Benefits Explorer – Data and Methods

1 Global map of urban source watersheds

Data

There are four main data sources used to identify urban source watershed areas: hydrological data, global city data, surface water withdrawal locations for cities and HydroBASIN-derived modeling data.

Hydrological data comprises the flow direction, flow accumulation (i.e., watershed size) and discharge grids provided by the HydroSHEDS database at 15 arc-second (approx. 500 meters at the equator) pixel resolution (Lehner and Grill, 2013). All watershed boundaries were calculated from this data.

The second data source comprises the global city locations and population numbers taken from the Global Rural-Urban Mapping Project (GRUMP), obtained from the Center for International Earth Science Information Network (CIESIN, et al., 2011). The original vector data contains 67,935 points representing cities recorded with various attributes, including population estimates, valid as of the year 2000.

The third data source comprises the water intake locations for cities obtained from The Nature Conservancy's Urban Water Blueprint (UWB) project and its underpinning City Water Map (CWM) (McDonald, et al., 2014). This dataset originally contained 471 global cities with 1,505 unique intake locations.

The final data source comprises information on HydroBASIN-derived watersheds from source watershed protection models. The Watershed Conservation Screening Tool models non-atmospheric nonpoint sediment and nutrient (phosphorus) yields, and the potential for selected conservation practices to reduce these yields. This dataset includes more than 1 million watersheds with at least partial coverage across all continents (excluding Antarctica).

Importantly, these data sources focus only on potential surface water sources for cities. These data and related analyses do not consider implications of other water sources, most notably groundwater.

Methodology

City selection criteria

All cities of the world with a reported population of at least 100,000 people in the GRUMP database were used. Additionally, we used all CWM cities with surface water intakes and their intake locations.

City Water Map cities

The database of the City Water Map (CWM) originally contained 471 cities with 1,505 intake locations. The point locations of CWM intake points represent manually assigned withdrawal points that were snapped to the HydroSHEDS river network. However, 12 locations did not have data on withdrawal points or city names and were thus removed, resulting in 1,493 unique withdrawal locations.

GRUMP cities

The global GRUMP data used in this project also contained the same cities and suburbs of the urban agglomerations included in the CWM. These duplicated cities were manually identified and removed in order to eliminate double-counting of cities. After applying the 100,000-population threshold and removing the duplicate cities, 3,724 cities remained.

For all GRUMP cities, the precise water intake location was not known. In order to estimate most likely locations, two criteria were postulated: 1) that cities generally draw water from the largest river nearby; and 2) that larger cities have more capacity and size to reach further out. In order to simulate these criteria, the GRUMP cities were separated into three groups based on population size and then snapped to the highest flow accumulation value (i.e., the largest watershed size as given in the HydroSHEDS database) within a size-dependent distance (see Table 1). The snapped points were then assumed to represent the water intake locations of the GRUMP cities.

Table 1. Snapping distances for the GRUMP city locations

Population	Snapping Distance (decimal degrees)
100,000 – 500,000	0.10 (~10 km)
500,000 – 1,000,000	0.15 (~15 km)
> 1,000,000	0.20 (~20 km)

Combined CWM and GRUMP intakes
The snapped GRUMP points (3,724) and UWB withdrawal points (1,493) were then combined to create the final combined layer of potential intakes, containing 5,217 points. If two points were located within the same pixel of the HydroSHEDS flow direction grid, the point with the higher identifier was shifted one pixel downstream.

Final watershed layer
Each intake point was then mapped to its enclosing level-12 HydroBASIN unit. For each of these HydroBASIN units, the Watershed Conservation Screening Tool has a corresponding polygon which includes all upstream HydroBASIN units. In this manner, each intake point is then associated with a corresponding polygon representing the entire upstream contributing area or watershed for that intake point. For all intake points, this HydroBASIN derived watershed differs in spatial extent from a watershed that might be derived using the precise intake point in conjunction with elevation data. These discrepancies are usually minor, but can be significant for smaller watersheds. Cities outside the spatial extent of the Screening Tool data set were excluded from subsequent analyses. The final watershed layer includes a total of 4,546 watersheds representing surface water sources for 4,138 cities.

