9 Section 9: Stream-to-River

9.1 Introduction

The Chesapeake Bay Program partnership's Watershed Model (Phase 6) has the overall structure shown in Figure 9-1. The focus in this section is the fate and transport of nutrient and sediment in small-order streams and reservoirs. Larger rivers and reservoirs are handled with a dynamic model based on a modified version of the Hydrologic Simulation Program Fortran (HSPF) code as described in Section 10. Figure 9-2 represents the transport processes included in the Phase 6 simulation of small streams and reservoirs. Nutrient and sediment loads from the land are modified as they move through the system for the processes of denitrification, bank erosion, floodplain deposition, and reservoir deposition. Table 9-1 repeats the overview of transport processes presented in Section 7 and identifies the processes that will be discussed in this section.

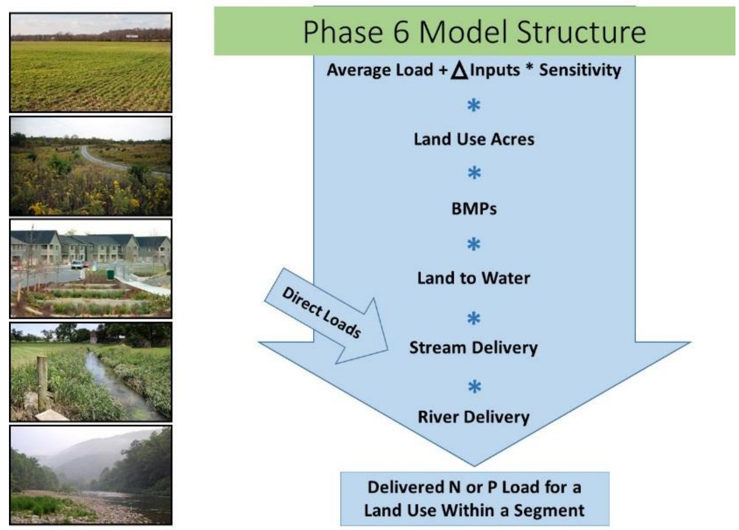

Figure 9-2: Structure of the Phase 6 Watershed Model

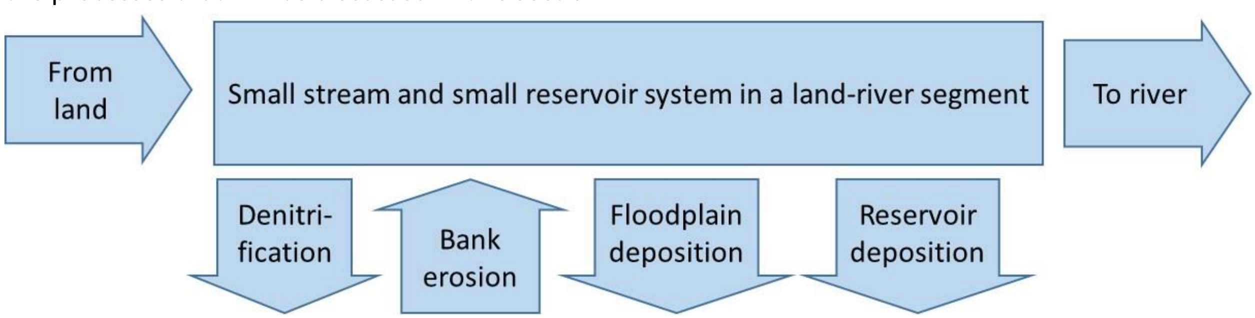

Figure 9-1: Processes represented in stream-to-river factors

Two complementary approaches were used to represent small stream processes in Phase 6. In the first approach, stream-to-river delivery factors are calculated by SPARROW as a representation of aquatic decay in reaches and reservoirs. The SPARROW stream-to-river factors account for denitrification and reservoir deposition. The SPARROW model is described in Section 7 and the specific application of SPARROW to stream-to-river factors is discussed in Section 9.2. The second approach derives an estimate of fluxes of sediment and nutrients in streambank erosion and floodplain deposition based on estimated average fluxes from the USGS's Chesapeake Floodplain Network (CFN). Bank erosion is modeled as a direct load to streams. Floodplain deposition is modeled as a separate stream-to-river factor. Streambank erosion and floodplain deposition estimation using the CFN is discussed in Section 9.3. Additional bank erosion in streams is estimated due to impervious cover as discussed in Section 9.3.2. Section 9.4 discusses the combination of the SPARROW, CFN, and impervious factors.

Two alternative approaches to streambank erosion that were developed with an eye towards their application in Phase 6 but were not used in the final version of the model are documented in Appendix 9A.

Table 9-1: Transport Processes Represented in the Phase 6 Watershed Model

Process	Phase 6 Nutrients	Phase 6 Sediment
Edge-of-Field	Average loads + input load variability + land-to-water factors	RUSLE estimates
Hillslope		Interconnectivity factors
Groundwater		NA
Small Stream	SPARROW stream-to-river factors Average Streambank Erosion and Floodplain Deposition	SPARROW stream-to-river factors Average Streambank Erosion and Floodplain Deposition Streambank Erosion Due to Impervious Cover
Large River	HSPF River simulation	HPSF River simulation

9.2 SPARROW Stream-to-River Aquatic Decay Factors

In SPARROW, stream-to-river aquatic decay factors represent how much of the nutrient loads input into an NHDPlus reach are output from the reach. The SPARROW stream-to-river factors were used to calculate nutrient losses in small order streams not represented in the Phase 6 river segmentation as described in Section 11. Like the calculation of land-to-water factors in Section 7, they are calculated by general land classes (crop, pasture, developed, and natural land) and aggregated from the NHDPlus catchment scale to the land-river segment scale:

Equation 9-1: Aggregate land-river segment Stream-to-River Factors

$$S2R_{LR,k} = \sum_{i=1}^{N} Total\ S2R_i * A_{i,k}/A_{LR,k}$$

where:

$S2R_{LR,k}$ = stream-to-river factor at land-river segment scale for land class k
Total $S2R_i$ = Total stream-to-river delivery factor from NHDPlus catchment i to Phase 6 river reach network
$A_{i,k}$ = Area of land class k in catchment i in land-river segment
$A_{LR,k}$ = Area land class k in land-river segment
N = number of catchments wholly or partially in the land-river segment

The area of each land class in the NHDPlus catchment were derived from the 2013 High Resolution Land Cover, as described in Section 7.3. Stream-to-river delivery factors are uniform in individual catchments, without regard to the source of the reach loads. Stream-to-river delivery factors at the land-river segment scale are calculated by land classes, to capture variation in distribution of land class acreage over a land-river segment.

The principal complexity in the stream-to-river factor calculations is in determining the aggregate delivery for the loads in a given NHDPlus catchment as they move from the catchment to a reach on the Phase 6 river reach network. Figure 9-3 illustrates the relation between NHDPlus catchments, NHDPlus reaches, and Phase 6 reaches. Loads from an NHDPlus catchment draining to a tributary of a Phase 6 reach must pass through all of the NHDPlus reaches downstream until they arrive at a Phase 6 reach. The total stream-to-river factor is the product of the delivery factors for all of the tributary reaches between the catchment and the Phase 6 reach:

Equation 9-2: total Stream-to-River factors

$$Total\ S2R_i = \prod_{j \in \mathrm{N}} S2R_{i,j}$$

Where:

stream-to-river$_{i,j}$ = stream-to-river factor for individual reach or reservoir j upstream of P6 reach and downstream of NHDPlus catchment i

N = total number of reaches downstream of catchment *i* (including *i* itself)

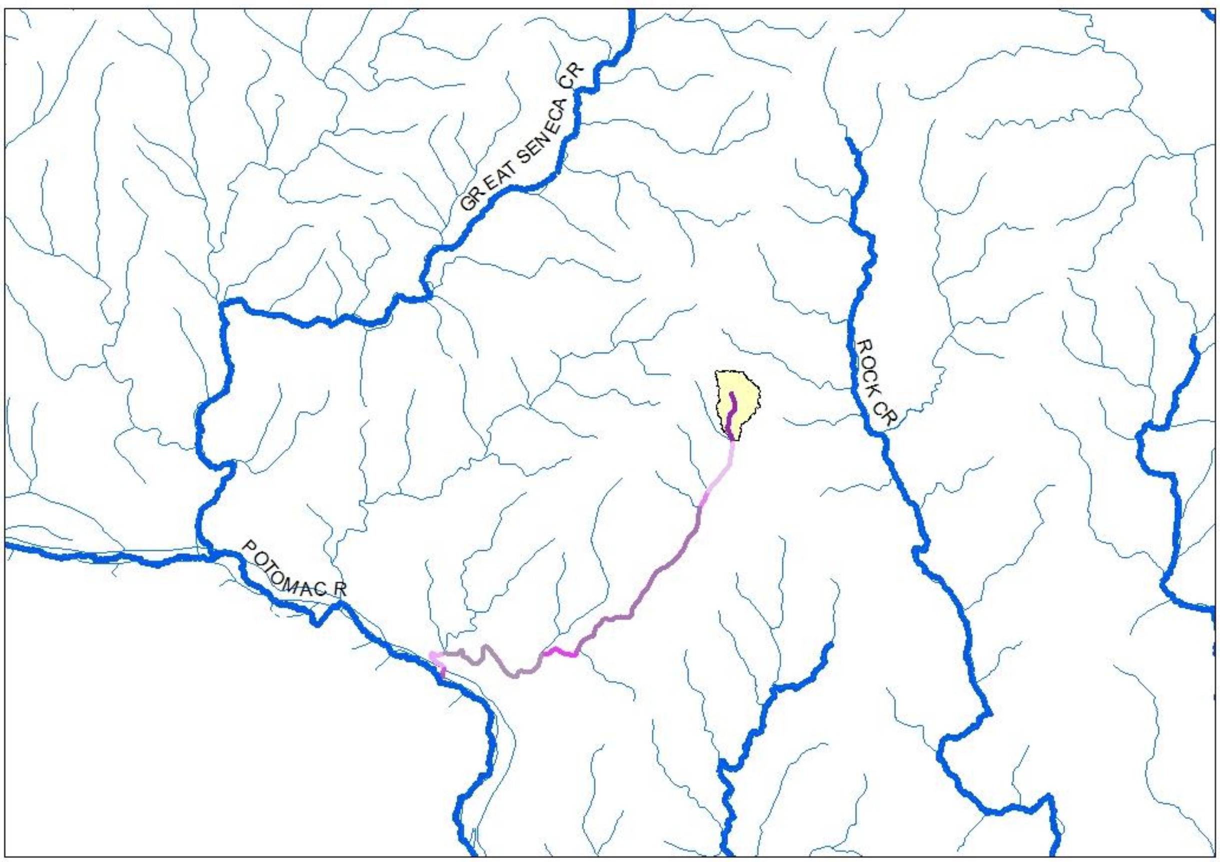

Figure 9-3: Transport path for NHDPlus catchment to Phase 6 river reach

Each catchment will have a different total stream-to-river delivery factor, depending on the travel time of the stream reaches or presence of reservoirs in its transport path downstream.

An added complication is that SPARROW assumes that the load from a catchment enters a river reach at the midpoint of a river reach, so in contrast to the load from upstream reaches, which are subject to the full stream-to-river delivery factor, loads from the catchment are subject to the square root of the stream-to-river delivery factor. If the reach is an impoundment, the catchment reaches are subject to the full stream-to-river delivery factor.

