Spokane River Location Ratios

Water Quality Research Group
Department of Civil and Environmental Engineering
Maseeh College of Engineering and Computer Science

And

Washington Department of Ecology

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Portland State
UNIVERSITY

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Portland State University
Portland, Oregon 97201-0751

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Introduction

A total phosphorus (TP) point to point source discharge trading scheme may be proposed for the Spokane River total maximum daily load (TMDL) study area. The section of the river proposed for trading would extend from the Washington/Idaho border at river mile (RM) 96 to the TMDL assessment point, occurring 38 miles downstream, at RM 58. Among the initial steps to providing a framework for any trading activity is the determination of location ratios for this river section.

The Upper Spokane River system is located in the northeastern part of Washington State and flows from Coeur d'Alene Lake, Idaho at RM (River Mile) 111.3 downstream to Long Lake dam at RM 32.5. The Washington Department of Ecology has issued a dissolved oxygen TMDL and national pollutant discharge elimination system (NPDES) permits for five Washington wastewater treatment plants on the Spokane River from the Idaho border to Long Lake Dam. The United State Environmental Protection Agency (EPA) will likely issue NPDES permits to wastewater treatment plants on the Idaho portion of the Spokane River in 2012, and the Idaho Department of Environmental Quality will issue 401 certifications for those permits. The TMDL, along with a 401 certification for the federal energy regulatory commission (FERC) relicensing of Spokane River dams, will reduce phosphorus loadings and affect minimum in-stream flows in the Spokane River.

The model used for the Spokane River system is the publicly available CE-QUAL-W2 (Cole and Wells, 2008) This model is a 2-dimensional (longitudinal-vertical) hydrodynamic and water quality model capable of predicting water surface, velocity, temperature, nutrients, multiple algae groups, periphyton, dissolved oxygen, pH, alkalinity, multiple CBOD groups, and multiple organic matter groups, both dissolved and particulate. The model is set up to predict these state variables at longitudinal segments and vertical layers. Typical model longitudinal resolution is between 446-1072 m; vertical resolution is usually between 0.5 m and 1 m. The user manual and documentation can be found at the Portland State University (PSU) website for the model: http://www.cee.pdx.edu/w2. Since 2000, this model has been used extensively throughout the world in 116 different countries. Existing CE-QUAL-W2 water quality models (Washington and Idaho) of the Spokane River were updated to the more recent version 3.6 (Berger et al., 2009). These models were used to help determine the impact of the TMDL and the FERC relicensing on the Spokane River water quality. The models were originally developed by Portland State University for the Washington Department of Ecology and EPA to simulate temperature, dissolved oxygen, nutrients, algae, and organic matter. The updated model simulates the year 2001, and the calibration has also been checked for the year 2000.

The Spokane River TMDL timeline is summarized in Table 1. Prior reports prepared for the Spokane River modeling in Washington and Idaho include:

- Annear et al. (2001) - Upper Spokane River Model: Boundary Conditions and Model Setup for 1991 and 2000
- Berger et al. (2002) - Upper Spokane River Model: Calibration for 1991 and 2000
- Slominski et al. (2002) - Upper Spokane River Model: Boundary Conditions and Model Setup for 2001 where information such as the following were detailed:
    1. Inflows, temperatures, and water quality
    2. Meteorological conditions
    3. Bathymetry of the Spokane River and Long Lake and the model grid
    4. Reservoir operations and structure information
- Berger et al. (2003) - Upper Spokane River Model: Calibration for 2001

- Annear et al. (2005)- Upper Spokane River Model in Idaho: Boundary Conditions and Model Setup for 2001 and 2004.
- Wells and Berger (2009)- Spokane River in Idaho and Washington TMDL Water Quality and Hydrodynamic Modeling, Quality Assurance Project Plan.
- Berger et al. (2009)- Spokane River Modeling Report 2009, Model Update and Calibration Check.
- Water Quality Research Group (2009) - Spokane River Modeling Scenarios Report 2009
- Water Quality Research Group (2010) - Spokane River Modeling Final Scenarios Report 2010

For the development of location ratios the 38 mile section between the Washington-Idaho state line and Long Lake will be analyzed. The concept of location ratios is that proximity has bearing on the net effect of any change in TP (total phosphorus) loading occurring as a consequence of a trade as observed at a downstream fixed location. This is because the TP load, within the 38 mile study section, is subjected to a variety of pathways that phosphorus is both gained and lost from the water column. TP is introduced to the river by point source discharges such as municipal wastewater treatment plants, storm water, tributaries such as Hangman Creek, and groundwater inflow, among other sources. Losses (referred to as attenuation) occur through a variety of physical and biological processes. Additional considerations include the river's complex hydraulics affected by a number of dam structures and its connection with the Spokane Valley–Rathdrum Prairie aquifer. For this reason, accounting of these various pathways is a critical consideration in determining location ratios. In application, the location ratio is a factor, potentially between 0 and 1, which accounts for the level of attenuation and, in the process, potentially modifies the actual amount of credit awarded through a trade.