References

Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI), the World Bank; and Centro Internacional de Agricultura Tropical (CIAT). (2011). Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Settlement Points. Socioeconomic Data and Applications Center (SEDAC), Columbia University, Palisades, New York. Available from http://sedac.ciesin.columbia.edu/data/dataset/grump-v1-settlement-points.

Lehner, B. and Grill, G. (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.

McDonald, R.I. (2016). EcoLogic--The Watershed Conservation Screening Tool: A Resource for Large Water Users. *Journal-American Water Works Association* **108**: 18-20.
McDonald, R.I., Weber, K., Padowski, J., et al., (2014). Water on an Urban Planet: Urbanization and the Reach of Urban Water Infrastructure. *Global Environmental Change* **27**: 96-105.

2 Climate Change Mitigation

2.1 Standing forest carbon

To visualize the distribution of pan-tropical, above-ground biomass stored in live woody vegetation, we summarized the total amount of above-ground carbon stored in all level-5 HydroBASINs that intersect with our urban source watersheds. The primary data used to quantify above-ground biomass comes from a high resolution product that expands upon the methodology presented in Baccini, et al., (2012) in order to generate a pan-tropical map of above-ground live woody biomass density at 30-meter resolution for the year 2000 (Baccini, et al., *in review*; Zarin, et al., 2016).

First, we calculated the total amount of above-ground biomass in live woody vegetation within the boundary of source watersheds that intersects with the tropical extent of the biomass data. We then converted the total estimate of above-ground biomass in our source watersheds into above-ground carbon using a conversion factor of 0.5 (IPCC, 2003), since about 50 percent of plant biomass consists of carbon.

References

Baccini, A., Goetz, S.J., Walker, W.S., et al., (2012). Estimated Carbon Dioxide Emissions from Tropical Deforestation Improved by Carbon-Density Maps. *Nature Climate Change* **2**: 182-185.
Baccini A., Walker, W., Carvahlo, L., Farina, M., Sulla-Menashe, D., and Houghton, R. (2015). Tropical Forests are a Net Carbon Source Based on New Measurements of Gain and Loss. In review. Accessed through *Global Forest Watch Climate: Summary of Methods and Data* on July 22nd, 2016. climate.globalforestwatch.org.
Intergovernmental Panel on Climate Change (IPCC). (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme, Hayama, Kanagawa, Japan. Available from http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf (accessed July 2016).

Zarin, D.J., Harris, N.L., Baccini, A., et al., (2016). Can Carbon Emissions from Tropical Deforestation Drop by 50% in 5 Years? *Global Change Biology* **22**: 1336-1347. doi: 10.1111/gcb.13153

2.2 Forest loss

We quantified the extent of forest loss in urban source watersheds using global-scale data from Hansen et al. (2013). We retrieved the global forest cover loss data from Google Earth Engine (GEE) and modified a Java-Script code by Tracewski et al. (2016) to conduct the analysis in GEE. We estimated tree cover in the year 2000 and tree cover loss between 2001 and 2014 with 30-meter cells from Landsat imagery. The original Hansen et al. (2013) data has been updated with years 2013 and 2014 on GEE using updated methodology.

For each level-5 HydroBASIN unit that intersects with the urban source watersheds, we analyzed tree cover from the year 2000 and then calculated the total area of forest loss each subsequent year based on the year of loss. These years were summed to provide total square kilometers lost between 2001 and 2014 within each HydroBASIN.

These calculations assume that all original tree cover (based on the tree cover in the year 2000) within the pixel was lost. If the pixel's tree cover value in the year 2000 was 70 percent, then it was assumed that 70 percent of the pixel area lost forest in the year of forest loss (Tracewski, et al., 2016). Each year of forest loss is mutually exclusive, meaning that forest loss can only occur in one pixel during one year.