Land-river segments in tidal areas are frequently not associated with reaches and drain directly to tidal waters. Each NHDPlus catchment within these tidal land-river segments is associated with a terminal NHDPlus catchment representing the connection to tidal waters. The terminal NHDPlus catchments were either NHDPlus catchments that were attributed as artificial channels in tidal areas or SPARROW reaches designated as the centerline of tidal waters, or both.

Nitrogen and phosphorus stream-to-rivers for Phase 6 representing denitrification in streams and small reservoir attenuation were calculated from the aquatic decay coefficients from the CBTN_v4 and CBTP_v4 SPARROW simulations introduced in Section 7.2. These coefficients are shown in Tables 7-2 and 7-3 along with other estimated coefficients and repeated in Table 9-2. As discussed in Section 7.2, there are no phosphorus losses in river reaches, only in reservoirs and impoundments. This finding of no attenuation or loss of phosphorus in impounded river reaches is consistent with theory. Phosphorus tends toward being conservative in watersheds, as phosphorus has no analog to denitrification.

Table 9-2: SPARROW aquatic loss coefficients for CBTN_v4 and CBTP_v4 models

Variable	**Estimate**	**90% Confidence Interval**	**Standard Error**	**P-value**
Aquatic Decay for nitrogen				
Impoundments				
Inverse hydraulic load (yr m^{-1})	5.93	0.271 – 11.6	3.42	0.0424
Streams, time of travel (d) MAQ =mean annual flow; T30 = 30 year mean maximum temperature				
Small (MAQ ≤ 3.45 m^3 s^{-1})	0.339	0.0936 – 0.585	0.148	0.0118
Large (MAQ > 3.45 m^3 s^{-1}) T30 > 18.5°C	0.153	0.0622 – 0.245	0.0551	0.003
Large (MAQ > 3.45 m^3 s^{-1}) T30 ≤ 15°C	0.0131	-0.111 – 0.137	0.0751	0.431
Aquatic Decay for phosphorus				
Impoundments- inverse hydraulic load (yr m^{-1})	54.3	12.1 – 96.5	25.5	0.0174
Aquatic Decay for Sediment				
Streams in the Coastal Plain				
Storage, all streams Below Fall Line	1.27		0.419	0.003
Impoundments				
Reservoir Settling Velocity	137.45		61.05	0.013

Sediment stream-to-river factors that account for reservoir and impoundment effects also calculated from the SPARROW sediment model using the reservoir settling rate in Table 9-2.

9.2.1 Reservoirs and Impoundments

The effects of over 4,000 reservoirs and impoundments are included in SPARROW. The reservoirs represented in SPARROW were taken directly from the NHD Waterbody GIS layer without alteration. The CBP partners had the opportunity to review the reservoirs represented in that layer and identify both reservoirs that should be removed and reservoirs missing from the layer which should be included in Phase 6. Based on their review, the following actions were taken:

- Removal of impoundments such as stormwater ponds whose effects are already included in the Phase 6 Model as BMPs;
- Removal of tidal marshes misidentified as impoundments; and
- Adding effects of missing reservoirs to the stream-to-river delivery factors by calculating the delivery factors based on their area and flow rate of the associated NHDPlus reach.

The Maryland Department of the Environment (MDE) and the Virginia Department of Environmental Quality (DEQ) reviewed the reservoirs represented in SPARROW and provided the following direction for the removal and addition of reservoirs. MDE recommended removing 486 impoundments, either because they were tidal wetland or because they should be considered as BMPs and requested adding 29 reservoirs. DEQ requested that 128 impoundments that were reported as BMPs be removed from the Phase 6 simulation. The NHDPlus catchments excluded are listed in Appendix 9B.

One hundred and eighty-seven reservoirs or impoundments represented in SPARROW are located directly on HSPF river reaches in Phase 6. Therefore, the effects of these impoundments are not included in the stream-to-river delivery factors described in the preceding section. Thirty-two of these reservoirs are already represented as reservoirs in HSPF, but the rest are not. The remaining reservoirs were divided into two classes, depending they were located on a Phase 6 reach without another Phase 6 reach upstream, i.e. a “headwater reach,” or were located on a Phase 6 reach with upstream Phase 6 reaches.

The effect of reservoirs and impoundments on headwater reaches were incorporated into the stream-to-river delivery factors for their land-river segments as follows:

1. The aquatic decay rate for the impoundment or reservoir was calculated;
2. All catchments with the land-river segment upstream of the impoundment were identified;
3. The aquatic decay due to the impoundment was included in the calculation of the total decay in each upstream catchment; and
4. The revised total decay of the upstream catchment was included in the calculation of the stream-to-river decay factor for that land-river segment.

Figure 9-2 illustrates the impact of impoundment on a headwater reach. Lake Needwood in Montgomery County is an impoundment on Rock Creek. There are no upstream Phase 6 reaches. Lake Needwood impacts the catchments which drain to Rock Creek upstream and has no impact on the catchments downstream of it. The aquatic decay rate for Lake Needwood is applied to the upstream catchment and not to the downstream catchments when calculating the overall stream-to-river delivery factor for the land-river segment.

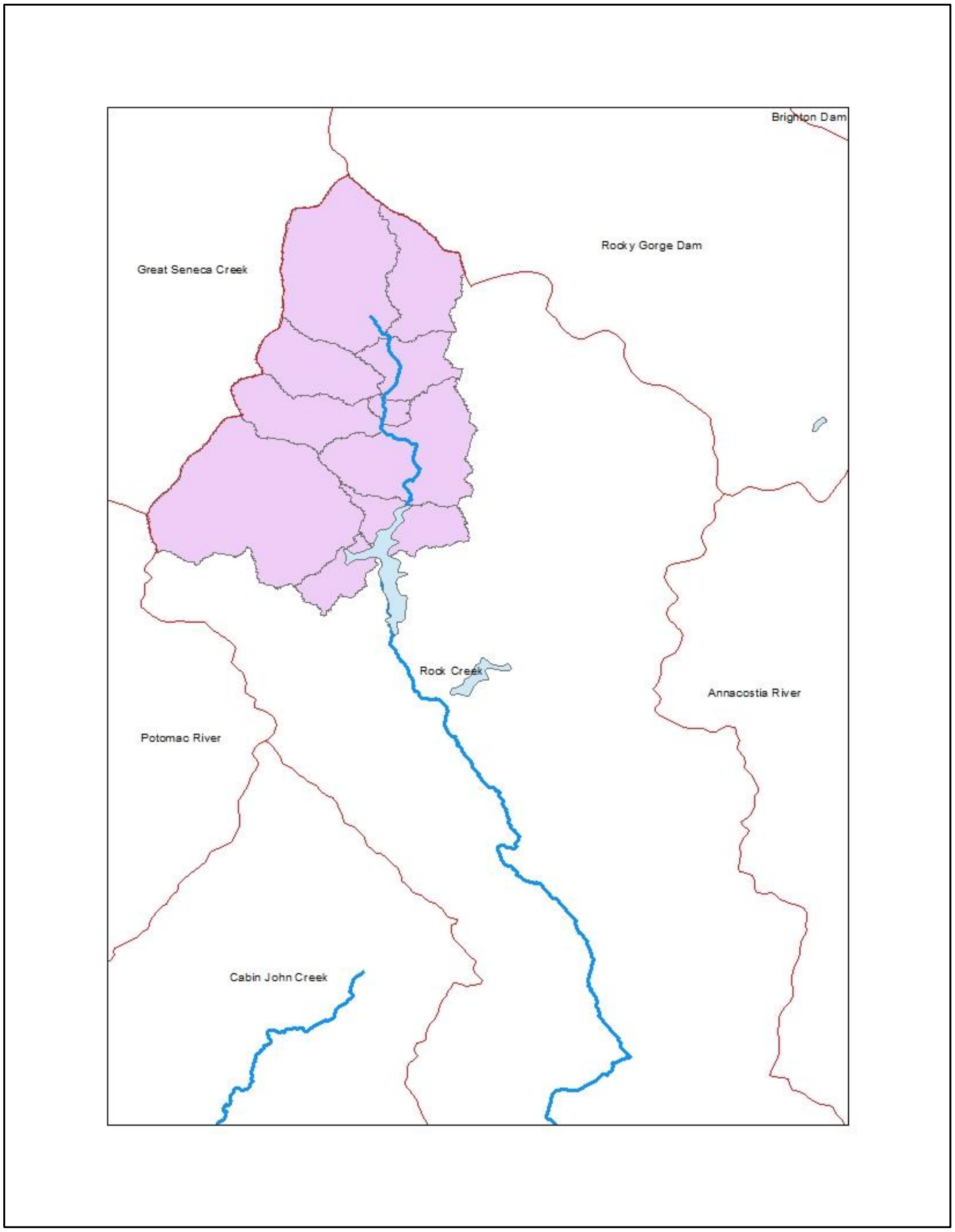

Figure 9-2: Impact of Lake Needwood on Rock Creek NHDPlus Catchments. Only NHDPlus catchments upstream of Lake Needwood (in purple) were attenuated by the impoundment.

For a reservoir or impoundment on a Phase 6 reach which has other Phase 6 reaches upstream, functionality has been added to the dynamic Phase 6 model structure to apply the effect of aquatic decay from that impoundment to the outflow of TN, TP, and sediment from the reach. Table 9-2 shows the Phase 6 river segments with impoundments and the delivery factors associated with them.

Table 9-2: Delivery factors for Phase 6 river reaches with impoundments

River Segment	Nitrogen Delivery Factor	Phosphorus Delivery Factor	Sediment Delivery Factor
JA2_7290_0001	0.958	0.7	0.454
JU3_6650_7300	0.999	0.995	0.987
JU4_7000_7300	1.000	0.996	0.991
PL0_5490_0001	0.978	0.831	0.661
PL1_5130_0001	0.937	0.62	0.392
PL1_5690_0001	0.945	0.654	0.427
PL2_5140_5360	0.996	0.962	0.908
PL3_5360_5250	0.989	0.911	0.801
PM7_4820_0001	1.000	0.997	0.992
PS2_6420_6360	0.999	0.988	0.969
PS2_6490_6420	0.999	0.99	0.975
PS3_6280_6230	1.000	0.998	0.995
PU4_3970_3890	1.000	0.997	0.993
PU6_3600_3602	0.998	0.981	0.952
PU6_3602_3730	0.998	0.98	0.952
PU6_3750_3752	0.997	0.977	0.943
SJ3_1980_2060	1.000	0.999	0.997
SL1_1700_1780	0.985	0.874	0.727
SL1_2830_2760	0.994	0.951	0.886
SL4_2100_2140	1.000	0.996	0.991
SL4_2140_2240	1.000	0.997	0.992
SU3_0180_0230	0.986	0.88	0.736
SU4_0270_0430	1.000	0.998	0.994
SW3_1600_1580	0.999	0.988	0.97
SW3_1660_1580	0.916	0.543	0.32
WM3_3880_4060	0.998	0.985	0.964
WM3_4060_0001	0.998	0.98	0.95
WU1_3330_0001	0.969	0.773	0.573

9.3 Representation of Streambank Erosion and Floodplain Deposition in Phase 6

Results from the CFN indicate that on average, long-term fluxes of sediment and nutrients in streambank erosion and floodplain deposition are in in equilibrium, so there is no long-term net change in load in small-order stream from these processes. The representation of these processes does change the sources of sediment and nutrients, since floodplain deposition traps some of the sediment from upland sources associated with land uses so that some of the sediment and nutrient load at the edge-of-river (EOR) scale is attributable to streambank erosion. However, it has long been recognized that watersheds under development are not in equilibrium because the increase in impervious cover results in higher peak flows in streams, with attendant additional streambank erosion. For sediment, but not for nutrients, there is an additional component to streambank erosion in Phase 6 representing the effects of impervious cover. Unlike the baseline component derived from the CFN, streambank erosion from impervious cover results in a net increase in EOR sediment loads. Streambank erosion due to impervious surfaces is quantified based on an analysis of sediment loads at the watershed scale reported in Langland and Cronin (2003) and used to develop calibration targets for impervious land uses in the Phase 5. Section 9.3 also discusses the component of streambank erosion due to impervious surfaces. Section 9.4 graphically shows the total stream-to-river factors, which is the product of the SPARROW stream-to-river delivery factors and the floodplain deposition, treated as a delivery factors. The total stream-to-river delivery factors are presented for nitrogen, phosphorus, and sediment for each general land class.

