# Appendix C Protocol 2 and 3 Supplemental Details

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 *mg N*/kg/day of soil at unrestored sites. The hydrologically connected, low-bank restored site consistently had significantly higher rates of denitrification than the other sites, with a mean in-situ denitrification of 132.4 *mg N*/kg/day of soil (2.65 x $10^{-4}$ pounds/ton/day of soil) (Table C-1). The Panel decided that this rate is representative of the denitrification that will occur as a result of Protocol 2.

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 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.

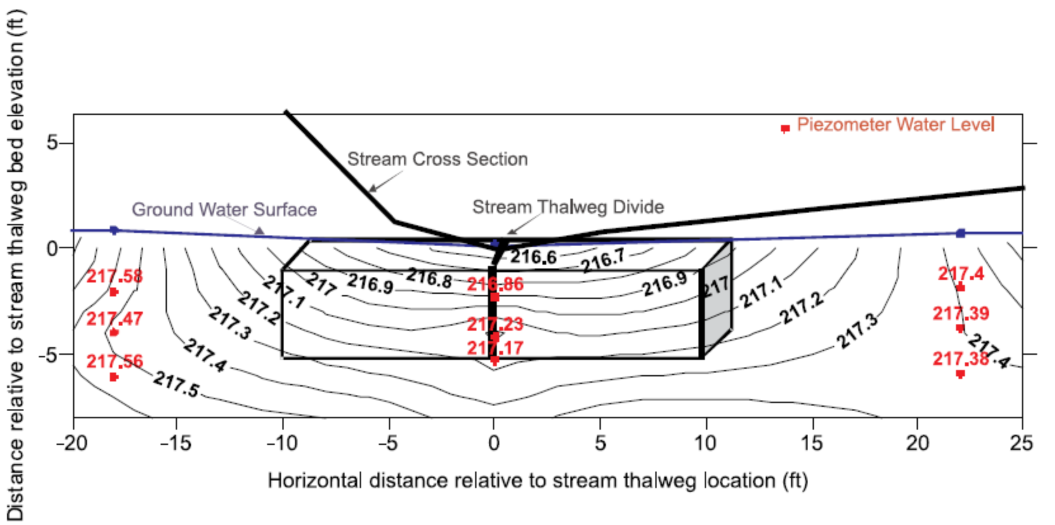


**Figure C-1. Example vertical equipotential stream cross section with left bank and right bank compartments on either side of the stream thalweg divide from Striz and Mayer (2008).**

**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·$kg^{-1}$·$d^{-1}$) | 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 steam 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. For projects that qualify for Protocol 3, credit for denitrification during base flow is given for designs where floodplain wetlands have been restored and groundwater-surface water interaction is occurring. Therefore Protocol 2 does not apply.

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.

*Protocol 3 Method Development and Spreadsheet Documentation*

This credit is given when stream channels are reconnected to the floodplain resulting in hydromodification, where the floodplain is able to provide some level of pollution reduction volume to storms equal to or less than the one year storm event.

This method assumes that sediment and nutrient removal occurs only for that volume of annual flow that is captured within the floodplain area. The floodplain area is assumed to be a riparian wetland with a maximum depth of 1.0 feet and a minimum wetland area to watershed area ratio of 1.0% to assure adequate hydraulic retention time. Partial credit is allowed for projects that cannot meet the minimum 1% ratio. For instance if a ratio of 0.75% would receive 75% of the credit that a project that meets the 1% minimum would receive.

The reduction credit for total nitrogen (20%), total phosphorus (30%) and total suspended solids 20% is taken from Jordan (2007) and reflects work that was approved through the Chesapeake Bay Program process. For projects that result in restored or enhanced floodplain wetlands with groundwater/surface water interaction, credit for baseflow nutrient removal is provided here instead of protocol 2.

These rates are lower than rates used in earlier versions of this draft that were based on stormwater treatment wetland efficiencies. Several panel members pointed out that riparian wetlands behave differently from stormwater treatment wetlands, which typically have much greater hydraulic detention times that allow for settling of particulates.

In developing this method, the following basic questions were asked:

A. How much runoff enters the floodplain?
B. How much of the floodplain (volume) can be considered wetlands?
C. How much of the runoff entering the floodplain receives effective treatment?
D. What is the nutrient removal efficiency of the floodplain wetlands?
E. What is the loading coming from the watershed?

