Appendix C Protocol 2 and 3 Supplemental Details

Revisions from the Test Drive are Highlighted in Blue for Panel Review

Protocol 2 – Credit for Instream and Riparian Nutrient Processing within the Hyporheic Zone during Base Flow and Protocol 3 – Credit for Floodplain Reconnection Volume- are presented in Section 5 and examples using the protocols are presented in Section 6. This Appendix provides supplemental details for the protocols and examples.

Protocol 2 Method Documentation

Protocol 2 relies heavily on in-situ denitrification studies in restored streams within the Baltimore Metropolitan area (Kaushal et al., 2008; Striz and Mayer, 2008). After communication with two of the principal researchers of these studies, Dr. Sujay Kaushal and Dr. Paul Mayer, the Panel assumed that credit from denitrification can be conservatively estimated as a result of increased hyporheic exchange between the floodplain and the stream channel.

Striz and Mayer (2008) and Kaushal et al. (2008) conducted a study in Minebank Run, an urban stream in Baltimore County, MD to evaluate if particular stream restoration techniques improve ground water- surface water interaction (GSI) and if beneficial hydrologic exchanges between the stream and riparian/floodplain areas may be enhanced to improve water quality. Minebank Run is a second order stream located within the Piedmont physiographic region of Maryland with a drainage area of 3.24 square miles of mostly suburban land cover (25% impervious cover). Stream restoration techniques for the 1,800 foot channel followed the Natural Channel Design methodology and included filling the channel (and relocating in places) with sediment, cobbles, and boulders and constructing point bars, riffles, and meander features along the reach and creating step-pool sequences. The restoration also included a riparian corridor landscaping plan.

Their results show that a simple model splitting the stream into two compartments at the thalweg was sufficient to quantify the GSI flow (Figure C-1 below) and that significant differences in mean denitrification rates between restored and unrestored reaches and rates were higher at low-bank, hydrologically connected sites than at high-bank sites. Denitrification rates were 77.4 ± 12.6 μg N/kg/day of soil at restored sites and 34.8 ± 8.0 μg *N*/kg/day of soil at unrestored sites. The hydrologically connected, low-bank restored sites consistently had significantly higher rates of denitrification than the other sites, with a mean in-situ denitrification of 132.4 μg *N*/kg/day of soil (2.65 x 10^{-4} pounds/ton/day of soil) (Table C-1). The Panel originally decided that this rate from low-bank restored sites was representative of the denitrification that will occur as a result of Protocol 2. To determine the additional denitrification that occurs in a restored reach versus an unrestored reach, the average rate at unrestored sites (34.8 ± 8.0 μg N/kg/day of soil) was subtracted from the low-bank restored site rate (132.4 μg *N*/kg/day of soil) and resulted in a denitrification rate of 97.6 μg *N*/kg/day of soil (1.95 x 10^{-4} pounds/ton/day of soil).

The six month test-drive results showed that the TN load reductions from Protocol 2 were high and in some cases exceeded the watershed loading rates. This could in part be due to confusion over qualifying conditions for this protocol (e.g., bank height ratio less than 1). Additional guidance is now provided in Appendix G. After discussion with Dr. Kaushal and Dr. Mayer who conducted the study in Minebank Run, they acknowledged that using the denitrification rates measured solely in the low-bank restored section could be biased because of the limited sample size. They agreed that using a denitrification rate based on both the high and low-bank restored sites would reduce the bias and would result in a more conservative lower rate. The Panel agreed that using an expanded data set that resulted in a more conservative denitrification rate made sense. The revised rate was calculated by subtracting the average rate of unrestored sites (34.8 ± 8.0 µg N/kg/day of soil) from the average rate of high and low-bank restored sites (83 µg *N*/kg/day of soil) to obtain a denitrification rate of 48.2 µg *N*/kg/day of soil (1.06 x 10^{-4} pounds/ton/day of soil).

To estimate the denitrification that would occur at a stream reach scale, Dr. Kaushal and Dr. Mayer, felt that a "hyporheic box" equal to the "restored" channel length multiplied times the width of the stream at median base flow depth plus 5 feet on each sided and a depth of 5 feet below the stream channel would be very conservative and follow similar dimensions to the example in Figure C-1.

