

Water Quality Decision Support Application Enhanced Geographic Information System (GIS) Water Quality Data Products

Introduction

The total phosphorus (TP), total nitrogen (TN) and sediment annual yields (mass / area / year) leaving the landscape and the amounts delivered downstream within the Water Quality Decision Support Application (WQDSA) (<http://www.rrbdin.org/wqdsa-welcome>) were developed using 3 m to 5 m raster¹ derived from a hydro conditioned digital elevation model (DEM). The hydro conditioned DEM was developed based on Houston Engineering, Inc. guidelines category B (Appendix A). Yields for sediment are estimated based on the implementation of the Revised Universal Soil Loss Equation (RUSLE) for the raster. Yields for TP and TN are based on land use dependent export coefficients using literature values (see Table 1 & 2). The mass leaving each cell comprising the raster is “routed” downstream to: 1) the catchment outlet / pour point (generally a drainage area no larger than 130 acres in size), the subwatershed outlet / pour point (a set of subwatershed outlets input by the user) and the watershed outlet / pour point, using a first order decay computed as a function of overland flow travel time for the runoff resulting from a 10-year, 24 hr precipitation event (other precipitation events can be used). The decay or loss of mass after leaving the landscape is used to represent the reduction in mass from physical, chemical and biological processes. A travel time raster is pre-computed for use in estimating the first order loss coefficient. The calculation methods for each water quality constituent can be subdivided into three parts’ i.e., (1) a source loading, (2) transport to the channel, and (3) an in-channel routing routine.

Sediment

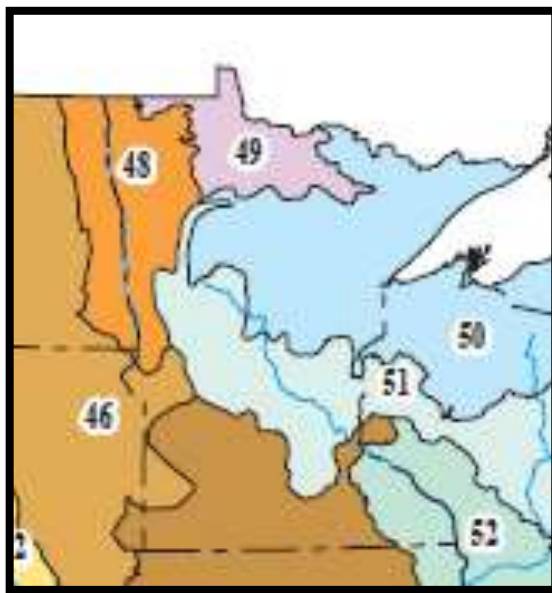
Annual sediment yield leaving the landscape is estimated using the RUSLE equation applied to each cell in the raster. The user has the ability to adjust the yield using a calibration factor when creating the data. Generally, the calibration factor has been used to adjust the sediment yield data at a pour point location based on monitoring data or information from the scientific literature. For example, the calibration factor can be used to adjust the watershed pour point sediment yields to ecoregion values developed by Klimetz and Simon (2009) for the Red River Basin (ecoregion 48 – see **Table 1** and **Figure 1**). The use of these data requires some assumption be made to adjust the data from Klimetz and Simon for the sediment washload and in-channel proportions.

¹ This same method can be applied to any size raster, provided the hydro conditioned DEM is complete. This includes NHDPlus products.

Table 1. Estimated annual sediment yields from the work of Klimetz and Simon (2009).

Ecoregion	46	47	48	50	51
All sites					
10th Percentile	0.00164	0.144	0.0261	0.0106	0.0155
25th Percentile	0.00357	0.359	0.0529	0.0211	0.037
50th Percentile	0.00831	1.57	0.085	0.0505	0.0714
75th Percentile	0.202	34.1	0.213	0.194	0.169
90th Percentile	0.572	102	0.306	1.8	0.598
Stable Sites					
10th Percentile	0.00124	0.0911	0.02539	0.0111	0.0125
25th Percentile	0.00233	0.178	0.0335	0.0203	0.0303
50th Percentile	0.00393	0.48	0.0602	0.035	0.0441
75th Percentile	0.00831	1.36	0.0837	0.0729	0.149
90th Percentile	0.131	3.28	0.086	0.143	1.06
Unstable sites					
10th Percentile	0.0021	0.317	0.0607	0.32	0.0873
25th Percentile	0.0142	1.42	0.0704	0.616	0.1
50th Percentile	0.0768	41.9	0.177	1.11	0.162
75th Percentile	0.304	95.4	0.288	3.43	0.224
90th Percentile	0.664	444	0.334	4.8	0.471

Figure 1. Level 3 Ecoregion Locations within Minnesota.