The steps outlined in more detail below reflect the process for developing the curves used in the spreadsheet.

A. The spreadsheet determines how much of the annual runoff volume enters the floodplain for a range of storm classes. Rainfall records at National Airport were used in developing the graphs. Using a model like HEC-RAS, the designer would determine the flow depth over the floodplain. For instance, the depth might be 2 ft for a given discharge. The discharge is converted to a precipitation depth so that the rainfall frequency distributions at National Airport can be used. Figure C-2 below shows the runoff amounts entering a floodplain at two connection depths; one corresponding to a rainfall depth of 0.5 in. and the other 1.0 in.

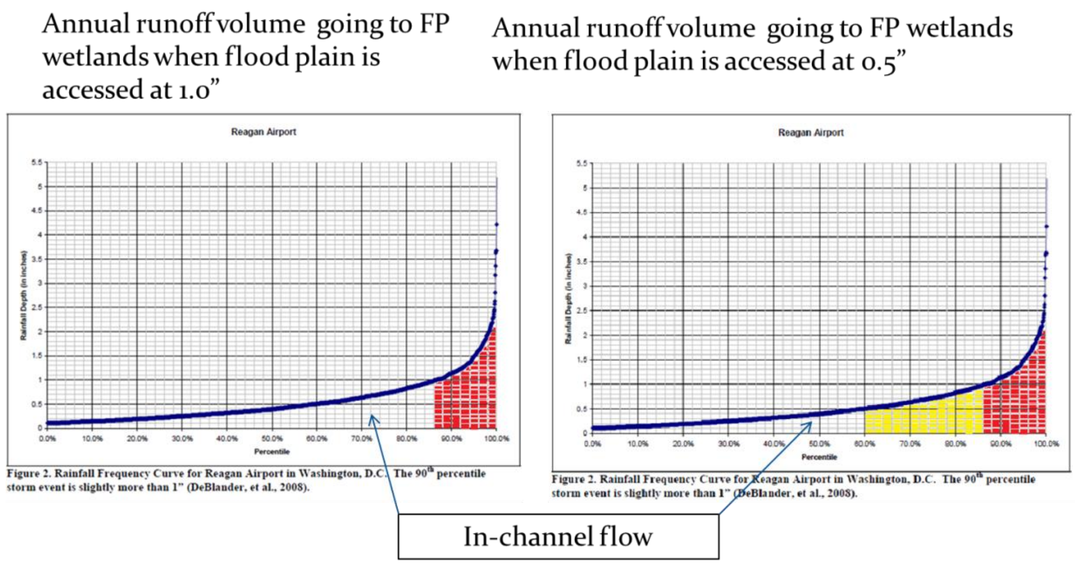


**Figure C-2. Runoff amount entering the floodplain a connection depths corresponding to a rainfall depth of 0.5 in. and 1.0 in. based on National Airport rainfall data.**

For instance, if reconnection occurred at 0.5 in. of rainfall (expressed as watershed inches) then only discharges resulting from storms exceeding this amount will enter the floodplain. All discharges (or rainfall depths) above this threshold discharge have the potential for being “treated” in the floodplain wetlands. Discharges below this amount are conveyed by the stream channel. The spreadsheet accounts for the frequency of events of 0.5 in. and greater that occur in a given year.

B. Figure C-3 shows the different floodplain storage volumes expressed in watershed inches (to make them dimensionless) along the x- axis. The average storage floodplain volume should be used for the full range of storms. The designer would typically develop floodplain storage volumes for different depths using site topography.

C. The curves on the graph in Figure C-3 represent the rainfall depths (rainfall is used instead of runoff to allow the use of the rainfall frequency distributions). In the example above, if floodplain reconnection occurs at a discharge equivalent to a rainfall depth of 0.5 in. (3rd curve) and there is floodplain storage of 0.25 in. (x-axis), then approximately 16% of the total annual runoff volume enters the floodplain (y-axis). The curves are developed for the discrete distribution of rainfall depths above those associated with the floodplain connection threshold (0.5, 0.75, 1.0...).

