6 Linking in the Loads

Introduction

Loads input to the Chesapeake Bay model come from a variety of sources and are reported in multiple forms. The loads must be linked or mapped into specific WQM state variables. The linkage process has evolved as the WQM has evolved and as the sources of loads have changed. The current linkage process combines methods developed for this phase of the study along with methods inherited from earlier phases. The methods employed to link to loads from the watershed, from point sources, from direct atmospheric deposition, and from shoreline erosion are described below.

Watershed Loads

Watershed loads are from the Phase 6 version of the Chesapeake Bay Program Watershed Model (WSM) and were provided to the WQM team in late November 2017. The WSM output is provided in annual files in which daily loads and flows are routed to WQM surface cells around the perimeter of the Bay and tributaries. Several WSM state variables have direct equivalents in the WQM while others require conversion to WQM state variables (Table 6-1). Two differences in the models require attention. The first is the conversion of the general WSM organic nitrogen and organic phosphorus state variables to the detailed suite of WQM variables. The second is provision of watershed organic carbon loads in the absence of a WSM state variable corresponding to the WQM organic carbon variable suite. The linkage process allows for individual specification of the parameters involved in the linkage at seven river inputs: Susquehanna, Patuxent, Potomac, Rappahannock, York, James, and Choptank. The remaining distributed loads are converted with one more available parameter set.

Organic Nitrogen

The steps required to map WSM organic nitrogen into WQM variables (Figure 6-1) are as follows:

- Remove the amount of nitrogen associated with phytoplankton loads.
- Split organic nitrogen into particulate and dissolved forms.
- Split particulate organic nitrogen into three reactive classes.

Phytoplankton nitrogen is represented implicitly in the WQM. That is, the nitrogen is represented as a fraction of phytoplankton carbon (see Chapter 2 Kinetics). The present version of the WQM employs WSM chlorophyll to compute phytoplankton entering tributaries from the watershed. In order to load the WQM with precisely the quantity of nitrogen provided by the WSM, the implicit nitrogen load incorporated in phytoplankton is removed from the explicit organic nitrogen load provided by the WSM.

The split of organic nitrogen into particulate and dissolved organic form is difficult to quantify definitively. Some uncertainty results from the multiple data bases and analyses available to inform the splits. Earlier analyses (Cerco and Cole 1994, Cerco and Noel 2004) detected an influence of river flow. For this phase of the study, we examined particulate and dissolved organic nitrogen at the first tidal monitoring station downstream of each river inflow. Our assumption was that the observations at these stations are representative of the material entering from the watershed. This method ensured consistency between the methodologies used to determine the splits and the data used to calibrate and validate the WQM. Little or no influence of flow was evident in this data base (Figures 6-2, 6-3). Splits (Table 6-2) were determined from the median fractions of particulate and dissolved organic nitrogen at each location.

Splits of particulate organic nitrogen into reactive classes were obtained from an ongoing study of the Conowingo Reservoir (Zhang 2017). The study estimated the splits through a mass balance analysis of solids entering and leaving the reservoir and of sediment-water nutrient fluxes within the reservoir. For the Susquehanna River, the reactive splits are influenced by flow above 6,500 $m^3\ s^{-1}$. The relationships used to determine the reactive classes are of the form:

$$Fg1 = FLPON - \propto 1 \cdot (Q - 6500) \qquad (1)$$
$$Fg2 = FRPON - \propto 2 \cdot (Q - 6500) \qquad (2)$$
$$Fg3 - 1 - Fg1 - Fg2 \qquad (3)$$

in which:

Fg1 = labile fraction of particulate organic nitrogen ($0 < Fg1 < 1$)
Fg2 = refractory fraction of particulate organic nitrogen ($0 < Fg2 < 1$)
Fg3 = G3 fraction of particulate organic nitrogen ($0 < Fg3 < 1$)
α1 = Effect of flow > 6,500 $m^3\ s^{-1}$ on Fg1 ($s\ m^{-3}$)
α2 = Effect of flow > 6,500 $m^3\ s^{-1}$ on Fg2 ($s\ m^{-3}$)
Q = Flow at Conowingo outfall ($m^3\ s^{-1}$)

The parameters α1 and α2 (Table 6-3) have non-zero values only when flow exceeds 6,500 $m^3\ s^{-1}$. In the absence of information, the values of FLPON and FRPON determined for the Susquehanna are transferred to the other river inputs without flow effects.