There are two components to the representation of the streambank erosion and floodplain deposition of sediment in Phase 6. These are discussed in Sections 9.3.1 and 9.3.2. The first component also affects the fate and transport of nitrogen and phosphorus, but the second component, which tries to account for the generation of streambank erosion due to the effects of impervious surfaces on stream flow, is only applied to sediment. Section 9.3.3 discusses how streambank erosion and floodplain deposition are applied in management scenarios. The representation of streambank erosion and floodplain deposition fulfills a Bay Partnership mandate to represent streambank erosion as a distinct source in Phase 6, so streambank restoration can be credited as a BMP.

9.3.1 Average Effects of Streambank Erosion and Floodplain Deposition

The first component to the representation of streambank erosion and floodplain deposition is derived from the USGS's Chesapeake Floodplain Network (CFN) (Noe *et al*. 2015). The CFN consists of 43 sites in the Piedmont, the Ridge and Valley, and Coastal Plain physiographic provinces. The sites are located in proximity to Nontidal Network gages where there are flow measurements as well as long-term estimates of sediment and nutrient loads. The areas of the watersheds above the gages range from 8.5 to 773.7 mi^2. Noe et al. estimated long-term sediment and nutrient fluxes of streambank erosion and floodplain deposition at CFN sites using dendrogeomorphic analysis. Their methods are described in more detail in Section 9.5. Figure 9-3 shows the results for sediment.

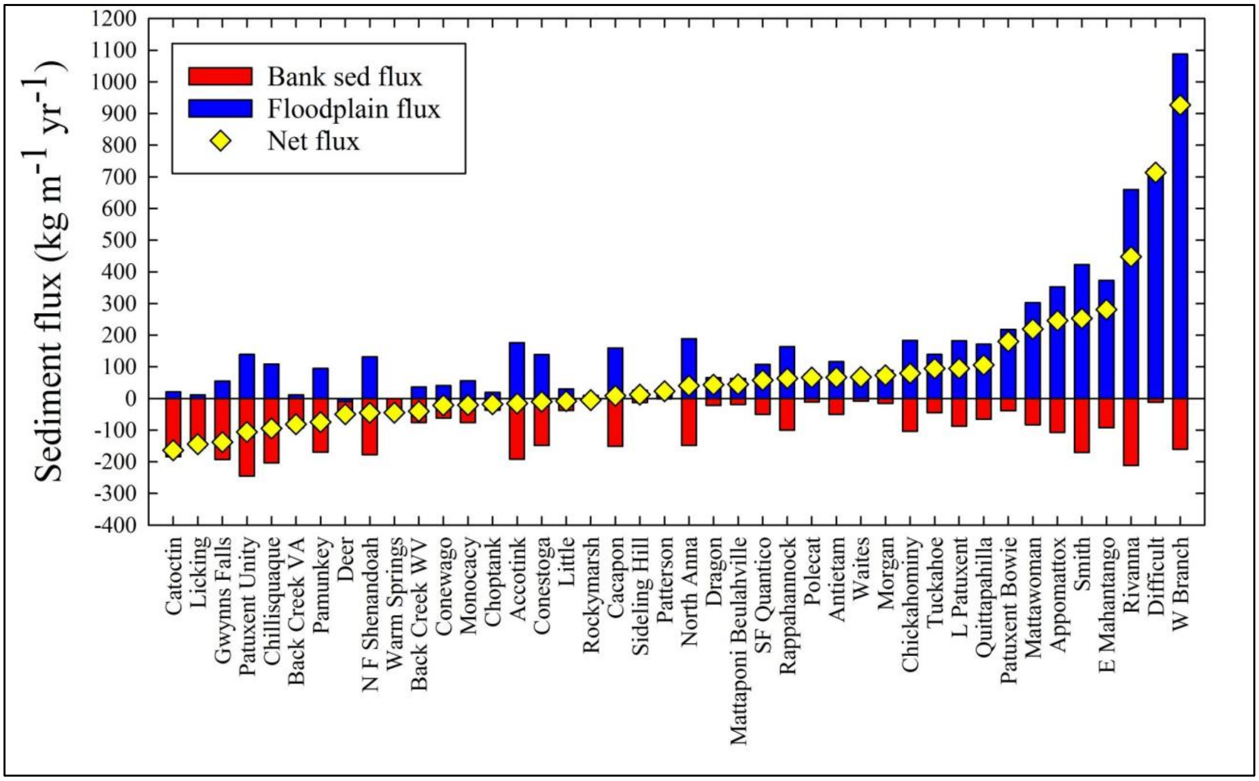

*Figure 9-3: Sediment Streambank and floodplain fluxes at Chesapeake Bay Floodplain Network sites (Noe et al. 2016**)***

As Figure 9-3 shows, there is considerable variability in bank erosion and sediment deposition across the sites. Across the sites, however, on average, the flux of sediment in bank erosion is balanced by the flux in sediment deposition, so that on average across the sites, the net flux is zero. This is the primary assumption of representation of streambank erosion and floodplain deposition in Phase 6: in the absence of any information specific to a reach, it is assumed that the flux of nutrients and sediment in streambank erosion and floodplain deposition are in equilibrium, so that the flux of nutrients and sediment in streambank erosion is equal in magnitude and opposite in sign to the flux in streambank deposition. The magnitudes of the fluxes are estimated from the average streambank erosion fluxes determined from the CFN sites. These are shown in Table 9-3.

Table 9-3: Average streambank erosion flux rates (lbs/ft/yr) at Chesapeake Bay Floodplain Network sites

Constituent	**Flux Rate (lbs/ft/yr)**
Sediment	62.69
Nitrogen	0.093
Phosphorus	0.310

The total flux streambank flux in a land-river segment (LRS) is the product of the erosion flux rates and the total length of the National Hydrography Dataset (NHD) streams in the LRS. Streambank fluxes are sources of sediment and nutrients, which are matched by the corresponding fluxes of sediment deposition which act as sinks.

The average streambank and floodplain sediment and nutrient flux rates are implemented in Phase 6 by transforming the floodplain depositional fluxes into delivery factors. This floodplain delivery factor (FDF) is, for nitrogen and phosphorus, equal to the fraction of the total load in the LRS from upstream sources (US) and streambank erosion (SE) at the edge-of-small stream which is delivered to the represented river (neglecting other stream-to-river losses), or

FDF = (US + SE – FD) / (US +SE)

where FD is equal in magnitude to the floodplain deposition. For sediment, as will be discussed in Section 9.3.2, the calculation of the FDF also has to take into account the additional streambank erosion load due to impervious cover. Stream restoration and other stream erosion BMPs are not included in the calculation of FDF. Table 9-4 provides an example of the calculation of FDF and its application.

Table 9-4: Example streambank erosion and floodplain deposition calculations for phosphorus

Upstream Load (EOS)	500 P (lbs/yr)
Streambank Erosion (EOS)	50 P (lbs/yr)
Floodplain Deposition (EOS)	50 P (lbs/yr)
Floodplain Delivery Factor (FDF)	0.909091
Stream-to-River Factor (from SPARROW)	1.0
(EOR) Upstream Load Delivered to River	454.55 P (lbs/yr)
(EOR) Streambank Erosion Delivered to River	45.45 P (lbs/yr)
Total EOR Load	500.00 P (lbs/yr)

The FDF is calculated by the equation above. In this example there are no BMPs acting on streambank erosion and no reservoirs in the LRS, so the SPARROW stream-to-river (stream-to-river) delivery factor is 1.0. Floodplain deposition traps 50 lbs/yr, which is equal to the sediment load generated by streambank erosion and approximately 91% of the total sediment load from streambank erosion and upstream sources. The total EOR load delivered to the river is equal in magnitude to the upstream load, which is what would be expected if there were no reservoir losses in the LRS and streambank erosion is equal to floodplain deposition. The EOR load, however, is distributed between upstream load and streambank erosion in proportion to their relative size. This reflects the fact that some of the sediment which is trapped in the floodplain is from upstream sources, so if the watershed instream processes are in equilibrium, some of the load which passes to the river must have come from streambank erosion.

9.3.2 Streambank Erosion Due to Impervious Cover

An increase in impervious surface in areas under development is known to alter stream hydrology and lead to a net increase in erosion from stream beds and banks. The Phase 5 Watershed Model did not explicitly represent streambank erosion as a source category, but the effect of impervious surfaces on streambank erosion was implicitly included in the sediment export rate targets. According to the Phase 5 documentation (USEPA 2010), Langland and Cronin (2003) reported average annual loading rates for developed land uses at the watershed scale from two Storm Water Management Model (SWMM) studies and a third study by Dreher and Price (1995). Because these studies represent sediment export at the watershed scale, they implicitly include the loads generated by instream erosion. Phase 5 does not have explicit developed land used categories such as residential, commercial or industrial land. These categories are aggregated into developed pervious and developed impervious land. To estimate the sediment export on the watershed scale for impervious developed land, the developed land uses in the three studies were assigned a percent impervious cover. For example, industrial land was assigned a percent impervious cover of 90% while medium density residential land was assigned a percent impervious cover of 25%. Figure 9-4 shows the estimates of sediment export from the three studies graphed against the percent impervious cover. Each observation represents an estimate of average annual sediment export from a particular land use in a study, graphed against the percent imperviousness for that land use. From this data a regression relation between sediment export and percent imperviousness can be calculated. The resulting relation is shown in Figure 9-4. As the figure shows, the export rate for 100% impervious cover is seven times the export rate for 0% impervious cover. On this basis, the impervious export rate was set at seven times the pervious loading rate. Because these represent watershed studies (as opposed to edge-of-field or edge-of-stream estimates), they implicitly include instream processes like streambank erosion.