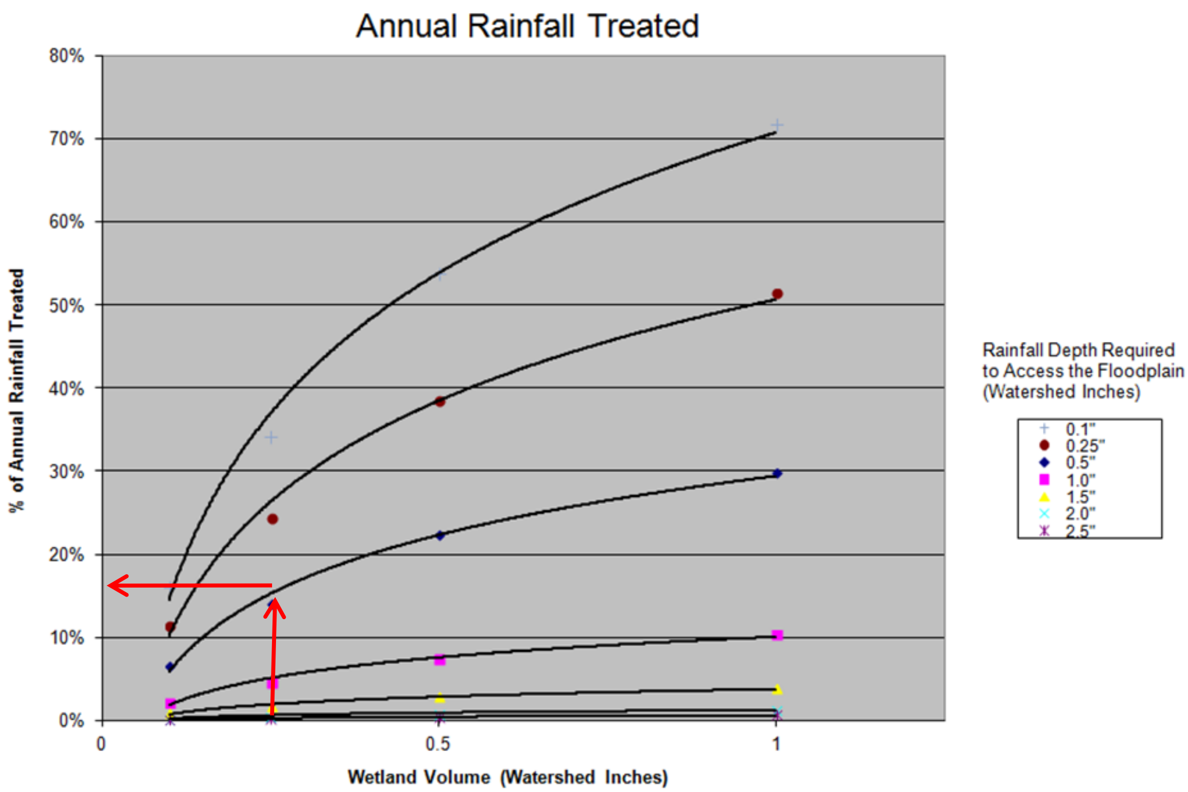


**Figure C-3. Annual runoff volume treated as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.**

D. Once the fraction of annual runoff treated is determined, the wetland efficiencies from Jordan (2007) are used to convert these values to the percent TN, TP and TSS reduction. These graphs are shown on the Nitrogen, Phosphorus, and Sediment tabs (Figure C-4 for TN) of the spreadsheet. The y-axis is the percent along the y-axis from Figure C-3 multiplied by the reduction efficiencies from Jordan (2007). In the example above, if 16% of the annual rainfall runoff volume is being treated by the floodplain wetland, and the wetland efficiency for TN is 20% then the annual removal rate is determined by multiplying 16% by 20% or 3.2%.