Organic and Particulate Inorganic Phosphorus

The routing of WSM organic phosphorus into WQM state variables is similar to organic nitrogen. The presence of particulate inorganic phosphorus (PIP) requires an additional step, however. Both the WSM and the WQM include PIP state variables but their nature differs in the two models. PIP in the WSM is loosely sorbed to sediment particles. The amount sorbed is determined by a linear partition coefficient. Reversible exchange is possible between dissolved and particulate form. In the WQM, PIP is an independent form of phosphorus which potentially decays to dissolved inorganic form at a first-order rate. In view of the differences in these two PIP variables, WSM PIP is first combined with organic phosphorus. The combination is then mapped into WQM variables (Figure 6-4). The steps necessary to route WSM organic phosphorus and PIP into WQM state variables are:

- Combine WSM organic phosphorus and particulate inorganic phosphorus.
- Remove the amount of phosphorus associated with phytoplankton loads.
- Split the combination into particulate and dissolved forms.
- Split particulate phosphorus into organic and inorganic forms.
- Split particulate organic phosphorus into three reactive classes.

The reasoning behind the removal of algal phosphorus is analogous to removal of algal nitrogen. Likewise, the splits between dissolved and particulate phosphorus are determined for individual river inflows based on median fractions observed immediately below the river inputs (Table 6-2). Observations collected at the river inputs indicate PIP represents a consistent faction of particulate phosphorus (Figures 6-5, 6-6). Fractions based on observations (Table 6-2) were used to split particulate phosphorus into organic and inorganic forms at each river inflow location. Particulate organic phosphorus was split into reactive classes with relationships analogous to Equations 1-3. Parameters appropriate to phosphorus (Table 6-3) are obtained from the same study which provided the nitrogen parameters.

Organic Carbon

The WSM has no state variable corresponding to the WQM organic carbon suite. Watershed organic carbon loads are derived by ratio to organic nitrogen. The ratios (Table 6-2) were derived from observations at the river inputs and are adapted here from the 2010 TMDL model (Cerco et al. 2010). The distribution of watershed organic carbon into WQM state variables is analogous to the process for organic nitrogen. First, organic carbon is split into dissolved and particulate forms. Then the particulate organic carbon is routed into three reaction classes. The splits between particulate and dissolved form are the same as for organic nitrogen. Routing of particulate organic carbon into reaction classes is conducted via relationships analogous to Equations 1-3. Parameters appropriate to carbon (Table 6-3) are obtained from the same study which provided the nitrogen parameters.

Point-Source Loads

The WQM considers loads from municipal and industrial sources located along the tidal shoreline of the Bay and tributaries. Loads from point sources above the fall lines of major tributaries are incorporated into the watershed loads. Point-source loads are provided by the CBP in a format similar to watershed loads. The loads are provided in annual files which contain daily loads routed to WQM surface cells. Constituents in the files are similar to outputs from the WSM (Table 6-1). Routing of point-source loads into WQM state variables follows a process similar to the routing of WSM loads. Point-source loads of organic nitrogen and phosphorus must be routed to the detailed suite of WQM state variables. No point-source carbon loads are provided so the carbon loads must be derived from available information.

The data available to guide mapping of point-source loads into WQM state variables is sparse. Most values employed here (Table 6-4) are adopted from the 2002 model version (Cerco and Noel 2004). Those values were based on sampling of Virginia point sources and on preliminary experiments to determine reactivity. The determination of point-source carbon load is revised from the 2002 model, however, and is now based on ratio to BOD5 rather than nitrogen load.

Shoreline Erosion

Nutrient loads from shoreline erosion were initially calculated and implemented by the WQM team. Subsequently, these loads were incorporated into the WSM. Incorporation into the WSM facilitated implementation of credits for management actions to control shoreline erosion. Shoreline erosion loads of solids and nutrients were provided by the CBP as annual files containing daily loads routed to WQM surface cells. Daily loads were assigned in proportion to runoff. Care was taken so that annual loads to each WQM cell equaled the loads computed using long-term average shoreline recession rates (Chapter 5).

Following precedent for distributed and point-source loads, carbon loads from shoreline erosion were computed from available information since organic carbon is not a WSM variable. The carbon fraction of shoreline solids, 4.35 mg C g^{-1} solids, was taken as the mean of values reported by Ibison et al. (1990). Daily loads were computed as the product of carbon fraction and daily solids loads. Organic carbon was split 20% refractory particulate and 80% G3, consistent with values employed for nitrogen and phosphorus (Chapter 5).