In interpreting the results of this analysis, it is important to understand the definition of tree cover loss as it is defined by the algorithm used by Hansen et al. (2013) and that "loss" does not always equate to deforestation. Tree cover loss is identified by Hansen, et al., in such a way that it includes anthropogenic causes of forest loss, including timber harvesting and deforestation, as well as natural causes such as disease. The dataset also identifies forest loss from fires that can start from both natural and human sources. Our analysis does not report forest cover gain, even though forests across source watersheds do experience variable rates of tree cover gain.

References

Google Earth Engine Team. (2015). Google Earth Engine: A Planetary-Scale Geospatial Analysis Platform. https://earthengine.google.com

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., and Townshend, J.R.G. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **342**: 850–853. Data available online from: http://earthenginepartners.appspot.com/science-2013-global-forest.

Tracewski, Ł., Butchart, S.H., Donald, P.F., Evans, M., Fishpool, L.D., and Graeme, M. (2016). Patterns of Twenty-First Century Forest Loss Across a Global Network of Important Sites for Biodiversity. *Remote Sensing in Ecology and Conservation* **2**: 37-44. doi: 10.1002/rse2.13.

2.3 Reforestation potential

We used data derived from WRI's Atlas of Forest and Landscape Restoration Opportunities (WRI, 2014) to determine a reasonable estimate for the maximum area of reforestation opportunity per HydroBASIN intersecting the urban source watersheds. We applied two additional steps to extract only reforestation opportunities from WRI's data. First, we removed pixels located in grassland ecosystems using a spatially explicit dataset of global grassland types (Dixon, et al., 2014). Then, we removed pixels of data that would not transition from a non-forested status to a forested status (here we define the transition from less than 25 percent tree cover to greater than 25 percent tree cover) (WRI, 2014). Any of the reforestation and restoration opportunities that were not located within the boundaries of the urban source watersheds were removed from the analysis.

References

Dixon, A.P., Faber-Langendoen, D., Josse, C., Morrison, J., and Loucks, C.J. (2014). Distribution Mapping of World Grassland Types. *Journal of Biogeography* **41**: 2003-2019. Doi: 10.1111/jbi.12381

World Resources Institute (WRI). (2014). Atlas of Forest Landscape Restoration Opportunities. World Resources Institute, Washington, D.C., USA. Available from www.wri.org/forest-restoration-atlas.

3 Biodiversity

3.1 Freshwater Biodiversity Threat Index

We used data from Vörösmarty et al. (2010) to examine levels of threat to freshwater biodiversity across the urban source watersheds. Vörösmarty et al. (2010) developed an incident index of freshwater biodiversity threat by combing various themes of impact, including catchment disturbance, pollution, water resource development and biotic factors. The incident values for the index of freshwater biodiversity threat are standardized and normalized between values 0 and 1. We summarized the HydroBASINs within our source watersheds by the average biodiversity threat value. Vörösmarty et al. (2010) removed pixel values from the original data if they did not meet a minimum threshold of average annual runoff. If 20 percent of the HydroBASIN's area had insufficient data due to the minimum threshold of average annual runoff, we did not calculate the average index value of threat.

Reference

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., and Davies, P.M. (2010). Global Threats to Human Water Security and River Biodiversity. *Nature* **467**: 555-561. doi:10.1038/nature09440

3.2 Imperiled terrestrial species

We quantified the number of imperiled terrestrial species that could benefit from source water protection activities within each HydroBASIN that intersects with the urban source watersheds. We incorporated birds, amphibians and terrestrial mammals into our analysis of terrestrial species. We used the spatial database for the IUCN Red List of Threatened Species to quantify the number of imperiled species that occur within urban source watersheds (BirdLife International and NatureServe 2015; IUCN, 2016). Species were selected for the analysis if they had an IUCN code of critically endangered, endangered or vulnerable and if they are native or reintroduced and are extant to the region.