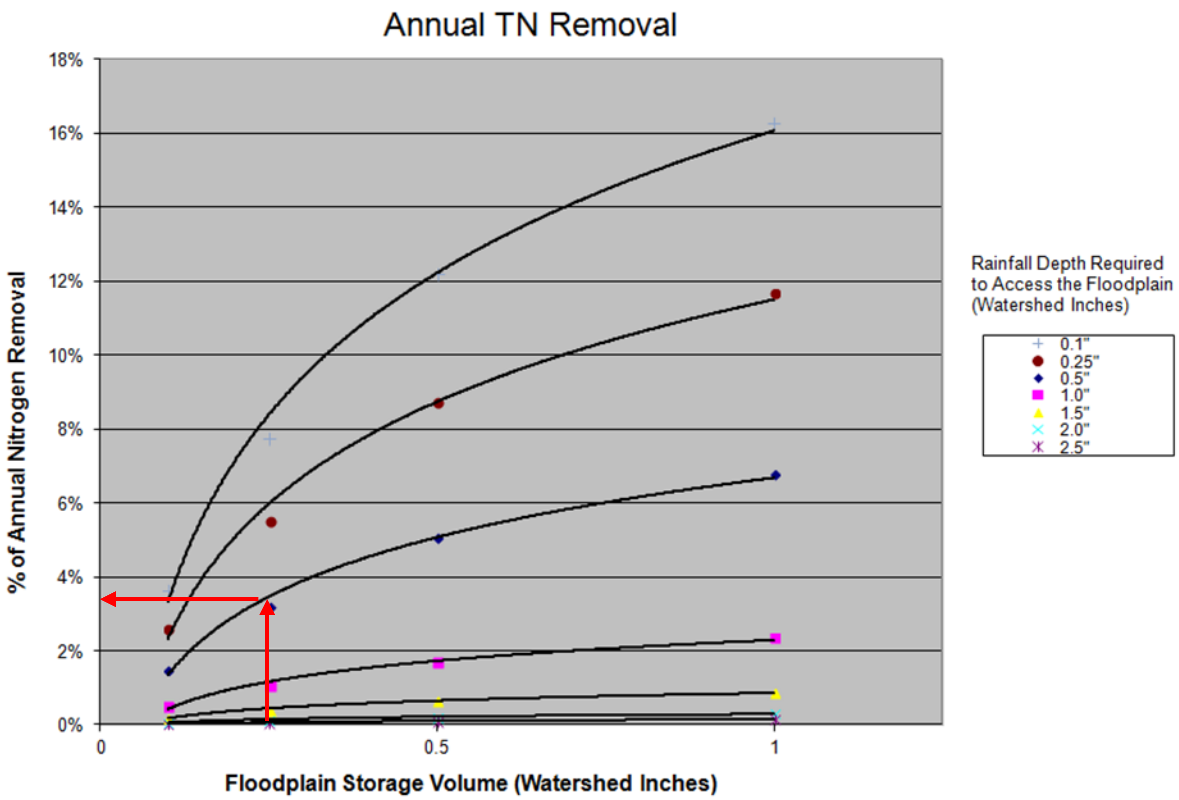


**Figure C-4. Annual TN removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.**

E. The next step is to multiply the watershed loading from the CBWM (Table C-1) by the reduction efficiencies from Figure C-4. The Panel decided that the loading rates for impervious land provided an estimation of the load delivered during storm flow. These unit loads are readily available from CBP tools such as CAST, MAST and VAST. BMPs installed within the drainage area to the project will reduce the delivered loads by serving as a treatment train. The Modeling Team will discuss the possibility of incorporating treatment train effects into the CBWM and CAST. If treatment train effects cannot be explicitly modeled in the CBWM and CAST, another option could be to first input all upland BMPs into CAST to determine the delivered loads to the stream restoration project and then use the resulting reduced loads for this step. For projects where groundwater/surface water interaction can be demonstrated through enhancements to the wetland, credit for base flow load reduction can added to the stormflow credit by multiplying the efficiencies in Figure C-4 times the entire annual loading rate from Table C-2.