Atmospheric Loads

The WQM incorporates atmospheric nitrogen and phosphorus loads to the water surface. Atmospheric loads to the land surface are incorporated into the watershed loads. Atmospheric loads were provided by the CBP in annual files which contained daily loads to WQM surface cells. Loads included ammonium, nitrate, organic nitrogen, phosphate, and organic phosphorus. Organic nitrogen and phosphorus loads were split 20% refractory particulate and 80% G3, consistent with shoreline erosion loads.

References

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Cerco, C., and Noel, M. (2004). "The 2002 Chesapeake Bay eutrophication model," EPA 903-R-04-004, Chesapeake Bay Program Office, US Environmental Protection Agency, Annapolis MD. (available at http://www.chesapeakebay.net/modsc.htm)

Cerco, C., Kim, S.-C. and Noel, M. (2010). "The 2010 Chesapeake Bay eutrophication model," Chesapeake Bay Program Office, US Environmental Protection Agency, Annapolis MD. (available at http://www.chesapeakebay.net/publications/title/the_2010_chesapeake_bay_eutrophication_model1)

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Zhang, Q. (2017). "Fractions of G1/G2/G3 Particulate Organics Scoured from the Conowingo Reservoir," Chesapeake Bay Program Modeling Workgroup April 2017 Quarterly Review, Annapolis, MD. (available at https://www.chesapeakebay.net/channel_files/24719/2017-04-04_conowingo_hdr_g1g2g3_2.pdf)

Table 6-1
Constituents in Watershed and Water Quality Models

WSM Variable	Maps to	WQM Variable
Ammonium	------>	Ammonium
Nitrate	------>	Nitrate
Organic Nitrogen	------>	Dissolved Organic Nitrogen, Labile Particulate Organic Nitrogen, Refractory Particulate Organic Nitrogen, G3 Particulate Organic Nitrogen
Dissolved Phosphate	------>	Phosphate
Organic Phosphorus plus Particulate Inorganic Phosphorus	------>	Dissolved Organic Phosphorus, Particulate Inorganic Phosphorus, Labile Particulate Organic Phosphorus, Refractory Particulate Organic Phosphorus, G3 Particulate Organic Phosphorus

Table 6-2
Routing WSM Organics into WQM State Variables

River	Fraction Particulate, Nitrogen and Carbon	Fraction Particulate, Phosphorus	Faction Particulate Inorganic Phosphorus	Carbon to Nitrogen Ratio
Susquehanna	0.4	0.65	0.58	8
Patuxent	0.26	0.692	0.6	6
Potomac	0.26	0.65	0.47	8
Rappahannock	0.36	0.772	0.6	8
York	0.21	0.516	0.6	8
James	0.21	0.61	0.6	8
Choptank	0.33	0.645	0.7	8
Other	0.3	0.65	0.6	8

Table 6-3
Calculation of Reactive Fractions of Watershed Particles

Parameter	Nitrogen	Phosphorus	Carbon
Fraction Labile	0.15	0.3	0.15
Fraction Refractory	0.45	0.4	0.35
α1	7.49×10^{-6}	1.091×10^{-5}	7.64×10^{-6}
α2	1.638×10^{-5}	9.49×10^{-6}	1.33×10^{-5}

Table 6-4
Routing Point-Source Loads into WQM Variables

	Fraction Dissolved	Faction Labile Particles	Fraction Refractory Particles	Fraction G3 Particles
Organic N	0.5	0.15	0.28	0.07
Organic P	0.4	0.07	0.42	0.11
Organic C	0.8	0.15	0.04	0.01
C:BOD5 ratio = 1.0				