As discussed in Section 2.3.3, the Phase 6 impervious loading rate was derived in a similar manner to the Phase 5 rate. The Phase 6 sediment target export rate was determined as a multiplier of the pervious rate, except the starting point was average monitored outfall event mean concentrations for four land use types: commercial (113 mg/l), industrial (168 mg/l), residential (123 mg/l), and open space (99 mg/l). Using an assumed percent impervious rates of 80%, 90%, 25%, and 5%, respectively, as well as the average flow rates for pervious and impervious surfaces, the surface flow for each land use relative to pervious land and therefore the load relative to pervious land could be calculated. The relative load as a function of percent impervious cover could also be calculated. Figure 9-5 (which repeats Figure 2-9) shows this relation. As Figure 9-5 shows, at 100% impervious, the relative load is three times the size of the impervious load. In each land segment, the sediment export rate for pervious urban land was based on RUSLE2. The corresponding impervious export rate was set at three times that value.

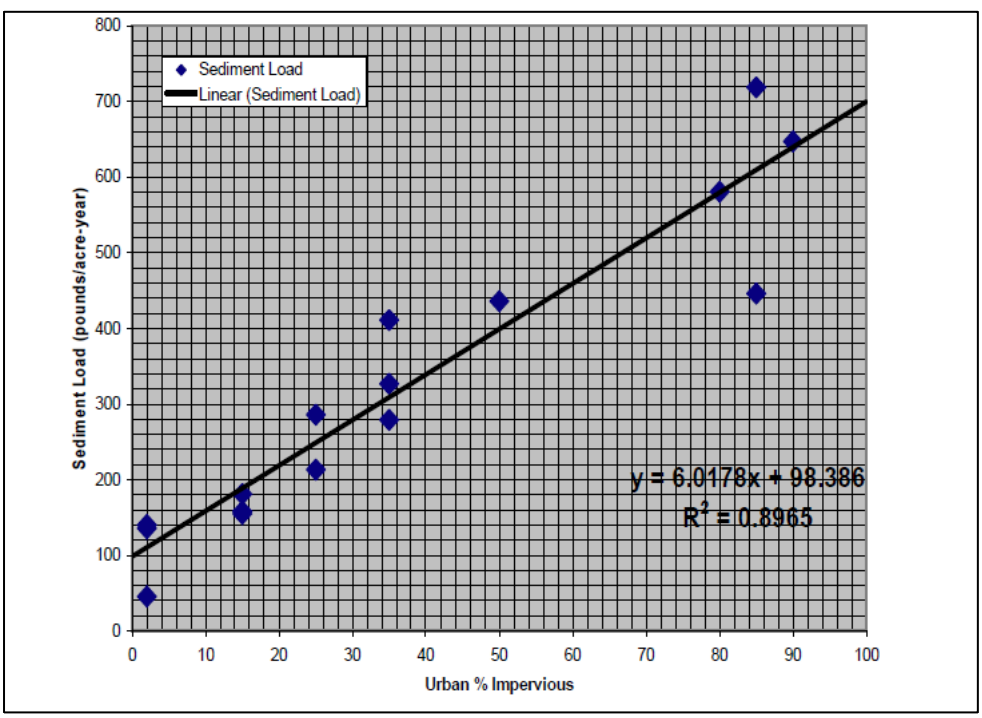

Figure 9-4: Relation between percent impervious cover and sediment export rate, Phase 5 Watershed Model (Source: USEPA, 2010)

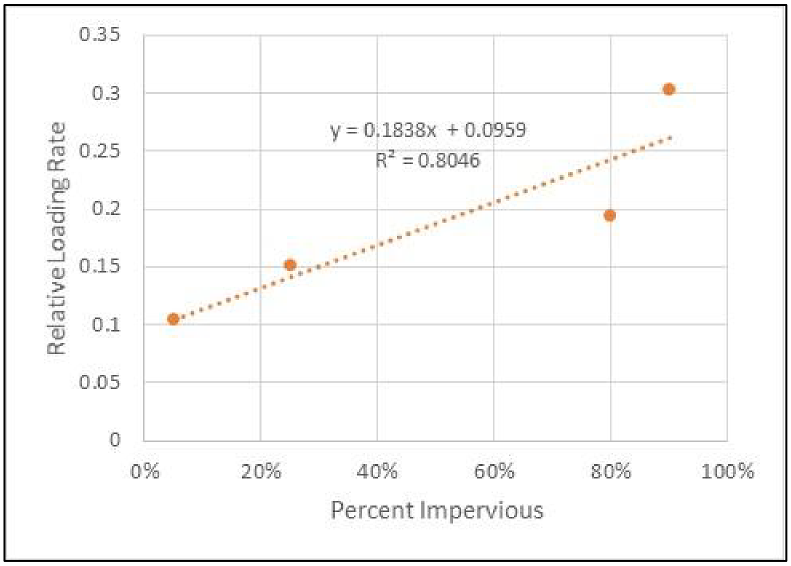

Figure 9-5: Relation between percent impervious cover and edge-of-stream sediment loading rate (Replication of Figure 2-9, Section 2.2.3.)

The Phase 6 export rates for impervious land are calculated at the outfall or edge-of-stream. Unlike Phase 5, the Phase 6 sediment target represents the EOS sediment load from impervious surface and does not include the effects of streambank erosion. The Phase 5 export rates represented watershed rates which included streambank erosion. If the watershed loading rate is seven times the pervious export rate, and the EOS impervious loading rate is 3 times the pervious loading rate, then streambank erosion, which accounts for the difference between them, must equal four times the pervious loading rate or 4/3 of the impervious loading rate. Sediment from streambank erosion equal to four times the pervious loading rate (or 4/3 times the impervious loading rate) was added to the Phase 6 equilibrium streambank erosion rate to differentiate streambank loads in developed areas and include the effect of impervious cover on streambank erosion loads. This additional load is not matched by an increase in floodplain deposition. No additional nutrient loads were added.

Table 9-5 provides an example of the calculation of FDF and its application for sediment. An additional 50 tons/yr of sediment due to impervious cover has been added to the 50 tons/yr background streambank erosion. The background floodplain deposition also remains 50 tons/yr. The FDF is calculated using the total streambank erosion. Like the phosphorus example in Table 9-4, it is assumed that there are no reservoirs in the LRS so the stream-to-river factor from SPARROW is 1.0. The total EOR load in this case is equal in magnitude to the sum of the upstream load and the streambank erosion due to impervious cover, because the streambank load due to impervious cover represents a genuine increase in load.

Table 9-5: Example Streambank Erosion and Floodplain Deposition Calculations for Sediment

Upstream Load (EOS)	500 tons/yr
Background Streambank Erosion (EOS)	50 tons/yr
Additional Streambank Erosion Due to Impervious Cover (EOS)	50 tons/yr
Total Streambank Erosion (EOS)	100 tons/yr
Floodplain Deposition (EOS)	50 tons/yr
Floodplain Delivery Factor (FDF)	0.916667
stream-to-river Factor (from SPARROW)	1.0
(EOR) Upstream Load Delivered to River	458.33 tons/yr
(EOR) Streambank Erosion Delivered to River	91.67 tons/yr
Total EOR Load	550.00 tons/yr

9.3.3 Streambank Erosion and Floodplain Deposition under Management Scenarios

The FDFs calculated according to the methods described in Sections 9.3.1 and 9.3.2 is assumed to remain unchanged in magnitude in management scenarios. That is, once the FDFs are calculated in the calibration, they are applied to all management scenarios. Nutrient and sediment fluxes, however, are assumed to change with management scenarios. For nutrients, the nitrogen or phosphorus in streambank erosion is equal to the product of the rates in Table 9-3 and the total length of NHD streams in the LRS, adjusted by a factor equal to ratio of the upstream load in the scenario to the upstream load in the calibration. A similar adjustment factor is applied to the background sediment flux in streambank erosion under management scenarios; the total LRS streambank sediment load is equal to the sum of the background scenario load for the scenario and a load due to impervious cover whose magnitude is 4/3 the impervious sediment load in the LRS under the scenario.

Table 9-6 provides an example of the calculation of phosphorus loads in streambank erosion under a management scenario and the resulting effects. The management scenario reduces upstream loads by 20%, compared to the calibration. Phosphorus loads in streambank erosion are also reduced by 20%. The FDF is not recalculated. The total load delivered to the river reach is 400 lbs/yr, which is equal to the upstream load under the scenario, but it is distributed between upstream sources and streambank erosion.

Table 9-6: Example Streambank Erosion Calculations under a Scenario for Phosphorus

Load Category or Delivery Factor	**Calibration**	**Scenario**
Upstream Load (EOS)	500 P (lbs/yr)	400 P (lbs/yr)
Streambank Erosion (EOS)	50 P (lbs/yr)	40 P (lbs/yr)
Floodplain Deposition (EOS)	50 P (lbs/yr)	Not Used in Scenario
Floodplain Delivery Factor (FDF)	0.909091	0.909091
stream-to-river Factor (from SPARROW)	1.0	1.0
(EOR) Upstream Load Delivered to River	454.55 P (lbs/yr)	363.64 P (lbs/yr)
(EOR) Streambank Erosion Delivered to River	45.45 P (lbs/yr)	36.36 P (lbs/yr)
Total EOR Load	500.00 P (lbs/yr)	400.00 P (lbs/yr)

In this case, by mass balance, the floodplain deposition must equal 40 lbs/yr. Suppose, however, streambank restoration reduced streambank erosion to 20 lbs/yr. The EOR load from upstream sources and the FDF would not change, but the EOR load from streambank erosion would be 18.18 lbs/yr and the total EOR load would be 381.82. By mass balance, floodplain deposition would be 38.18, not 40 lbs/yr.

9.4 Total Stream-to-River Factors

The total stream-to-river delivery factor is the product of the SPARROW stream-to-river delivery factors and the floodplain stream-to-river factors. Figures 9-6, 9-7, 9-8, and 9-9 show the nitrogen stream-to-river delivery factors on the land-river segment scale for crops, pasture, developed land, and natural land, respectively. Figures 9-10 through 9-13 show the corresponding phosphorus stream-to-river delivery factors, and Figures 9-14 through 9-17 show the corresponding sediment stream-to-river delivery factors. SPARROW has estimates of stream and reservoir attenuation at the NHDplus catchment level without regard to land use or load source. Any spatial correlation of attenuation and land use is taken into account when applying SPARROW values to the coarser phase 6 land-river segmentation. For example, policies may drive land use upstream of drinking water reservoirs to be higher in forest and lower in developed which would show up as a higher attenuation rate for forests relative to developed in land-river segments containing drinking water reservoirs.