Table 1. Spokane River TMDL Timeline.

Date	**Description**
1970s	Occurrence of toxic algae blooms in Long Lake
1992	Total phosphorus TMDL developed to alleviate toxic blue-green algae blooms
1996-2008	Segments of Spokane River and Long Lake included on one or more of Washington Department of Ecology 303(d) lists of impaired water bodies for dissolved oxygen
2004	First draft dissolved oxygen TMDL
2010	Final dissolved oxygen TMDL

Methods

Phosphorus gains and losses will be calculated with a computer program that reads model input and output files. CE-QUAL-W2 will also be programmed to create a specialized output file that contains model predicted total phosphorus losses due to groundwater outflows.

Inflows and outflows that contribute to phosphorus loadings and losses between the state line and Long Lake are illustrated in Figure 1. Their seasonal loads for the March-October period are shown in Figure 2. The CE-QUAL-W2 model is divided into 11 branches in this section and the location ratios will be defined on a branch by branch basis. Inflows include point sources, tributaries, groundwater, storm water, and combined sewer overflows. TP gaining and losing pathways from the water column include inflows and outflows along with fluxes between the sediments and between periphyton (attached algae). The TP gaining pathways are:

- Point sources
- Groundwater inflows
- Tributaries
- Sediment 1st order decay
- Sediment zero order release
- Periphyton mortality and excretion
- Periphyton respiration

TP losing pathways are:

- Groundwater outflows
- Settling of algae
- Settling of particulate organic matter (POM)
- Ortho-phosphate (PO4-P) uptake by periphyton

These pathways are listed and described in more detail in Table 2. Figure 3 illustrates these pathways in and out of the water column. Sediment burial can also be considered a loss but will not be included in the calculation of location ratios because phosphorus contained in the buried sediment is already counted as a loss out of the water column through the settling of POM and algae.