Once the sediment yield leaving the landscape is estimated for a cell, the sediment reaching a channel or flowline within a catchment is estimated using a sediment delivery ratio. The estimated sediment delivery ratio (SDR) for the catchment is a function of area (see Handbook of Hydrology, DATE).

$$\text{Overland SDR} = 0.41 * \text{catchment drainage area (sq. km)}^{-0.3}$$

The SDR for each cell within a catchment raster is estimated as a function of the catchment SDR adjusted by the distance from a cell to the flowline.

$$\text{Overland SDR Adjustment Factor} = 1 - \frac{\frac{\text{Flow Length}}{\text{Maximum Flow Length in Catchment}}}{0.75 + \frac{\text{Flow Length}}{\text{Maximum Flow Length in Catchment}}}$$

Therefore, the SDR for each cell is computed as Overland SDR (for the catchment) * Overland SDR Adjustment Factor (for the cell).

The sediment transported downstream from each cell to the subwatershed and watershed pour points is further reduced using a first-order transport function.

In-channel downstream transport and loss follows a simple exponential decay function (i.e., first order loss) using travel time and median diameter of sediment (Williams 1977):

$$SY = Y e^{-\beta T \sqrt{d_{50}}}$$

Where Y is sediment yield from sub-basin, β is transport coefficient, T is travel time, d_{50} is mean sediment diameter. The channel routing will occur between pour points. The user can insert known transport coefficients and median sediment diameters if available. Default values of 0.2 and 0.1 are used for β and the d_{50} , respectively.

Essentially, four products are produced for each cell in the raster: 1) sediment yield leaving the landscape; 2) sediment yield reaching the catchment pour point; 3) sediment yield delivered to a user defined downstream subwatershed pour point; and 4) sediment yield reaching the watershed pour point. Mass reaching the watershed pour point can be adjusted using the calibration factor to achieve the interquartile range yield (e.g., assuming 50% washload and 50% in channel process) for the ecoregion as computed by Klemetz and Simon (2009).

Nutrients (Total Phosphorus and Total Nitrogen)

Annual Yield

Nutrient annual yields leaving the landscape are estimated using a method similar to sediment (i.e., they are computed for each cell in the raster). However different methods are used to compute yield leaving the landscape and reaching the catchment pour point. TP and TN annual yields are estimated using the values in **Table 2** and **Table 3** applied to each National Land Cover Dataset (NLCD) land use class.

Table 2: Total Phosphorus Loading Lookup Table for NLCD Land Use Classification

NLCD #	Description	TP Loading [kg/ha/yr]	Source
11	Open Water	0	
21	Developed, Open Space	1	
22	Developed, Low Intensity	0.91	LimnoTech 2007
23	Developed, Medium Intensity	1.15	LimnoTech 2007
24	Developed, High Intensity	1.5	LimnoTech 2007
31	Barren Land	1.35	
41	Deciduous Forest	0.075	LimnoTech 2007
42	Evergreen Forest	0.075	LimnoTech 2007
43	Mixed Forest	0.075	LimnoTech 2007
52	Shrub/Scrub	0.075	LimnoTech 2007
71	Grassland/Herbaceous	0.17	LimnoTech 2007
81	Pasture/Hay	0.17	LimnoTech 2007
82	Cultivated Crops	0.38	LimnoTech 2007
90	Woody Wetlands	0	LimnoTech 2007
95	Emergent Herbaceous Wetlands	0	LimnoTech 2007

Table 3: Total Nitrogen Loading Lookup Table for NLCD Land Use Classification

NLCD #	Description	TN Loading [kg/ha/yr]	Source
11	Open Water	3.5	Atmos Dep
21	Developed, Open Space	3.5	Atmos Dep
22	Developed, Low Intensity	5.4	USEPA 1983
23	Developed, Medium Intensity	9.6	USEPA 1983
24	Developed, High Intensity	18.0	USEPA 1983
31	Barren Land	3.5	Atmos Dep
41	Deciduous Forest	2	USEPA 1999
42	Evergreen Forest	2	USEPA 1999
43	Mixed Forest	2	USEPA 1999
52	Shrub/Scrub	2	USEPA 1999
71	Grassland/Herbaceous	1.3	USDA MANAGE database
81	Pasture/Hay	2.4	USDA MANAGE database
82	Cultivated Crops	7.8	USDA MANAGE database
90	Woody Wetlands	3.5	Atmos Dep
95	Emergent Herbaceous Wetlands	3.5	Atmos Dep