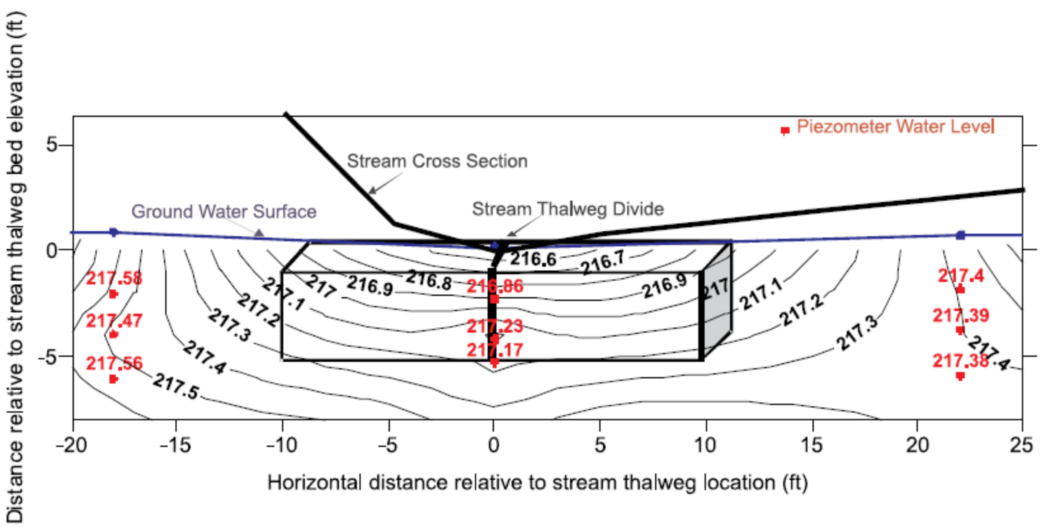

Figure C-1. Example vertical equipotential stream cross section with left bank and right bank compartments on either side of the stream thalweg divide from Striz and Mayer (2008).

Table C-1 Groundwater flow through a 1.5×1.5×1.5 m box adjacent to the restored reach of Minebank Run representing the riparian-zone-stream interface from Kaushal et al. (2008)

Date	Q (m^3/d)	Denitrification rate ($\mu g\ N \cdot kg^{-1} \cdot d^{-1}$)	Residence time (d)	Nitrate removal ($\mu g\ N/m^3$)
6 August	0.29	132.4	3.67	2806.5
2 September	0.55	132.4	1.91	1460.6
14 September	0.42	132.4	2.49	1904.1
21 September	0.42	132.4	2.49	1580.0
29 September	0.45	132.4	2.39	1516.6
5 October	0.41	132.4	2.60	1649.8
20 October	0.39	132.4	2.81	2202.7
17 November	0.37	132.4	2.98	2329.8

Note: The potential importance of estimates of mass removal of nitrate (in micrograms of N removed per cubic meter of groundwater flow) was investigated by coupling an average measurement of in situ denitrification rate during the study (in micrograms of N removed per kilogram of soil per day) on the south bank of transect 4 with a range of measurements of bank-to-stream groundwater flow during a three-month period in 2004 following denitrification measurements.

The mean bank height in the “restored connected” reach in Minebank Run was 77 cm compared to 114.7 cm in the “unconnected” reach. Reconnection was not necessarily defined as “floodplain” reconnection but connection between the stream channel and riparian zone to the groundwater interface or hyporheic zone. To define when “reconnection” would occur for qualifying for credit under this protocol, the Panel had proposed using a bank height ratio of 1.0 or less as the definition. The bank height ratio is an indicator of floodplain connectivity and is a common measurement taken by stream restoration professionals using the natural channel design method. It is defined as the lowest bank height of the channel cross section divided by the maximum bank full depth. Situations where the restored channel is connected to a floodplain wetland may also be eligible for additional credit under Protocol 3. Protocol 2 only provides a nitrogen removal credit; no credit is given for sediment or phosphorus removal.

The Minebank Run study also demonstrated the importance of “carbon” availability in denitrification, however the science determining how much is necessary is limited. Until more information becomes available, this protocol recommends that qualifying stream restoration projects include an extensive planting plan along the riparian corridor of the stream reach.

References

Kaushal, S., Groffman, P., Mayer, P., Striz, E., and A. Gold. 2008. Effects of stream restoration in an urbanizing watershed. *Ecological Applications* 18(3): 789-804.

Striz, E., and P. Mayer. 2008. Assessment of near-stream ground water-surface water interaction (GSI) of a degraded stream before restoration. U.S. Environmental Protection Agency Office of Research and Development. EPA 600/R-07/058.