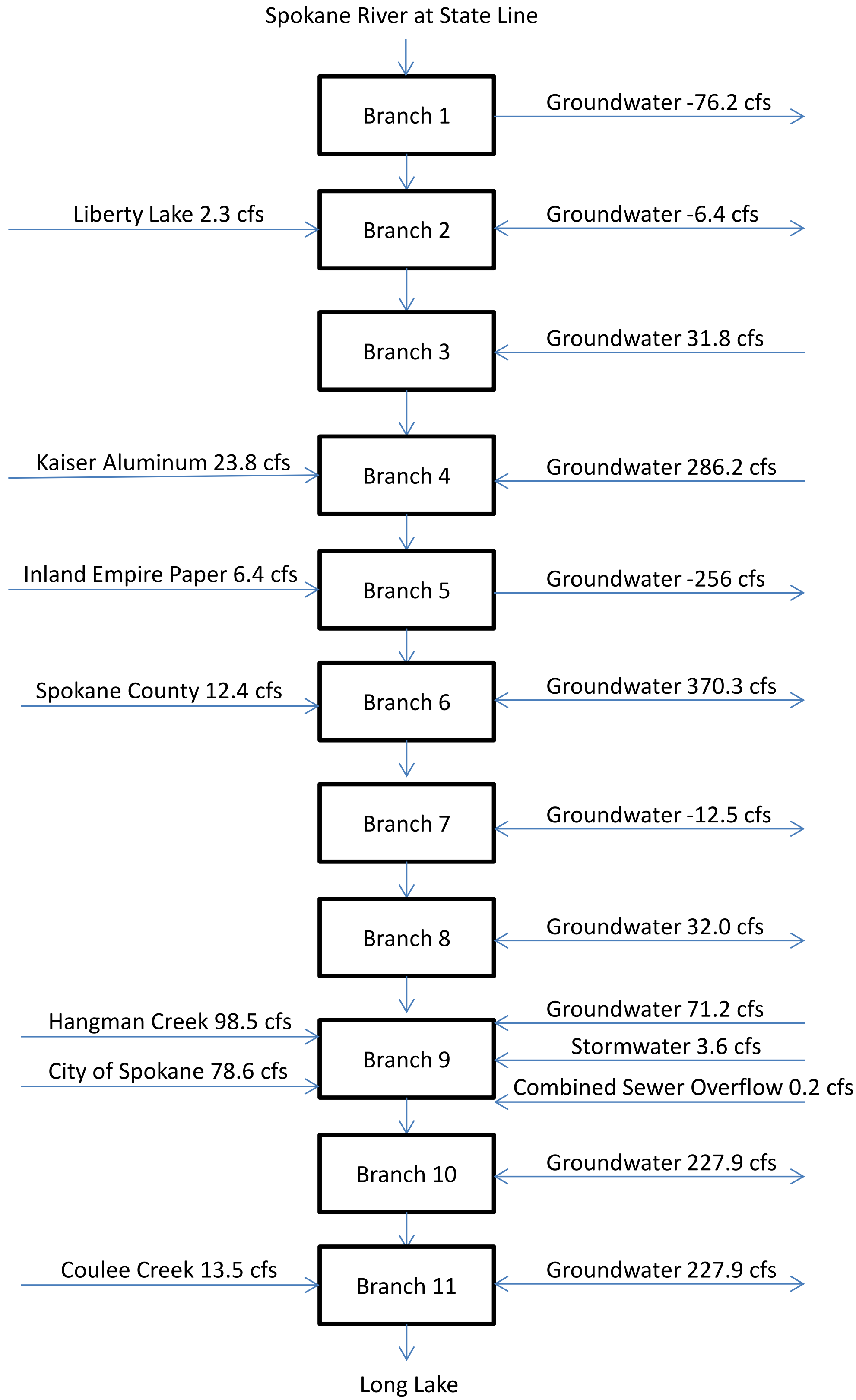

Figure 1. Average annual 0flow rate of Spokane River loading sources between state line and Long Lake.