F. The final step is to make any adjustments to account for if the wetland surface area to drainage area ratio is less than 1.0%. As described earlier, if the ratio was 0.75%, the credit would be 75% of the annual load reduction estimated in F.

| **Table C-2. Edge of Stream Unit Loading Rates for Bay States Using CBWM v. 5.3.2** | | | | | | |
|---|---|---|---|---|---|---|
| BAY STATE | Total Nitrogen | | Total Phosphorus | | Suspended Sediment | |
| | Pounds/acre/year | | | | Pounds/acre/year | |
| | IMPERV | PERV | IMPERV | PERV | IMPERV | PERV |
| DC | 13.2 | 6.9 | 1.53 | 0.28 | 1165 | 221 |
| DE | 12.4 | 8.7 | 1.09 | 0.25 | 360 | 42 |
| MD | 15.3 | 10.8 | 1.69 | 0.43 | 1116 | 175 |
| NY | 12.3 | 12.2 | 2.12 | 0.77 | 2182 | 294 |
| PA | 27.5 | 21.6 | 2.05 | 0.61 | 1816 | 251 |
| VA | 13.9 | 10.2 | 2.21 | 0.60 | 1175 | 178 |
| WV | 21.4 | 16.2 | 2.62 | 0.66 | 1892 | 265 |
| **Source:** Output provided by Chris Brosch, CBPO, 1/4/2012, "No Action" run (loading rates without BMPs), state-wide average loading rates, average of regulated and unregulated MS4 areas | | | | | | |

A detailed description of the spreadsheet analysis is described below.

1. Ordered the daily rainfall events for 30 years of data from least to greatest, and removed all events of 0.1" or less.
2. Summed the total rainfall volume.
3. Set floodplain depths (in watershed inches) of 0.5" – 2.5"
4. Set treatment volumes (in watershed inches) of 0.25" – 2.25"
5. Determine the value for each combination of floodplain depth and watershed inches by:
    a. Adding up all of the rainfall amounts between the floodplain depth and the floodplain depth + the treatment volume.
    b. Subtracting the floodplain depth from each event in the above sum.
    c. Adding the treatment depth for all rainfall amounts above the floodplain depth + the treatment volume.
    d. Dividing the total of a-c above by the total rainfall volume.
6. This value represents the percentage of the total rainfall treated by a given combination of floodplain depth and treatment volume.

The 88% in the stream restoration spreadsheet is based upon the assumption that the removal efficiency percentages we have for nitrogen and phosphorus are tied to the 1" storm. The 1" storm represents 88% of the rainfall volume in a given year (when all storms smaller than 1" and 1" per storm for all larger storms are summed). The removal efficiency percentages are therefore tied to the "benchmark" of 88%. To calculate the removal efficiency percentage for a given practice, the percent of annual rainfall volume captured is compared to 88%, and the resulting ratio is multiplied by the removal efficiency for the 1" storm. We did this for the previous version that used the wetland efficiencies based on stormwater wetlands. This is the approach that the Retrofit Panel used to adjust the retrofit efficiencies to account for removals at greater than the water quality treatment volume (1.0 inch).

An example:

A floodplain does not begin to fill until 0.5" of rainfall is reached, and has a 0.25" treatment volume. Given 374 storms between 0.5 and 0.75, 471 storms between 0.76 and 5.19 and 1125 storms in total:

a. Add up all of the rainfall amounts between 0.5" and 0.75" = 228.41"
b. Subtract 0.5" x 374 events = 187"; 228.41" – 187" = 41.41" *- 0.5 inch has to be subtracted because this amount never gets into the floodplain. The storage volume is only treating a fraction of these storms*
c. Add 0.25" for all rainfall amounts above 0.75" = 0.25" x 471 = 117.75": 41.41" + 117.75" = 159.16" - *treating the first .25 inches of storms greater than the bankfull*
d. Divide 159.16 by 1125.45" = 14.1% of total volume of runoff.

*Alternative Method for Protocol 3 from Panel Member, Dan Medina*

When detailed hydrologic and hydraulic data are available for the restored reach, the Protocol can be applied in a straightforward manner by following the steps below:

i. Calculate the volume of runoff that accesses the floodplain on an average annual basis
ii. Estimate the loads of nitrogen and phosphorus in that volume by multiplying the total pollutant load times the ratio of the floodplain runoff volume to the total runoff volume.
iii. Compute the nitrogen removal as 20% of the nitrogen load and the phosphorus removal as 30% of the phosphorus load.

Most of the complexity is in the first step but it is a straightforward calculationbecause hydrologic and hydraulic models are usually available as design tools. Below are two suggested procedures to accomplish this step, one for discrete storm modeling and another for continuous simulation.