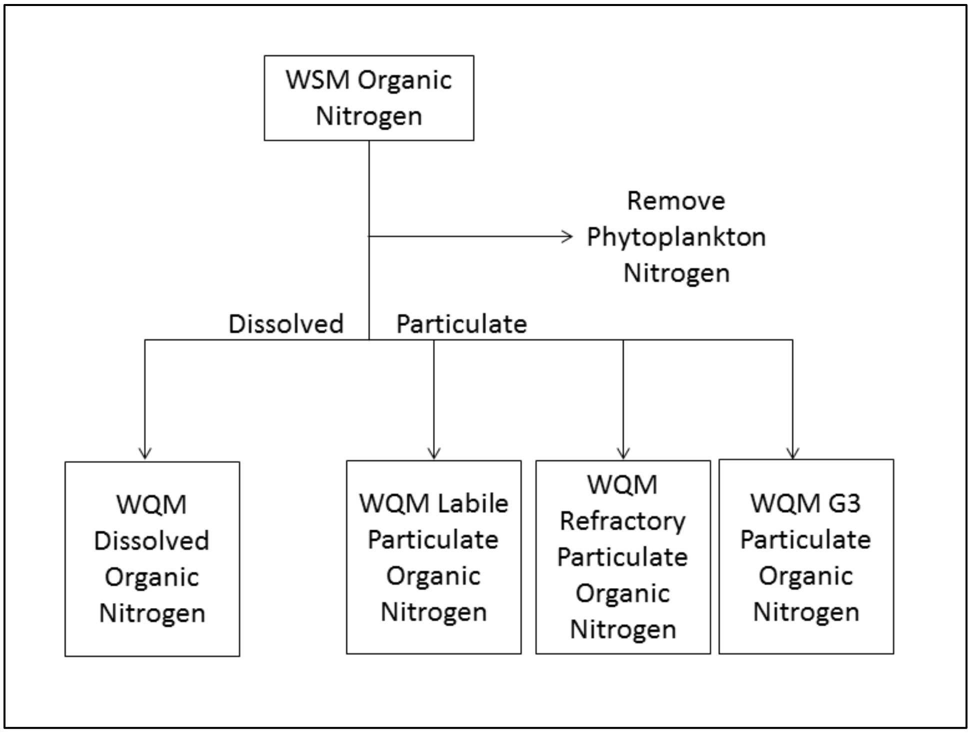

Figure 6-1. Routing watershed model organic nitrogen into water quality model state variables.

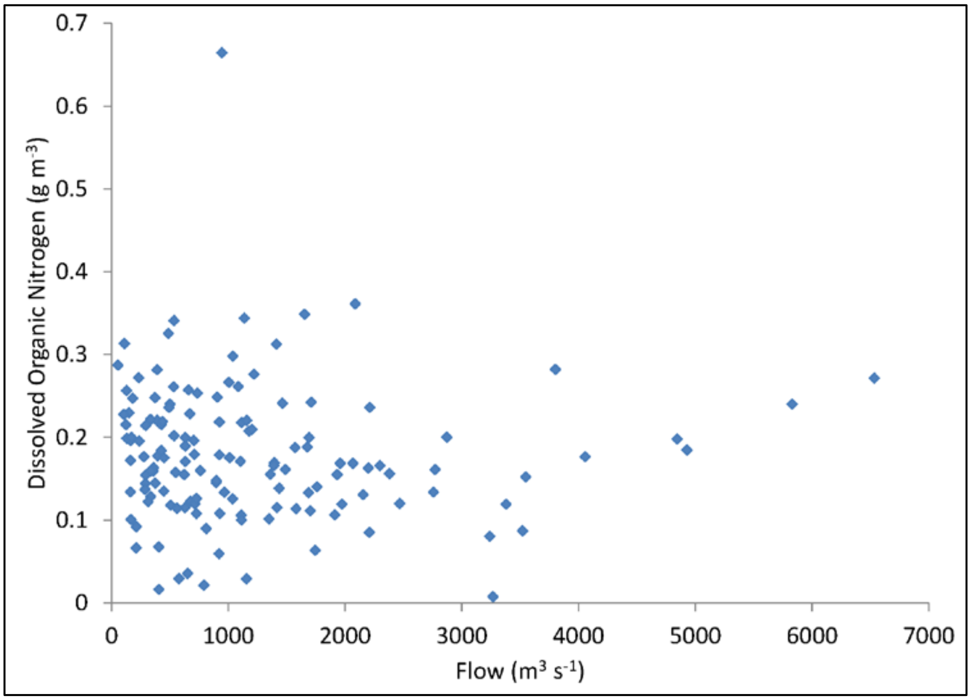

Figure 6-2. Dissolved organic nitrogen concentration at Station CB1.1, below Susquehanna River inflow. Note absence of relationship to flow.