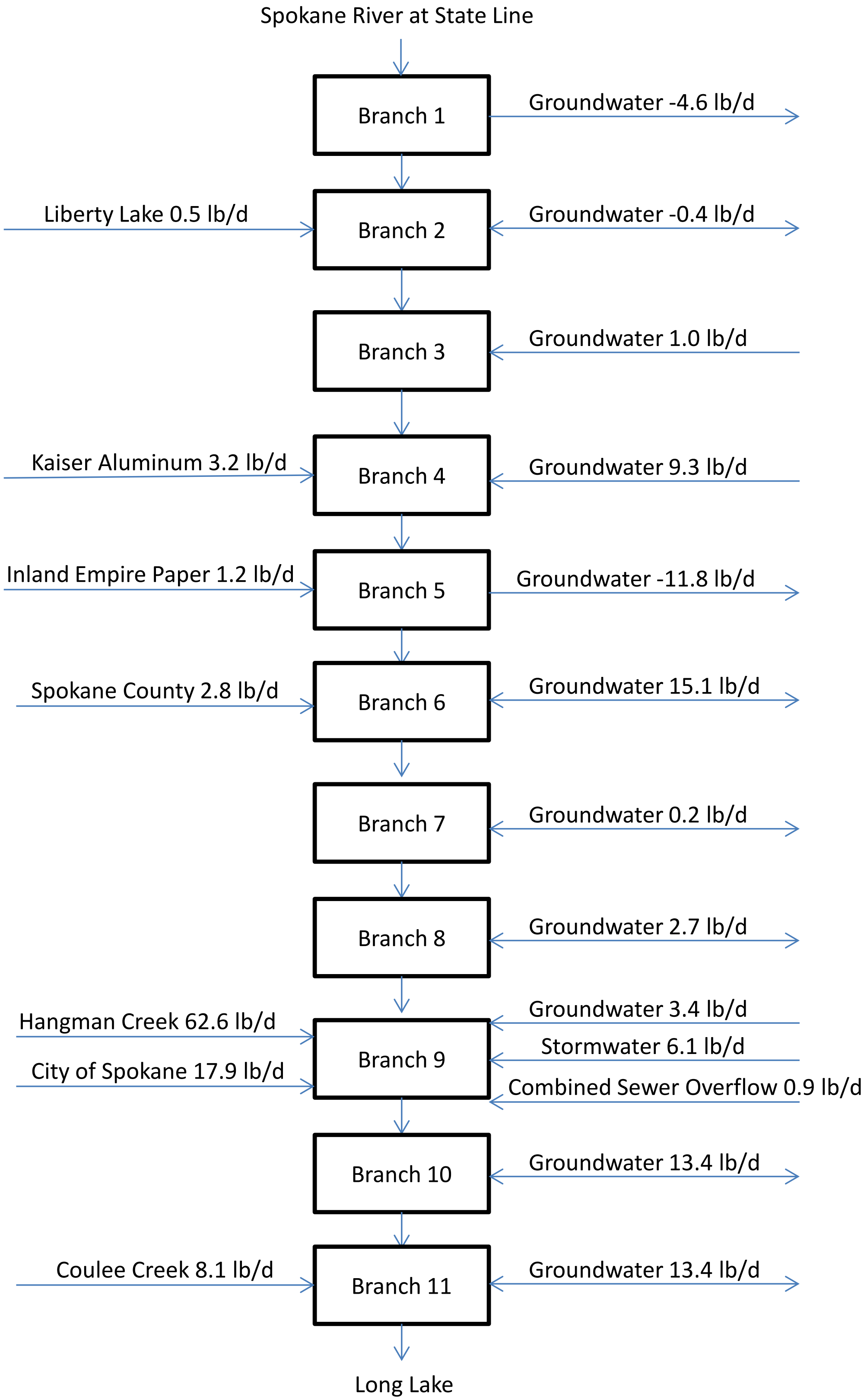

Figure 2. Seasonal (March-October) phosphorus loads of Spokane River loading sources between state line and Long Lake.

Table 2. TP gaining and losing pathways.

	Name	Description
TP Gaining Pathways	Point Sources, Stormwater, CSOs	Loadings from wastewater treatment plants, industrial dischargers, combined sewer overflows, and stormwater
	Groundwater Inflows	Inflows of groundwater. Modeled as distributed tributaries.
	Tributaries	Inflows from Hangman or Coulee Creek
	Sediment 1st Order Decay	Release of PO4-P through aerobic decay of sediments.
	Sediment Zeroth Order Release	Anaerobic release PO4-P through zeroth order sediment compartment.
	Periphyton Respiration	Release of PO4-P through periphyton respiration
	Periphyton mortality and excretion	Release of LDOM-P (labile dissolved organic matter – phosphorus) due to periphyton mortality and excretion
TP Losing Pathways	Groundwater Outflows	Inflows of groundwater. Modeled as distributed tributaries with negative flow rates
	Settling of algae	Settling of algae out of water column and into first order sediment compartment.
	Settling of Particulate Organic Matter	Settling of LPOM-P (labile particulate organic matter – phosphorus) and RPOM-P (refractory particulate organic matter - phosphorus) into first order sediment compartment
	Ortho-phosphate (PO4-P) Uptake by Periphyton	Uptake by periphyton (attached algae) for cell growth
	Sediment Burial	Burial of sediments in first order sediment compartment. Not included as a losing pathway calculation of location ratios because phosphorus in sediment has already been counted (settling of algae and POM) as loss from water column.