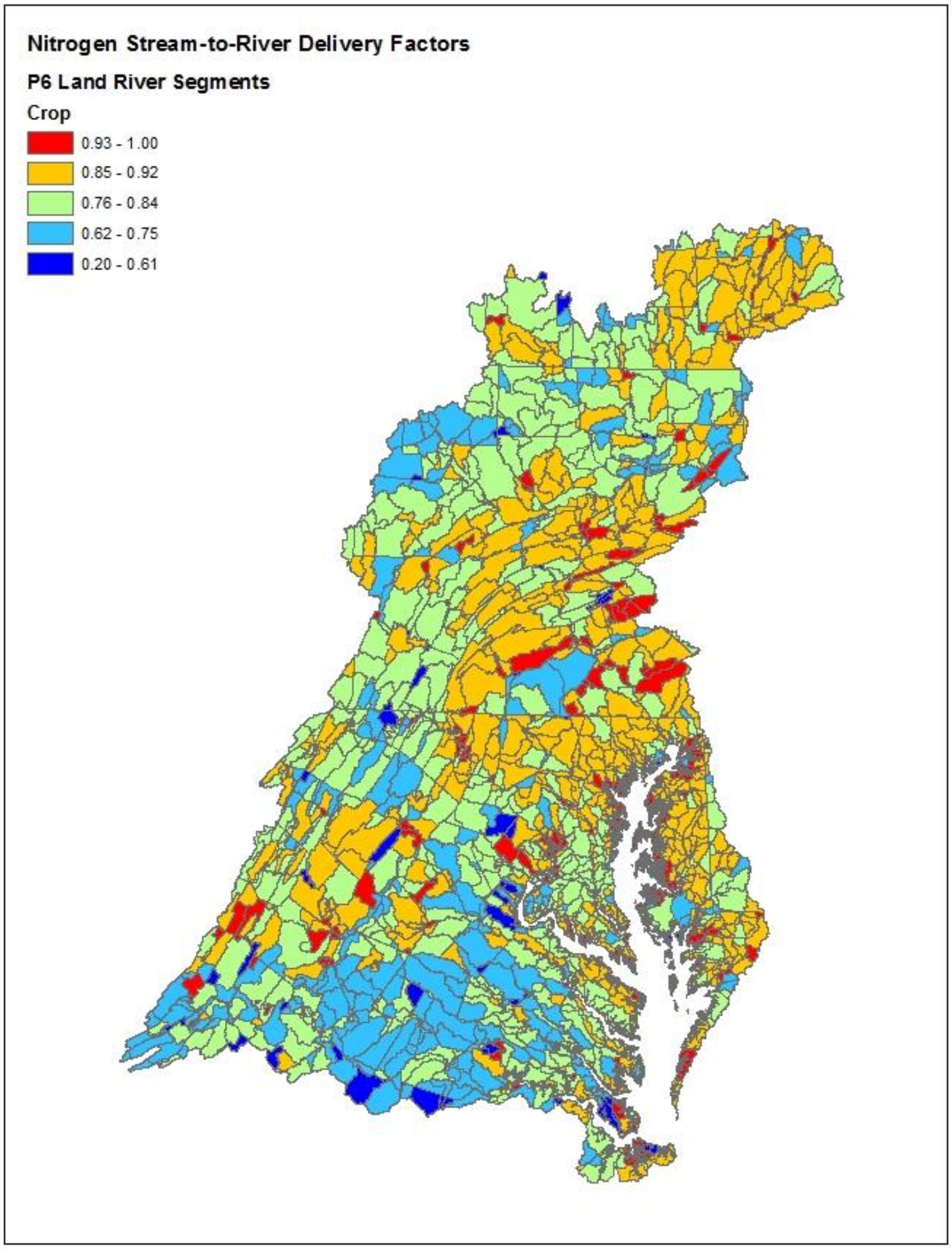

Figure 9-6: Phase 6 nitrogen crop stream-to-river delivery factors

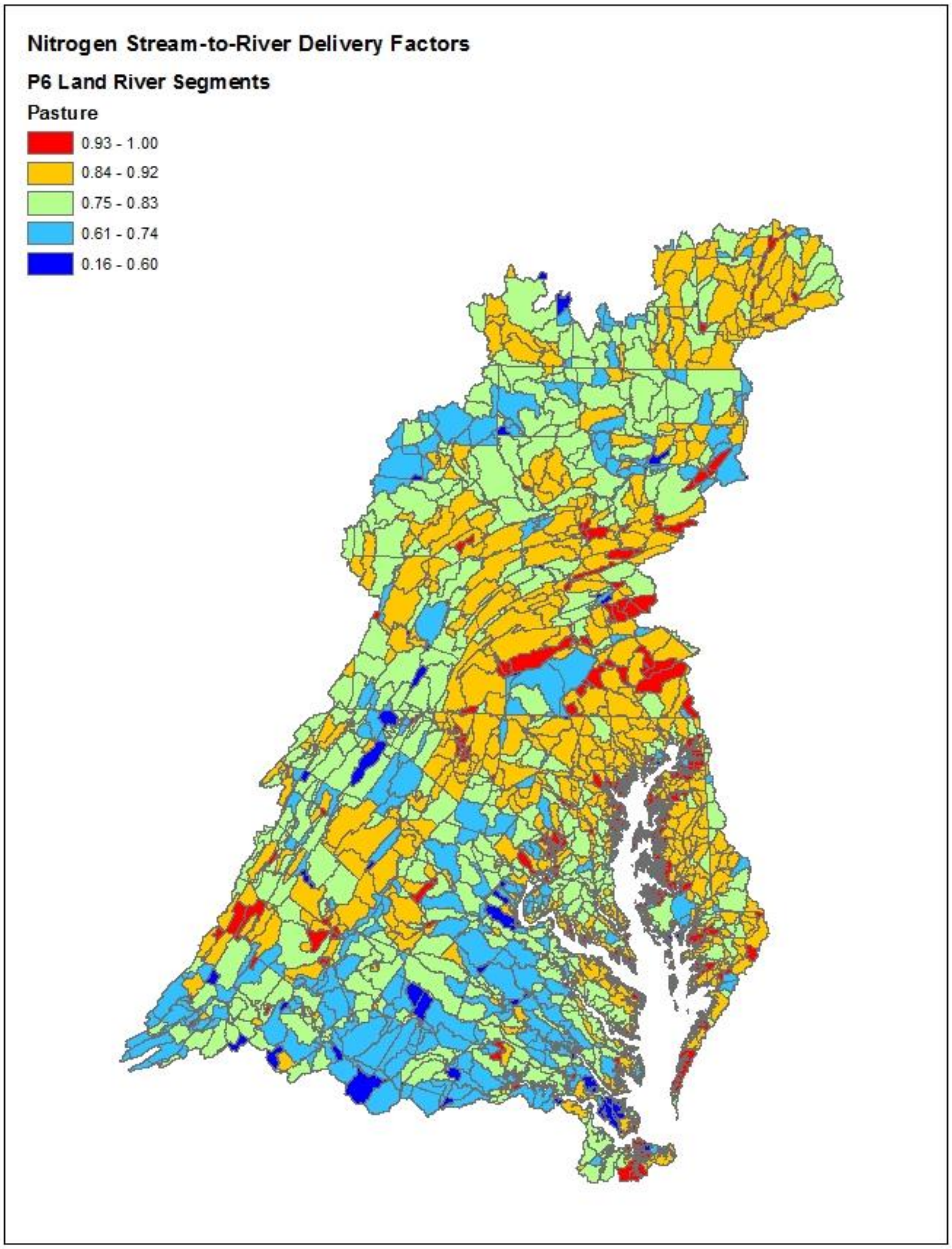

Figure 9-7: Phase 6 Nitrogen pasture stream-to-river delivery factors

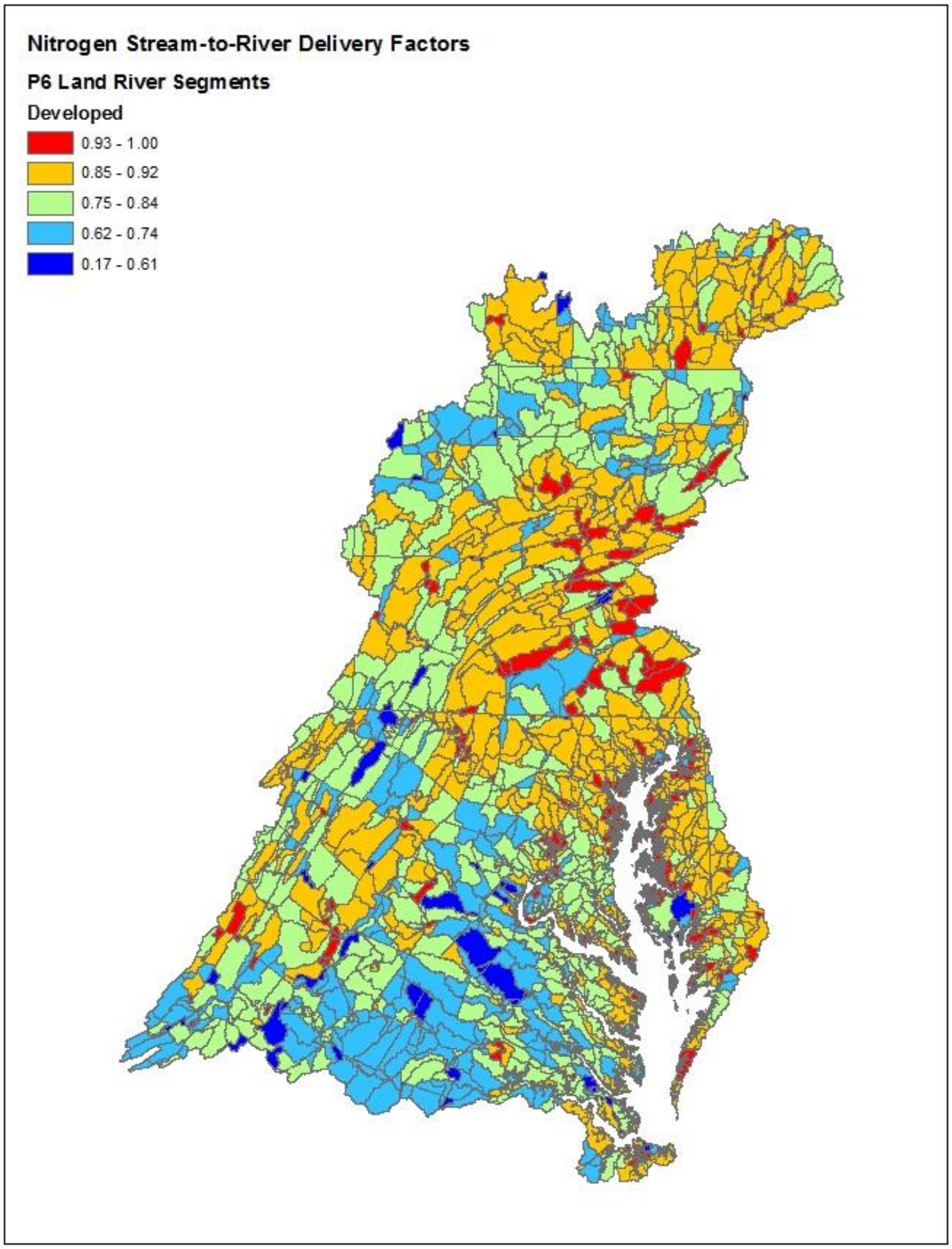

Figure 9-8: Phase 6 nitrogen developed land stream-to-river delivery factors