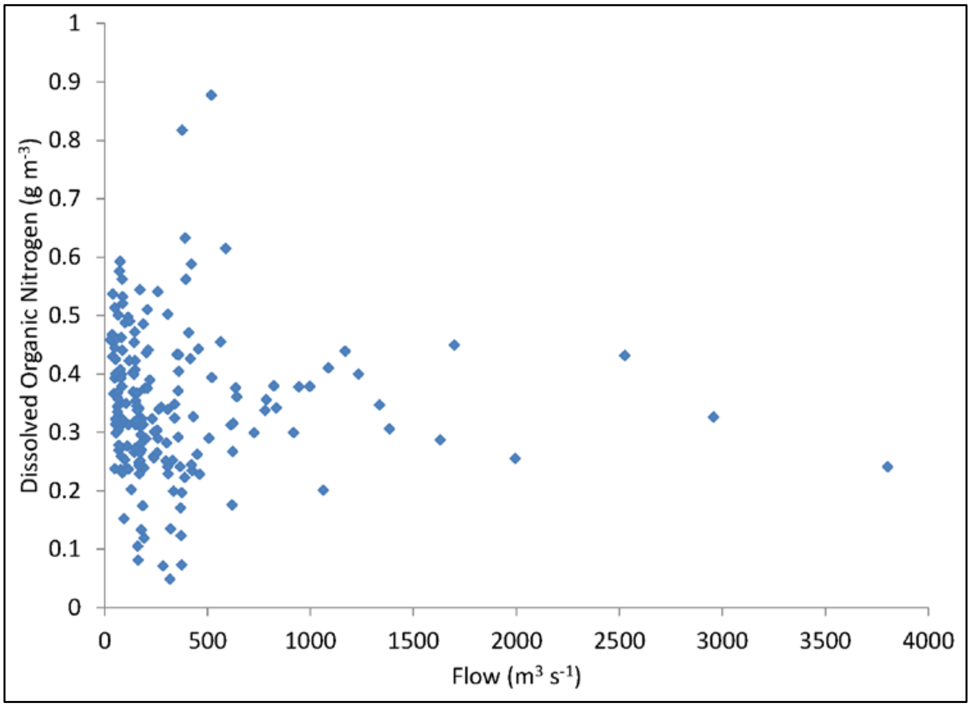

Figure 6-3. Dissolved organic nitrogen concentration at Station TF2.1, below Potomac River inflow. Note absence of relationship to flow.

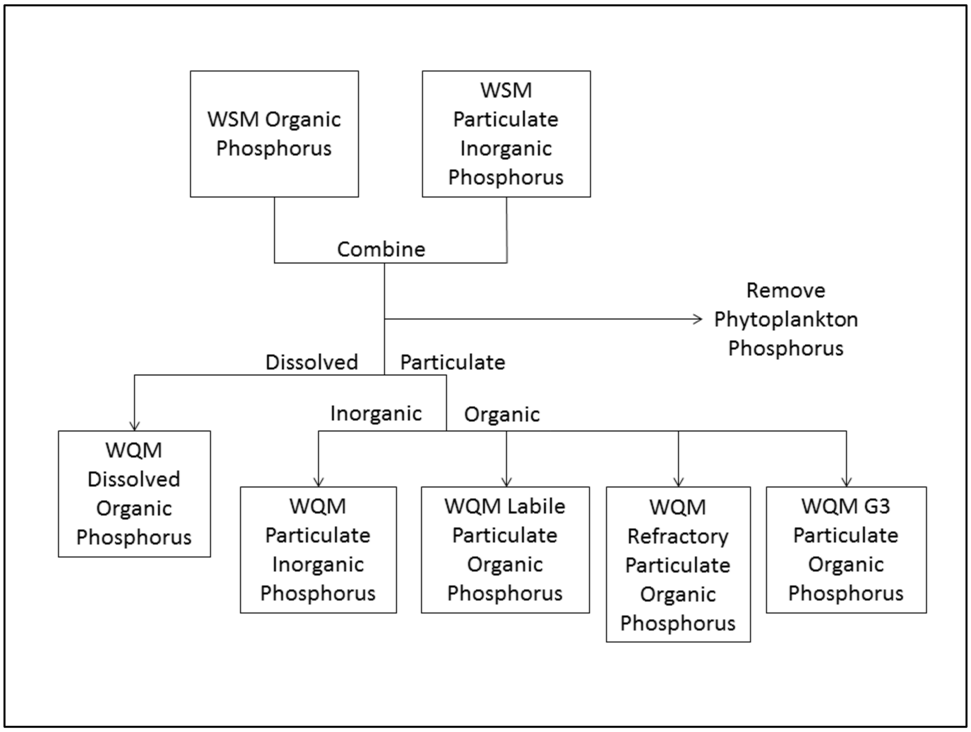

Figure 6-4. Routing watershed model organic and particulate inorganic phosphorus into water quality model state variables.