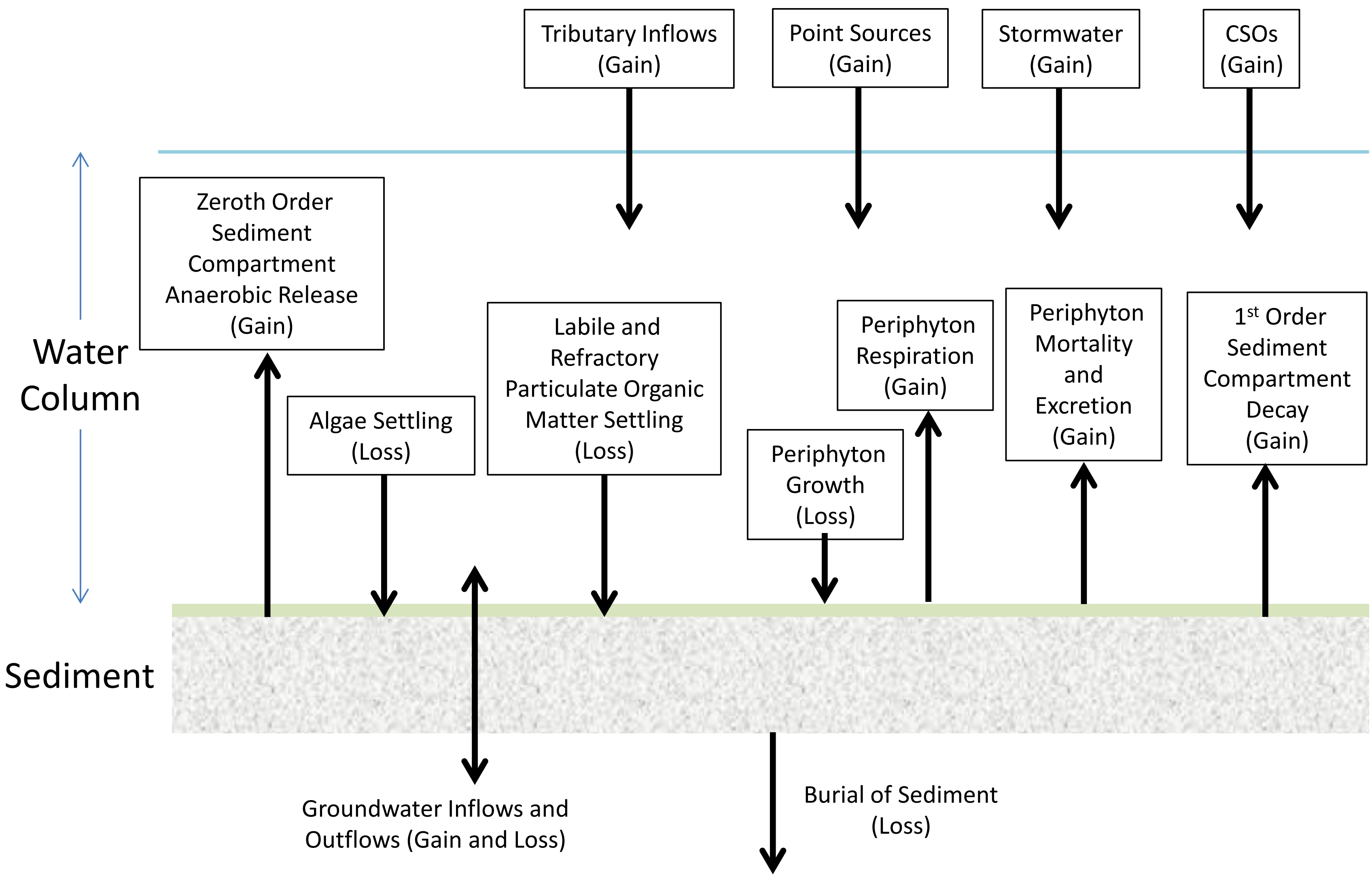

Figure 3. Modeled phosphorus pathways to and from water column.

Location ratios are based on an accounting of the portion of the total amount of phosphorus added between two locations (one fixed at the TMDL assessment point) that is "lost" and, therefore, not available for credit. Starting with branch 11 (the bottom of 11 is the TMDL assessment point) and working toward branch 1, the TP loading gains and losses are accounted for cumulatively. Percent attenuation A_j for a given model branch j is defined as ratio of accumulated losses divided by accumulated gains:

$$A_j = \frac{\sum_{i=11}^{j}(Losing\ Pathways)}{\sum_{i=11}^{j}(Gaining\ Pathways)} \times 100$$

For instance, the percent attenuation at branch 5 would be calculated by summing all the gaining pathways between branch 11 and branch 5 and dividing by the total losing pathways between branch 11 and 5, times 100. The location ratio L_j for branch j would then be calculated by subtracting the decimal value of attenuation from 1:

$$L_j = 1 - \frac{\sum_{i=11}^{j}(Losing\ Pathways)}{\sum_{i=11}^{j}(Gaining\ Pathways)}$$

Phosphorus gaining and losing pathways will be quantified and presented on a monthly and seasonal (March-October) basis as shown in Table 3. Location ratios and total gains and losses will be listed in a format as shown in Table 3.

Table 3. Water Column total phosphorus gaining and losing pathways.

Branch		TP Gaining Pathways							TP Losing Pathways					
	Point Sources (lb/d)	Ground-water Inflows (lb/d)	Trib-utaries (lb/d)	Storm water (lb/d)	CSO (lb/d)	Sedi-ment 1st Order Decay (lb/d)	Sedi-ment Zeroth Order Release (lb/d)	Peri-phyton Res-piration (lb/d)	Peri-phyton mortalit y and excretio n (lb/d)	Ground-water Outflow (lb/d)	Settling of algae (lb/d)	Settling of Par-ticulate Organic Matter (lb/d)	PO4-P Uptake by Peri-phyton (lb/d)	Sedi-ment Burial (lb/d)
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
Total														

Table 4. Location ratios.

Branch	Gain (lb/d)	Loss (lb/d)	Net (lb/d)	Cumulative Gains from Branch 11 (lb/d)	Cumulative Losses from Branch 11 (lb/d)	Attenuation (Losses/Gains)*100	Location Ratio (as decimal) 1 – attenuation
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
Total							

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