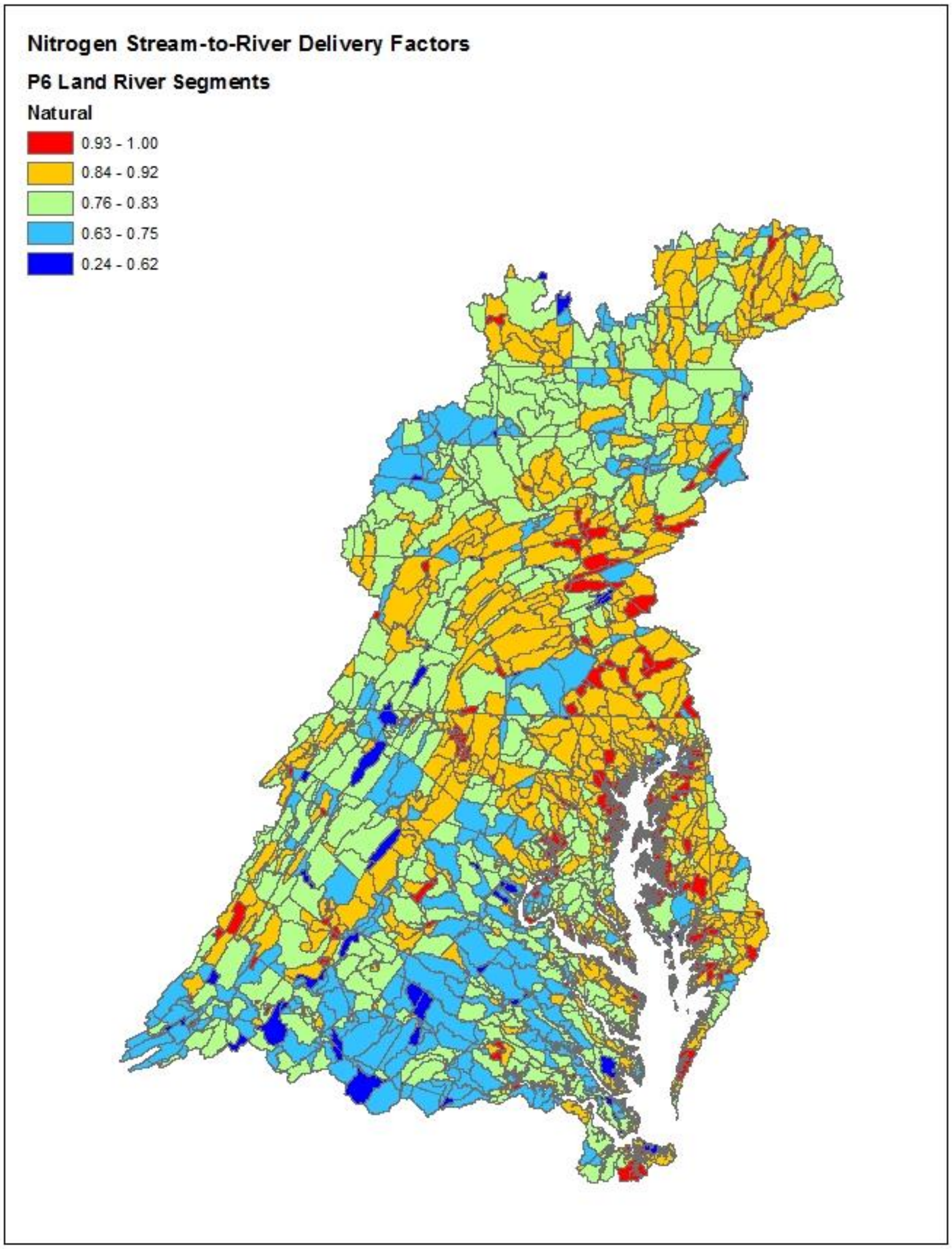

Figure 9-9: Phase 6 nitrogen natural land stream-to-river delivery factors

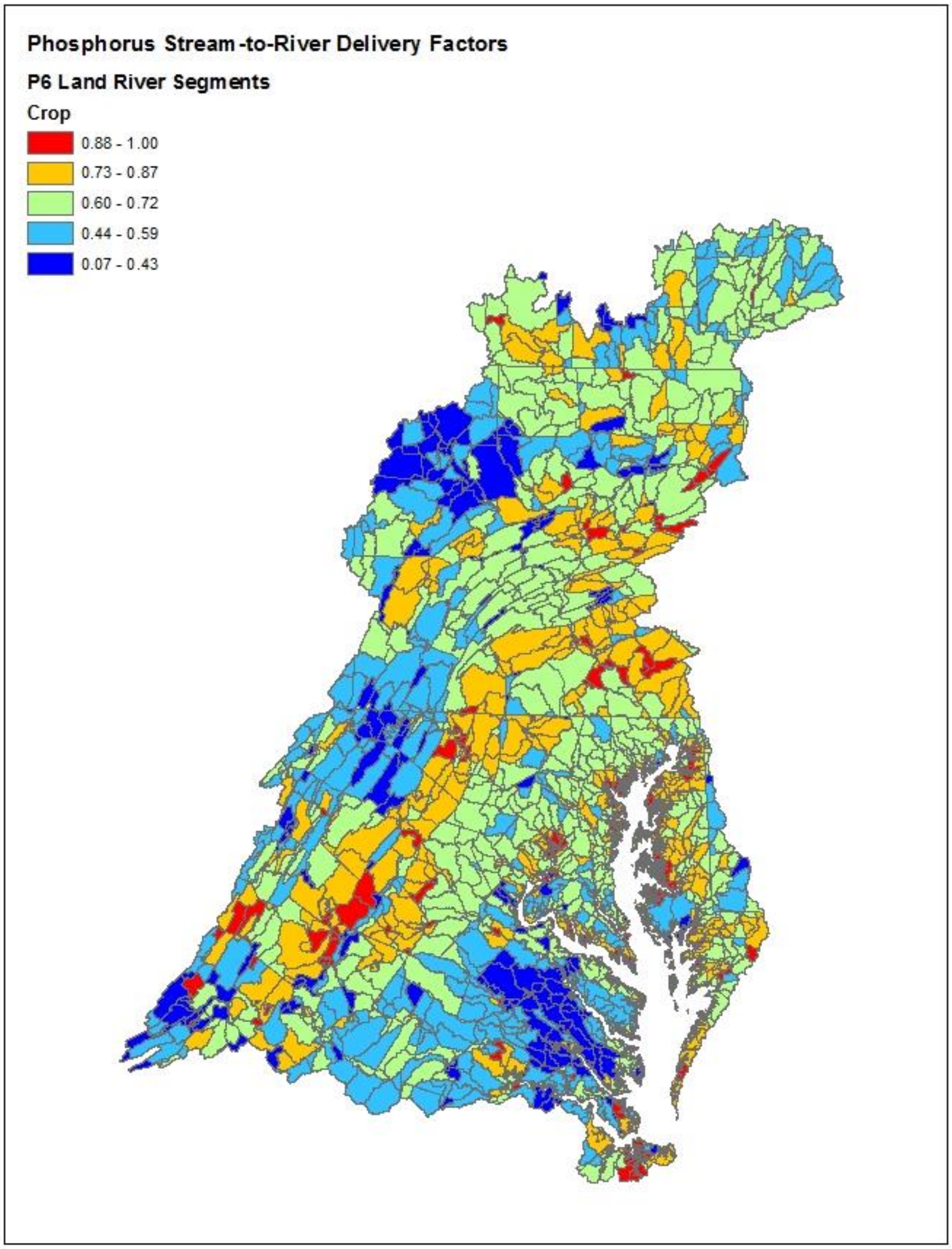

Figure 9-10: Phase 6 phosphorus crop stream-to-river delivery factors

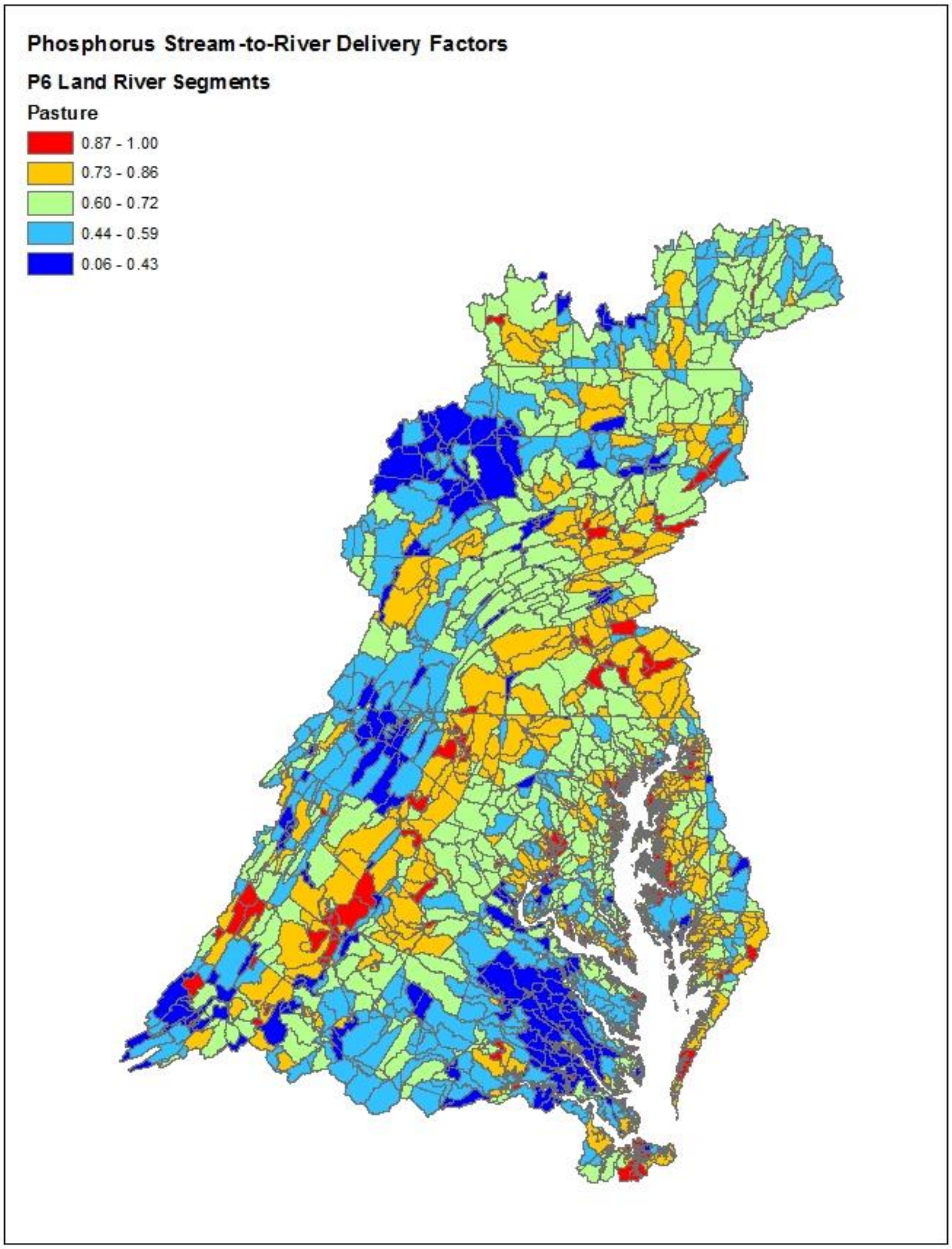

Figure 9-11: Phase 6 phosphorus pasture stream-to-river delivery factors

