natural area, as defined in WWF ecoregions.	The expected increase in pollutant load, defined as the probability of forest fire times the change in pollutant load if that occurs. Probability of forest fire calculated from Global Fire Emissions Database, version 4. Forest thinning reduces probability of a severe fire by 70 percent, based on review paper. If fire occurs, then changes calculated as the change in CP factor from natural land cover to barren.	Fuel management effectiveness average based on Martinson and Omi (Martinson and Omi 2013)
Riparian restoration	Agriculture pixels along riparian corridors, as defined with the HydroSHEDS DEM.	Buffers are assumed to be 10 meters on either side of a stream or river. The upland contributing area of a given stream segment is assumed to be one 15-arc second cell. Sediment: 86 percent reduction Phosphorus: 71.9 percent reduction	Based on average results for implementing 10 meter buffer (Zhang et al. 2010).

Comparing costs to water quality

The Screening Tool comes preloaded with estimates of annual costs of doing each conservation activity using broad, region-specific averages (see Table D-2). Users can alter this value with per-hectare costs of doing conservation that are appropriate for their intake. Note that each intake can have different per-hectare costs, if users wish to enter them differently.

Table D-2. Capital costs of conservation action assumed in our analysis, based upon a literature review. In addition to the capital costs below, in the Screening Tool we assume that maintenance and administrative costs were equal to the annualized project capital costs. In the Screening Tool, all costs are expressed as annual costs (i.e., annualized capital costs, assuming a 5% bond over 30 years, plus annual maintenance and administrative costs).

Location	Reforestation (one-time $/ha)	Riparian restoration (one-time $/ha)	Ag. BMPs (annual payment $/ha)	Forest Thinning (one time $/ha)	Forest Protection (one time $/ha)
North America	$3,700.00	$6,700.00	$188.00	$2,160.00	$2,914.00
Europe	$3,700.00	$6,700.00	$188.00	$2,160.00	$1,682.00
Oceania	$3,700.00	$6,700.00	$188.00	$2,160.00	$2,875.00
South/Latin America	$2,148.00	$1,095.00	$101.00	$2,160.00	$2,355.00
Africa	$800.00	$643.00	$101.00	$2,160.00	$300.00
Asia	$750.00	$643.00	$101.00	$2,160.00	$417.00

Bibliography

Bouwman, A. F., A. Beusen, and G. Billen. 2009. Human alteration of the global nitrogen and phosphoru soil balances for the period 1970-2050. Global Biogeochemical Cycles **23**:doi:10.1029/2009GB003576.

Farr, T. G., P. A. Rosen, E. Caro, R. Crippen, R. Duren, S. Hensley, M. Kobrick, M. Paller, E. Rodriguez, L. Roth, D. Seal, S. Shaffer, J. Shimada, J. Umland, M. Werner, M. Oskin, D. Burbank, and D. Alsdorf. 2007. The shuttle radar topography mission. Reviews of Geophysics **45**.

Kaspar, T., E. Kladivko, J. Singer, S. Morse, and D. Mutch. 2008. Potential and limitations of cover crops, living mulches, and perennials to reduce nutrient losses to water sources from agricultural fields in the Upper Mississippi River Basin. Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop. ASABE, St. Joseph, Michigan.

Lehner, B. and P. Döll. 2004. Development and validation of a global database of lakes, reservoirs and wetlands. Journal of Hydrology **296**:1-22.

Lehner, B. and G. Grill. 2013. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes **27**:2171-2186.

Lehner, B., K. Verdin, and A. Jarvis. 2008. New global hydrography derived from spaceborne elevation data. Eos, Transactions of the American Geophysical Union **89**:93-94.

Martinson, E. and P. Omi. 2013. Fuel treatments and fire severity: A meta-analysis. USDA, Rocky Mountain Research Station.

McGiveney, W. and S. Kawamura. 2008. Cost estimating manual for water treatment facilities. Wiley, Hoboken, NJ.

Preston, S. D., R. Alexander, and D. Wolock. 2011. Sparrow modeling to understand water-quality conditions in major regions of the United States: A featured collection introduction. Journal of the American Water Resources Association **47**:887-890.

Roose, E. 1996. Land Husbandry- Components and strategy. Food and Agriculture Organization of the UN, Rome, Italy.

Tallis, H. T., T. Ricketts, A. D. Guerry, S. A. Wood, R. Sharp, E. Nelson, D. Ennaanay, S. Wolny, N. Olwero, K. Vigerstol, D. Pennington, G. Mendoza, J. Aukema, J. Foster, J. Forrest, D. Cameron, K. Arkema, E. Lonsdorf, C. Kennedy, G. Verutes, C. K. Kim, G. Guannel, M. Papenfus, J. Toft, M. Marsik, J. Bernhardt, R. Griffin, K. Glowinski, N. Chaumont, A. Perelman, and M. Lacayo. 2013. InVEST 2.5.6 User's Guide. The Natural Capital Project, Stanford, CA.

Zhang, X., X. Liu, M. Zhang, R. Dahlgren, and M. Eitzel. 2010. A Review of Vegetated Buffers and a Meta-Analysis of Their Mitigation Efficacy in Reducing Nonpoint Source Pollution. Journal of Environmental Quality **39**:76-84.