<u>Discrete storm modeling</u>

1. Select a cross section representative of the restored reach
2. Using a hydraulic model such as HEC-RAS, compute the distribution of flows between the main channel and the "overbanks." This is a standard capability of all one-dimensional hydraulic models and results in plots similar to Figure C-5. The main channel is defined by suitable geomorphic indicators, for instance bankfull elevation, or geometric features when bankfull is not appropriate.

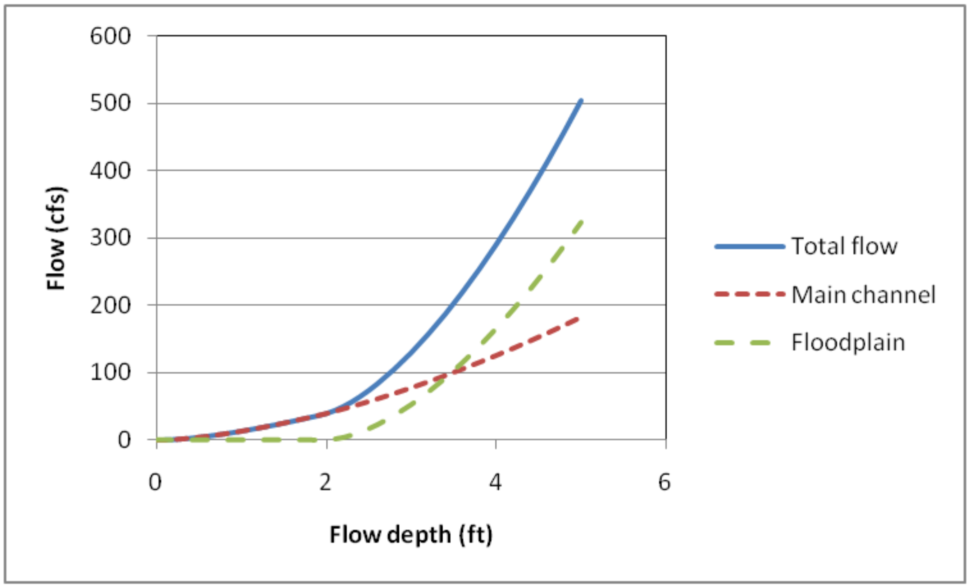


**Figure C-5.** Example flow distribution resulting from hydraulic modeling. This hypothetical example shows that the floodplain is accessed at a depth of two feet.

For application of Protocol 3, the tool needed is a plot of the floodplain flow as a function of the total flow as shown in Figure C-6. This relationship is a direct derivation from Figure C-5. For a given flow depth, the floodplain flow and total flow are plotted in Figure C-6.

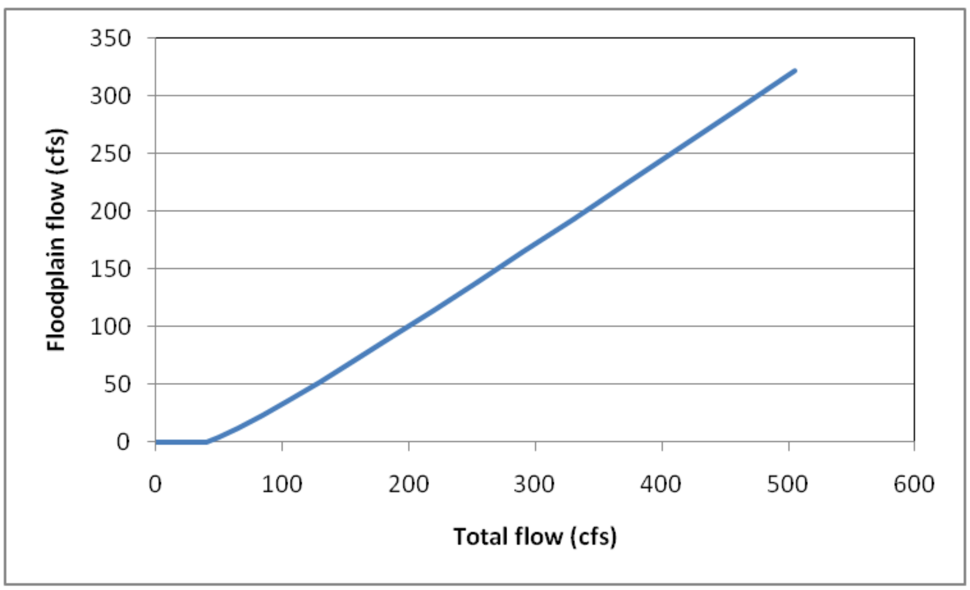


**Figure C-6.** Flow in the floodplain as a function of the total flow.

This relationship specifies how much of the discharge flows over the floodplain. For example, if the total flow is 200 cfs, about 100 cfs flow over the floodplain.