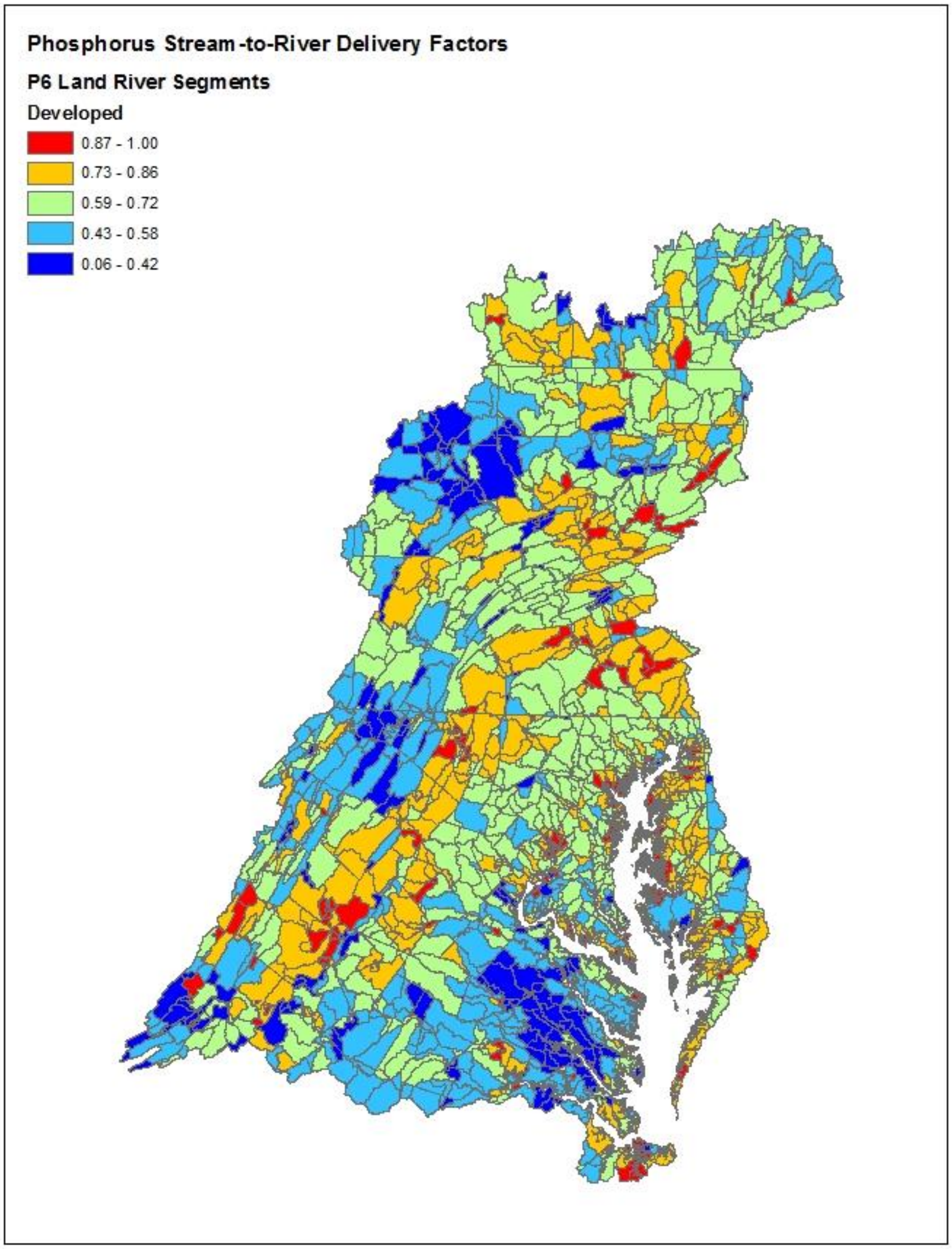

Figure 9-12: Phase 6 phosphorus developed land stream-to-river delivery factors

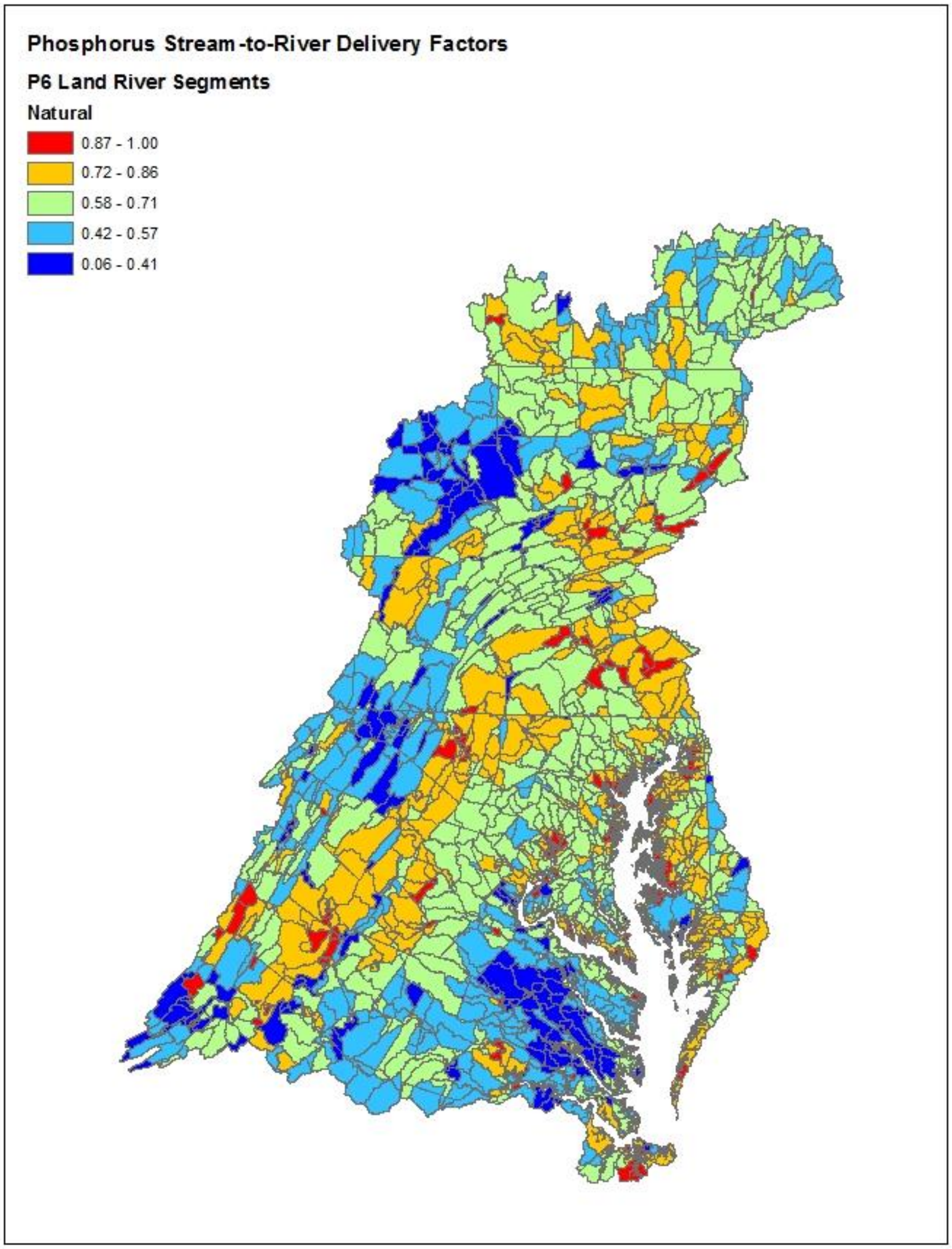

Figure 9-13: Phase 6 phosphorus natural land stream-to-river delivery factors

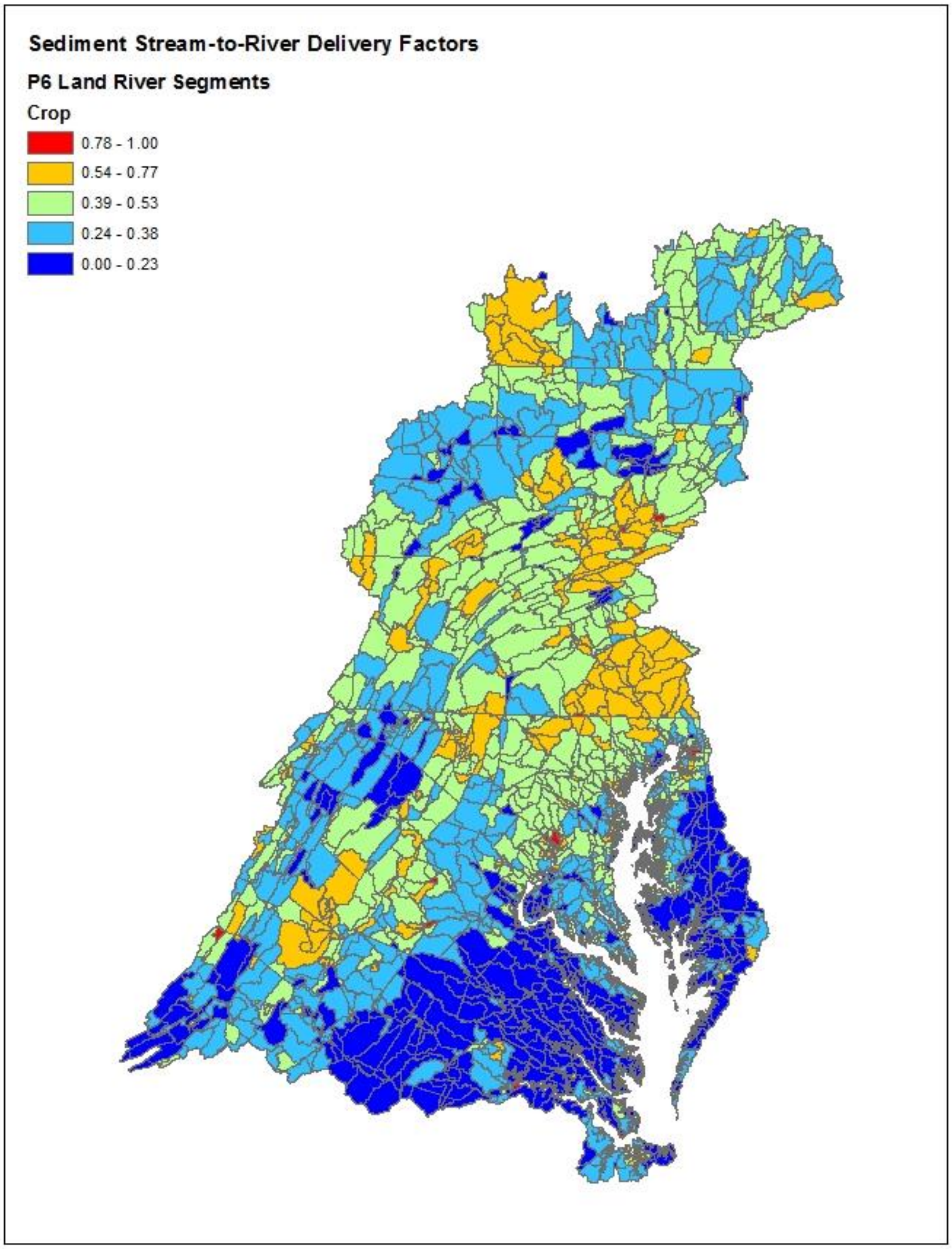

Figure 9-14: Phase 6 sediment crop stream-to-river delivery factors