Additional criteria were applied to identify imperiled terrestrial species that could benefit from source water protection activities. We developed an approach that combined WRI's Atlas of Forest and Landscape Restoration Opportunities (WRI, 2014) with Oakleaf's (2016) Human Modification Index, with the intention of restricting the count of species to places within urban source watersheds where source water protection activities could more realistically support their survival. We classified places within the urban source watershed region that have high human modification (HMI values > 0.66) and that are not classified by WRI as reforestation or restoration opportunities as unsuitable habitat for source water protection activities to support their survival. We assume that source water protection activities only support terrestrial species at the actual site of activity implementation

We also applied a 10 percent overlap threshold. For an imperiled terrestrial species to get counted within the source watersheds, at least 10 percent of its range had to intersect with the suitable habitat mask. For migratory birds, the IUCN data includes migration distributions that are mapped across oceans. In the event that a bird migrates across the ocean, the 10-percent threshold only considered the species' terrestrial range.

References

BirdLife International and NatureServe. (2015). Bird Species Distribution Maps of the World. Version 5.0. BirdLife International, Cambridge, UK and NatureServe, Arlington, USA.

International Union for the Conservation of Nature (IUCN) 2016. The IUCN Red List of Threatened Species. Version 2016-2. http://www.iucnredlist.org. Downloaded on 01 July 2016.

Oakleaf, J.R. (2016). Human Modification Index. Unpublished data. Retrieved from Jim Oakleaf, The Nature Conservancy (accessed July 2016).

World Resources Institute (WRI). (2014). Atlas of Forest Landscape Restoration Opportunities. World Resources Institute, Washington, D.C., USA. Available from www.wri.org/forest-restoration-atlas.

4 Human Health & Well Being

4.1 Impact of pollination loss on crop and vitamin A production and the agricultural opportunity cost

To characterize the impact of pollination services on agricultural value and micronutrient production, we used spatially explicit estimates of crop yield, hectares cultivated and country-specific prices. We used datasets on hectares in cultivation from Ramankutty et al. (2008) and crop yield from Monfreda et al. (2008). These datasets combined three sources of remotely-sensed land-cover data with a wide array of country- or county-specific agricultural census information to identify production and yield of 175 different crops for each 10-by-10 kilometer grid cell globally for the year 2000.

We combined the production and yield data with price information from the Food and Agricultural Organization of the United Nations (FAO, 2016), multiplying the yield of each of the 175 crops by crop-specific prices for each of 250 national administrative units, measured in 2013 US dollars. When price information for 2013 was not available, we used the average price from all prior years that had price information for that crop in that country (inflation adjusted to 2013), or, failing that, the world average price for the crop.

Lack of pollinator habitat has a detrimental effect on the yield of pollination-dependent crops. We used data from Klein et al. (2007) to specify the proportion of yield that would be lost (calculated in dry-weight tons, at the farm gate) if pollination services were not available to agricultural production on each grid cell. The effect of pollination services on yield exhibits spatially heterogeneous effects with very localized impacts. As a result, we did not identify the relationship between specific source water protection activities and agricultural yield loss (the marginal value of protection), instead we characterized the total effect that pollination services offer. We summarized agricultural production with two scenarios: 1) a “baseline scenario” based on observed yields; and 2) a “reduced-pollination scenario” where crop yield was reduced by the respective pollination dependence.

To translate yield losses in these scenarios into nutritional effects, we followed the methodology of Chaplin-Kramer, et al., (2014) to assign nutritional content information from the United States Department of Agriculture (2015) to each crop. We calculated the production of vitamin A under the baseline and reduced-pollination scenarios. We reported the average proportion of nutrient production that was lost for each source watershed.

To estimate the total agricultural economic value lost in the absence of pollination services, which we use as a proxy for the opportunity cost, we combined the high-resolution data (10-kilometer resolution) on crop production for 175 different crops (Monfred, et al., 2008) with 2014 price information from the FAO for each crop. The prices used were specific to each FAO country to account for spatial heterogeneity of prices available. The total agricultural value in each grid cell of data is defined by the following equation:

$$\pi(h_{xy}) = \sum_{j=1}^{J} \sum_{i=1}^{I} p_{ij} * y_{i,xy} \tag{1}$$

where p_{ij} is the crop- and country-specific price and $y_{i,xy}$ is the yield in dry-weight metric tons produced of crop i in the xy^{th} grid cell. If 2014 prices were not available for a country or crop, we used the average price from 2000 to 2013. If prices were not available at all for this time period, we used the continent average price.