The nutrient mass loss from the location of the cell to the flow line and as transported downstream is represented using a first order loss equation, as a function of travel time:

$$W = \exp(-kT)$$

where W is the portion of the yield leaving the landscape and delivered to the catchment pour point, k is the decay rate and T is travel time from one location to the next (e.g., cell to a catchment pour point). The default values for k are 0.1 for travel to the flowline and 0.4 for in-channel transport. The delivery raster (W_{raster}) is created using the travel time raster² to determine the portion of the mass leaving the landscape which reaches the catchment pour point. The portion of mass reaching downstream pour points is also computed using the above equation.

Default values are used when creating the nutrient yield (**Tables 1 and 2**) and when applying the decay functions to delivery rasters. However, the users can modify these including the data shown in **Table 1** and **Table 2**, when creating the products.

Post-Processing of the Data

A variety of products can be developed using the enhanced geographic information system water quality data products. For example, the cell values comprising a raster for a catchment or subwatershed can be summed, providing total yields at the catchment or subwatershed pour points. The yield data can be “ranked” to establish priority areas for implementing conservation practices.

References

- Frink, C. R. 1991. Estimating nutrient exports to estuaries. *Journal of Environmental Quality* 20: 717-724.
- Klimetz, L. and A. Simon. 2009. Characterization of “Reference” Suspended-Sediment Transport Rates for Level III Ecoregions of Minnesota. National Sedimentation Laboratory Technical Report 63.
- Maindment, David R. 1993. Handbook of Hydrology.
- U.S. Environmental Protection Agency. 1983. Final report of the Nationwide Urban Runoff Program. USEPA, Washington, DC.

² Time of travel computed generally following MnDNR Hydro Tools v1.0
(<ftp://lidar.dnr.state.mn.us/tools/.../Calculate%20Travel%20Time.docx>)

Appendix A
Standards for DEM Hydro Conditioning

Criteria		DEM Reconditioning and Data Product Scale						
		A	B	C	D	E	F	
1	Elevation Source Data	High Resolution Topographic Data (e.g., using LiDAR)						USGS National Elevation Dataset
2	Minimum drainage area threshold used for Quality Control	≤ 40 acres	≤ 160 acres	< 1 sq. mile	1 - 5 sq. miles	5 - 10 sq. miles	> 10 sq. miles	All Ranges
3	Maximum Digital Elevation Model and Raster Data Product	5 meter	5 meter	5 meter	5 meter	10 meter	30 meter	Any
4	Culvert Inventory	Available across entire watershed	Partial Coverage (E.G., MnDOT Structures, Topo Survey,	Not Required	Not Required	Not Required	Not Required	Not Applicable
5	Hydrologic Boundary and Vector Data Product	40 acres maximum	40 acres maximum	1 square mile maximum	1-5 square mile maximum	5-10 sq. mile maximum	> 10 square mile maximum	12-digit HUC
6	Source of Reconditioning Data	All reconditioning based on user interpretation of field-verified data (e.g. culvert inventory)	User interpretation using source elevation data, supplemented with field-verified data	User interpretation	User interpretation	User interpretation	User interpretation	Existing GIS dataset (NHD, MnDNR 24k Streams, etc...)
7	Intensity of Recondition	High <i>Several iterations by experienced hydrologist</i>	High <i>Several iterations by experienced hydrologist</i>	Moderately High <i>Several iterations by experienced hydrologist</i>	Moderately High <i>Several iterations by experienced hydrologist</i>	Moderate <i>Minimal iterations by experienced hydrologist</i>	Low <i>Minimal iterations by experienced hydrologist</i>	None
8	Local Stakeholder Involvement	Office/desktop review of watershed hydrography. Field review of questionable	Office/desktop review of watershed hydrography. Field review of questionable	Office/desktop review as necessary.	Office/desktop review as necessary.	Minimal. Typically not required.	None	None
9	Application	BMP Design Water Quality Overland Flow On-the-fly Watershed Delineation	BMP Design Water Quality Overland Flow On-the-fly Watershed Delineation	Water Quality Overland Flow On-the-fly Watershed Delineation Hydrographics	On-the-fly Watershed Delineation Hydrographics "Lumped" Parameter Modeling	Hydrographics "Lumped" Parameter Modeling	Hydrographics "Lumped" Parameter Modeling	NHD Plus