3. Run the hydrologic model for events of various return periods starting at the one-year flood.
4. Select the hydrograph corresponding to a given return period

5. Calculate the total runoff volume by computing the area under the hydrograph
6. Apply the relation in Figure C-6 to each ordinate of the total hydrograph and thus obtain the flow over the floodplains. If the flow depth over the floodplain is 1 ft or greater, then the flow for which credit is available is capped at the value corresponding to a depth of 1 ft over the floodplain. Figure C-7 shows a typical result.

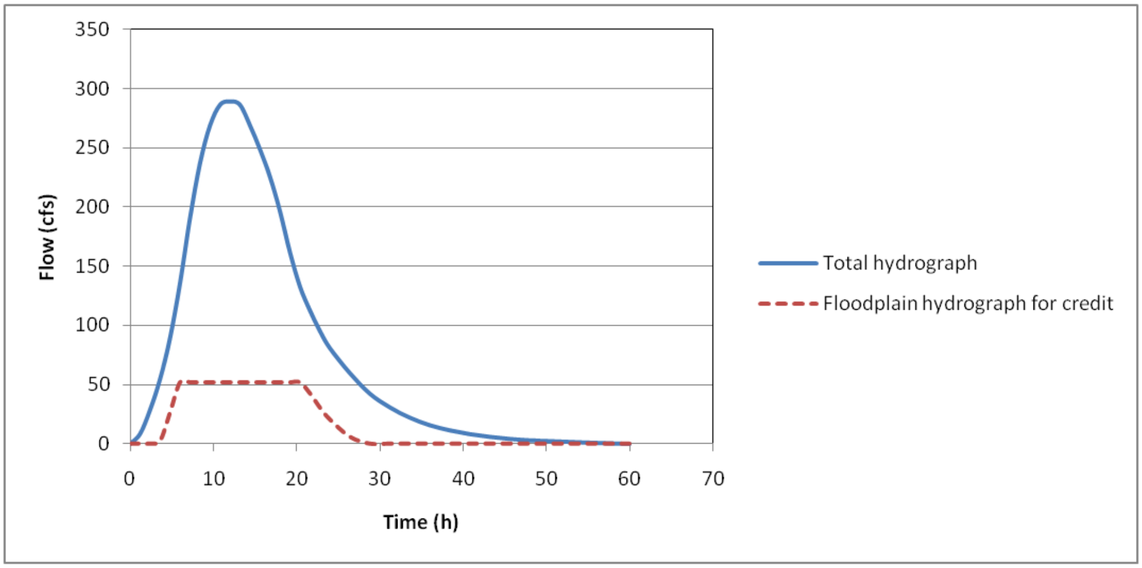


**Figure C-7.** Separation of the floodplain hydrograph. The horizontal portions at the beginning and end of the floodplain hydrograph indicate when the floodplain is not accessed. The horizontal portion in the middle indicates that the depth over the floodplain exceeds 1 ft and the maximum flow is set at the value corresponding to that depth.

7. Calculate the volume of runoff that flows through the floodplain by computing the area under the overbank hydrograph. For the example in Figure C-7, the total volume is about 383 ac-ft, whereas the floodplain volume is about 82 ac-ft.
8. Apply steps 4 through 7 for all other return periods
9. Construct a curve of the total runoff volumes versus their probabilities of exceedence, which are equal to the reciprocals of the return periods (e.g., the 5-year flood has a 1/5= 0.2 probability of being equaled or exceeded in any given year). The area under this curve is the average annual runoff volume
10. Construct another similar curve with the floodplain runoff volumes. The area under this curve is the average annual runoff volume that flows over the floodplains. The two curves are shown in Figure C-8.