References

Chaplin-Kramer R., Dombeck E., Gerber J., Knuth K.A., Mueller N.D., Mueller M., Ziv G., Klein A.-M. (2014). Global Malnutrition Overlaps with Pollinator-Dependent Micronutrient Production. *Proceedings of the Royal Society B Biological Sciences* **281**: p.20141799. doi: 10.1098/rspb.2014.1799

EarthStat. Cropland and Pasture Area in 2000. *EarthStat.org*, Global Landscapes Initiative, University of Minnesota and Ramankutty Lab, The University of British Columbia, Vancouver. Data available online from http://www.earthstat.org/data-download/

EarthStat. Harvested Area and Yield for 175 Crops. *EarthStat.org*, Global Landscapes Initiative, University of Minnesota and Ramankutty Lab, The University of British Columbia, Vancouver. Data available online from http://www.earthstat.org/data-download/

Food and Agriculture Organization of the United Nations (FAO). FAOSTAT. Available from http://faostat3.fao.org/home/E

Food and Agriculture Organization of the United Nations (FAO). FAO/INFOODS Food Composition Databases. Available from http://www.fao.org/infoods/infoods/tables-and-databases/faoinfoods-databases/en/

Klein, A.M., Vaissiere, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., and Tscharntke, T. (2007). Importance of Pollinators in Changing Landscapes for World Crops. *Proceedings of the Royal Society B Biological Sciences* **274**:303-313. doi: 10.1098/rspb.2006.3721

Monfreda, C., Ramankutty, N., and Foley, J.A. (2008). Farming the Planet: 2. Geographic Distribution of Crop Areas, Yields, Physiological Types, and Net Primary Production in the Year 2000. *Global Biogeochemical Cycles* **22**. doi: 10.1029/2007GB002947

Ramankutty, N., Evan, A.T., Monfreda, C. and Foley, J.A., 2008. Farming the Planet: 1. Geographic Distribution of Global Agricultural Lands in the Year 2000. *Global Biogeochemical Cycles* **22.** doi:10.1029/2007GB002952

USDA Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference (Release 28, released September 2015, slightly revised May 2016). Available from http://ndb.nal.usda.gov/ (accessed July 2016).

World Health Organization (WHO). (2009). Global Prevalence of Vitamin A Deficiency in Populations at Risk 1995–2005. WHO Global Database on Vitamin A Deficiency. WHO, Geneva, Switzerland.

4.2 Total annual excess nitrogen application

To estimate the total global excess nitrogen loads from source watersheds we use Global Nitrogen Balance dataset from West, et al., (2014) at a five-minute arc grid (~10 square kilometers) resolution. We summed pixel-level nitrogen balance values for each of the level-5 HydroBASIN units intersecting source watersheds. Polygons with positive nitrogen balances were summed to estimate total global potential excess nitrogen loading into adjacent waterbodies (~38 megatonnes). HydroBASINs with N-deficits or balanced N-budgets were not included in this global estimation.

The Global Nitrogen Balance dataset is derived from varying administrative unit detail (e.g. regional, state, country levels). In generally, estimates in this dataset are more accurate in areas with high quality census data, and less in less-developed regions. The confidence level also varies by the area of aggregation.

References

EarthStat. Total Fertilizer Balance for 140 Crops. EarthStat.org, Global Landscapes Initiative, University of Minnesota and Ramankutty Lab, The University of British Columbia, Vancouver. Data available online from http://www.earthstat.org/data-download/

West, P.C., Gerber, J.S., Engstrom, P.M., Mueller, N.D., Brauman, K.A., Carlson, K.M., Cassidy, E.S., Johnston, M., MacDonald, G.K., Ray, D.K., and Siebert, S. (2014). Leverage Points for Improving Global Food Security and the Environment. *Science* **345**: 325-328. doi: 10.1126/science.1246067