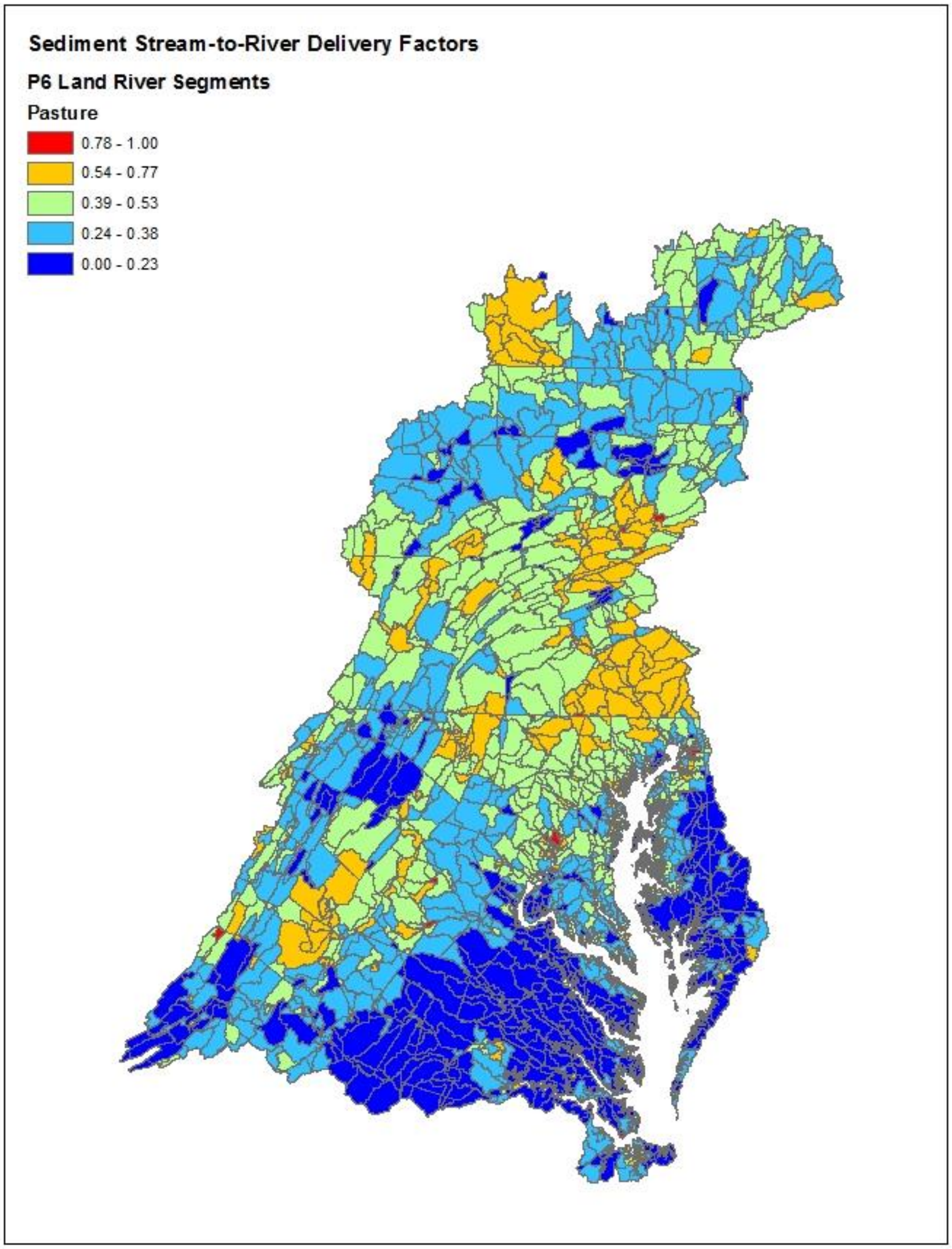

Figure 9-15: Phase 6 sediment pasture stream-to-river delivery factors

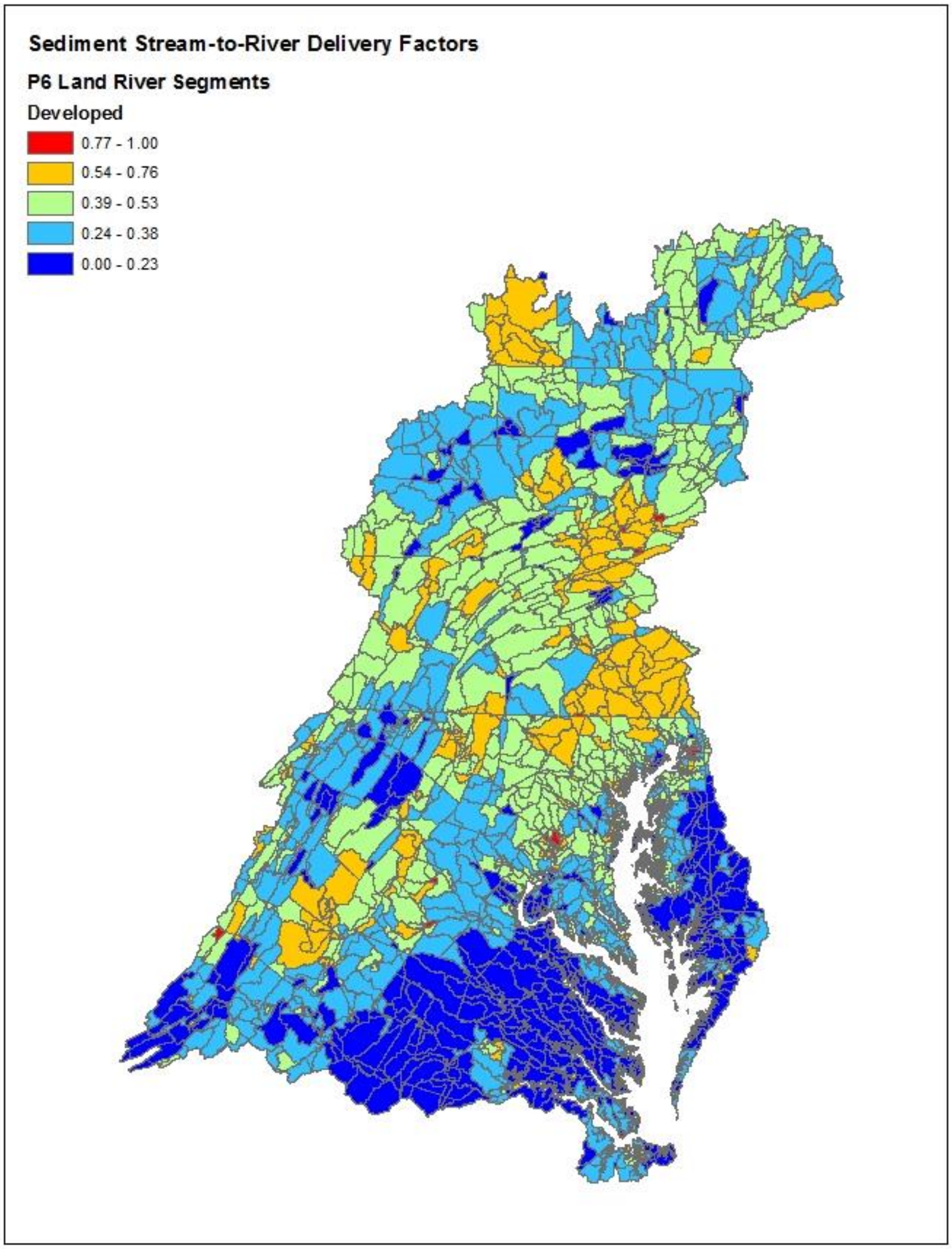

Figure 9-16: Phase 6 sediment developed land stream-to-river delivery factors

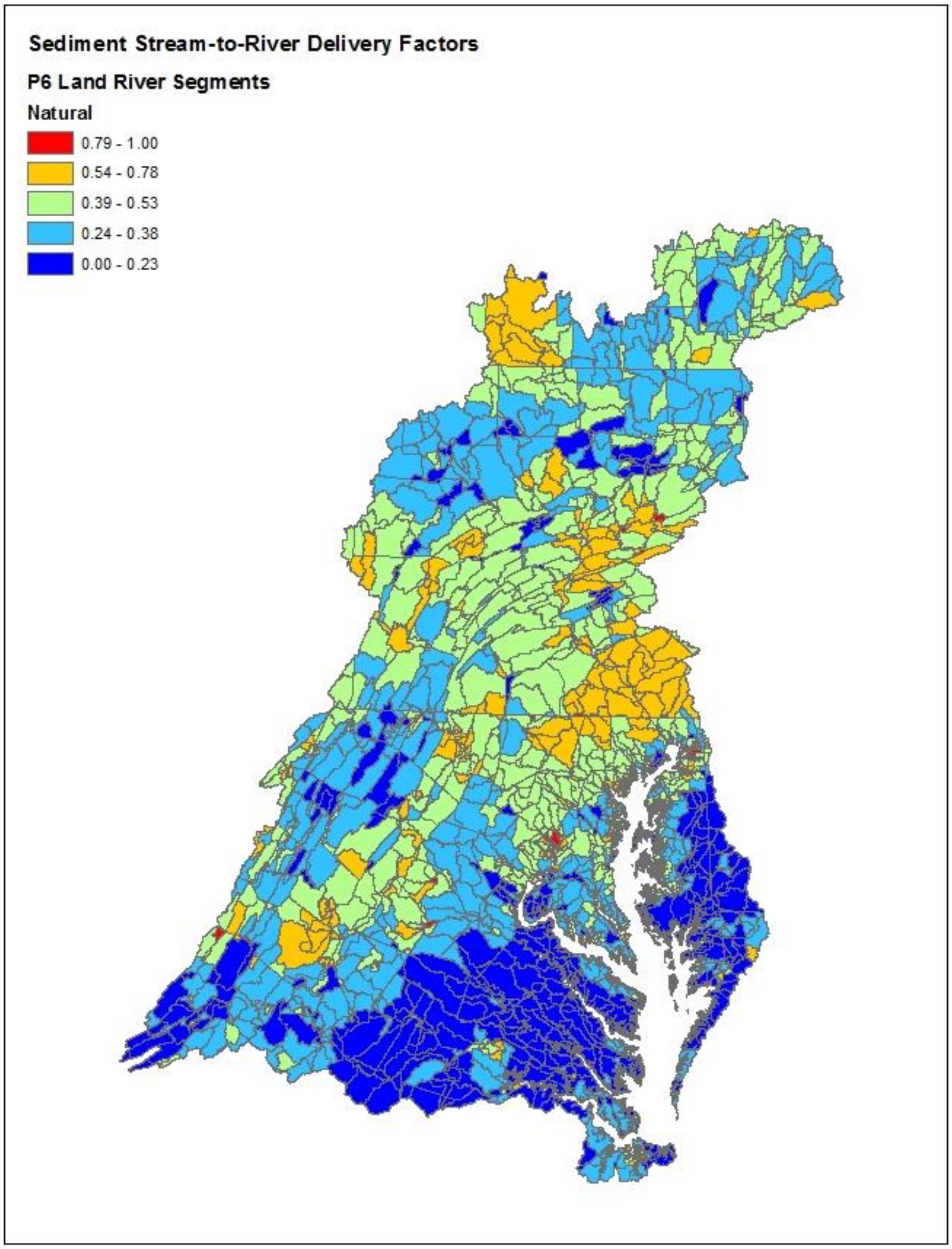

Figure 9-17: Phase 6 sediment natural land stream-to-river delivery factors