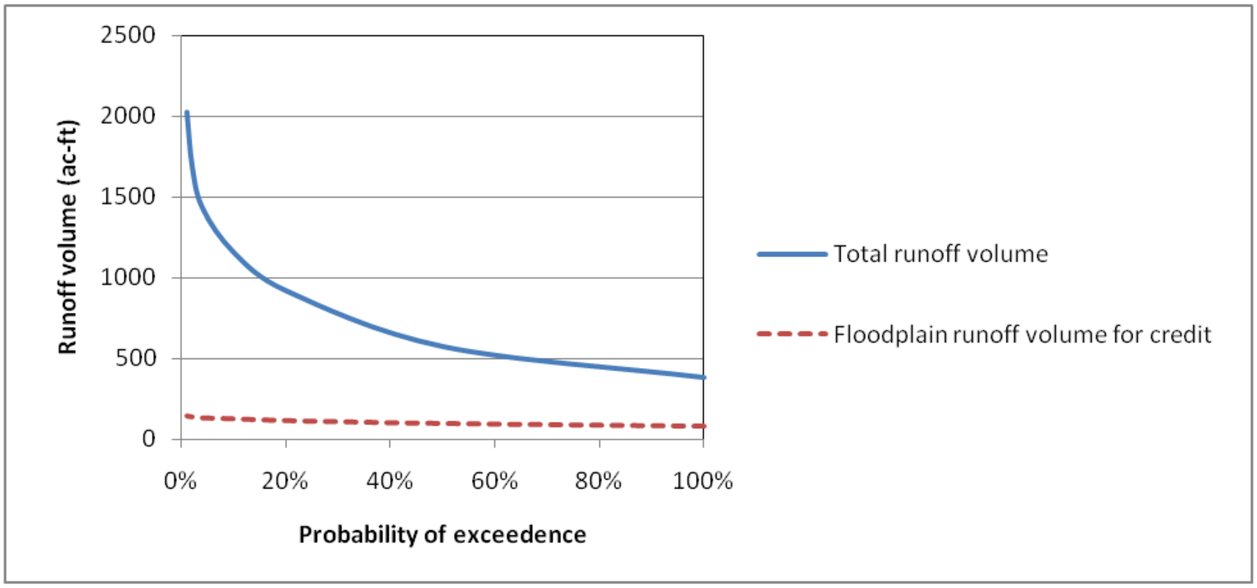


**Figure C-8.** Probability distribution of the total runoff volume and that flowing over the floodplain.

In this example, the average annual total runoff volume (the area under the solid curve) is 695 ac-ft, whereas the average annual runoff volume flowing over the floodplain is about 103 ac-ft.

11. The ratio of the floodplain runoff volume to the total volume is the fraction of the total runoff that comes in contact with the floodplain. For the example in Figure C-8, this ratio is 15%, which is the factor that will multiply the total pollutant loads coming from the entire watershed.

The loads from the watershed are determined from the CBWM. These loads must be modified to include the effect of upstream BMPs, which has two components: the load reduced by the treatment that takes place in the BMP, and the untreated load from the portions of large storms that bypass the BMP. Once the BMP effects are incorporated, the resulting loads are those that will come into contact with the floodplain. These loads have to be multiplied by the reduction efficiencies from Jordan (2007) for TN, TP and TSS.

Continuous Simulation

The discrete-storm approach is probably the most accessible to designers who are used to running hydrologic models for individual storms. However, increasingly more often, designers are beginning to apply continuous simulation to evaluate the performance of a design in response to a long-term period of rainfall, for example an average year, a wet year, of the full available rainfall record. Entering a continuous rainfall input dataset into the hydrologic model yields a continuous streamflow output dataset. In this case, the procedure outlined in Steps 1 and 2 is still carried out to derive the hydrograph separation relationship. This relationship is then applied to the continuous streamflow output from the hydrologic model in a manner analogous to Step 4. The result will be the continuous hydrograph over the floodplain.

The area under the hydrograph for the total flow is the total runoff volume in the period analyzed. Similarly, the area under the hydrograph for the floodplain is the runoff volume that accessed the floodplain during that period. The ratio of these two volumes is calculated and used as in Step 11.

*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.