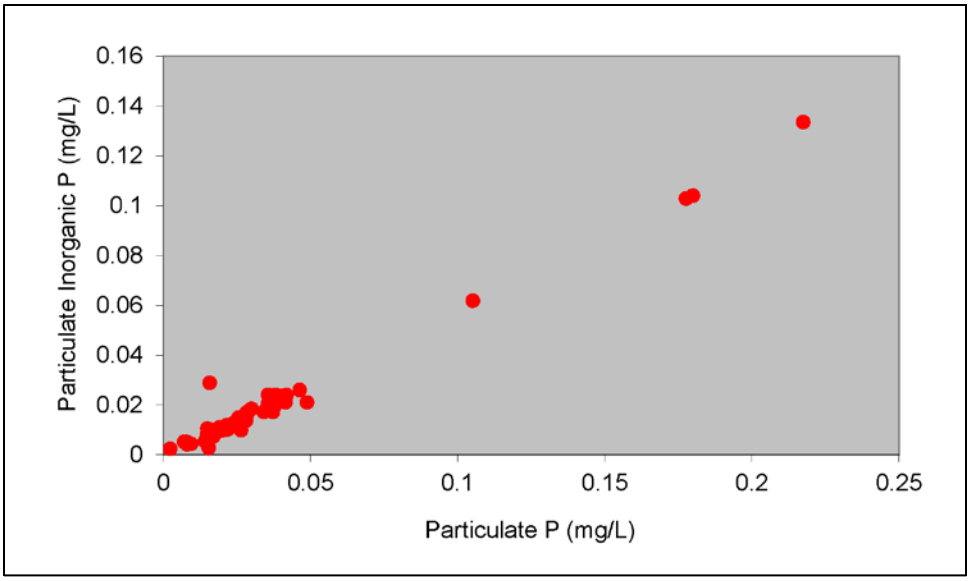

Figure 6-5. Particulate inorganic phosphorus vs. particulate phosphorus at Susquehanna River fall line. PIP is a consistent fraction of PP.

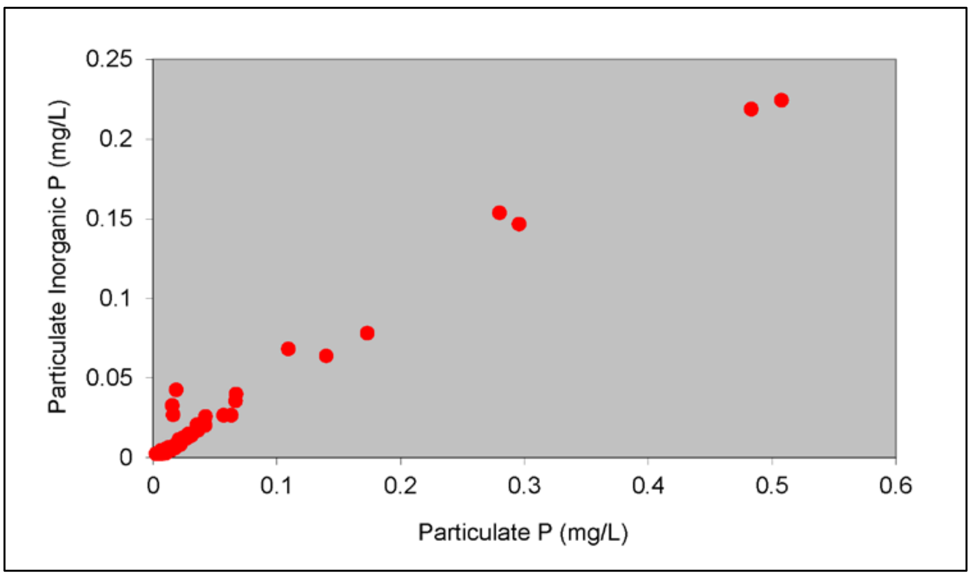

Figure 6-6. Particulate inorganic phosphorus vs. particulate phosphorus at Potomac River fall line. PIP is a consistent fraction of PP.