Little Spokane River Dissolved Oxygen, pH, and Total Phosphorus Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

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Water Quality Improvement Report and Implementation Plan

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Introduction

Overview

Section 303(d) of the Federal Clean Water Act (CWA) requires states to identify waters within their boundaries that are not meeting state water quality standards. For these impaired waterbodies, Section 303(d) further requires states to develop a Total Maximum Daily Load (TMDL) for the pollutant(s) violating or causing violation of water quality standards. A TMDL defines the maximum amount of the pollutant that a waterbody can receive while continuing to meet water quality standards. A TMDL also allocates the maximum allowable pollutant load between point and nonpoint sources of the pollutant. A TMDL provides a framework for EPA, states, and partner organizations to establish and implement pollution control and management plans, with the ultimate goal described in Section 101(a) (2) of the CWA: "water quality which provides for the protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water, wherever attainable."

This report presents TMDLs to address low dissolved oxygen (DO) and high pH impairments in surface waters in the Little Spokane watershed. This report also addresses total phosphorus load allocations set for the mouth of the Little Spokane River by the *Spokane River and Lake Spokane Dissolved Oxygen Total Maximum Daily Load Water Quality Improvement Report* (Moore and Ross, 2010) hereon referred to as the *Spokane River and Lake Spokane DO TMDL*.

Appendix A provides additional information about the Clean Water Act and TMDLs.

Why Ecology Conducted a TMDL Study in this Watershed

Ecology initiated TMDL studies in this watershed in the early 2000s. The initial effort focused on addressing fecal coliform bacteria, temperature, and turbidity impairments. EPA approved this TMDL in 2012 (Joy & Jones, 2012).

The Little Spokane River (LSR) and its tributaries are also impaired by low dissolved oxygen (DO) and high pH. 303(d) lists of impaired waterbodies have included locations in the LSR watershed going back to 1996. In addition, the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010) set total phosphorus (TP), ammonia, and carbonaceous biological oxygen demand (CBOD) allocations at the mouth of the Little Spokane River. Ecology developed this Little Spokane River DO, pH, and TP TMDL to address both the in-watershed DO and pH impairments and the total phosphorus allocations at the mouth.

The LSR watershed provides a recreational and scenic rural landscape consisting of forested ridges, small agricultural valleys, small urban centers, and abundant wildlife. However, historical resource extraction practices, development pressures, and detrimental land management practices have resulted in significant impacts to water resources and water quality in the watershed. Issues such as stormwater runoff, sedimentation, riparian vegetation losses, streambank erosion, wetland losses, and agricultural and forestry management are major concerns. These concerns will remain as development pressure in the watershed increases.

Appendix A provides additional details about the geography, climate, hydrology, and land uses of the Little Spokane River watershed.

DO, pH, temperature, and nutrients

DO and pH concerns are often linked to: 1) high water temperatures/low shade; and 2) excessive amounts of phosphorus and nitrogen. Warm water holds less dissolved oxygen than cold water. Lack of stream shading (also a key cause of high water temperatures) results in abundant light reaching algae and aquatic plants, which can cause excessive growth.

Phosphorus and nitrogen are nutrients essential for plant growth. In excess amounts they become a concern for most aquatic ecosystems. Under natural conditions where human activities do not dominate the landscape, nutrients are typically in short supply and are a limiting factor for aquatic plant growth. As more nitrogen and phosphorus enter a waterbody, they act to fertilize the aquatic system, allowing for more plant and algae growth. This condition of nutrient enrichment and high plant productivity is referred to as eutrophication. Eutrophication can alter the ecology of the waterbody and degrade the services it provides, including swimming, fishing, and other recreational uses, and supplies of clean drinking water.

Excessive plant and algae growth are an important driver of low DO and high pH conditions. Algal and plant photosynthesis during daylight hours consumes carbon dioxide and produces oxygen, raising DO and pH. Algal and plant respiration, which continues during the nighttime, consumes oxygen and produces carbon dioxide, lowering DO and pH. Therefore, excessive plant and algae growth tends to result in diel “swings” of DO and pH, with excessively high pH occurring during the afternoon and low DO occurring during the early morning.

TMDL goals

The goals of this TMDL are:

- To meet water quality standards for DO and pH in streams throughout the Little Spokane River watershed.
- To protect downstream DO in Lake Spokane, specifically by meeting the total phosphorus load allocation set for the mouth of the Little Spokane River in the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010).

The activities that need to be implemented to meet these goals include many of those included in the *Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity Total Maximum Daily Load* (Joy and Jones, 2012). These include increasing streamside shade, reducing or eliminating nutrient sources, and reducing erosion and runoff, which will provide more functional habitat to native whitefish, redband trout, and other aquatic species. It is also important to note that the Little Spokane River watershed historically provided important habitat for anadromous salmon and steelhead trout prior to the construction of Columbia River hydropower facilities, such as Grand Coulee Dam. The implementation activities will benefit those species if recovery efforts proceed. Implementing water quality improvements recommended in the TMDL to reduce nutrients will also ensure safe swimming, fishing, and boating. In turn, water quality improvements in the LSR watershed are imperative to meet downstream water quality standards in Lake Spokane.

Scope

This TMDL addresses dissolved oxygen, pH, and nutrient issues in all flowing streams in the Little Spokane River watershed (WRIA 55) within Washington State (Figure 1). It also protects downstream waterbodies (i.e. Lake Spokane).

This report does provide some limited data and analysis for lakes within the Little Spokane River watershed, as lakes are an integral part of the aquatic system, particularly within the West Branch LSR sub-basin. However, this TMDL only covers flowing (lotic) stream systems. It is beyond the scope of this TMDL to thoroughly address eutrophication in lakes and wetlands.

Impairments addressed by this TMDL

The primary use to be protected by this TMDL is the aquatic life use of core summer salmonid habitat. As described in the **Water Quality Criteria** section, dissolved oxygen and pH are important to the health and vitality of fish.

Table 1 and Figure 1 provide a summary of 303(d) impaired water bodies that are addressed by this TMDL. Dissolved oxygen and pH are affected by temperature and nutrient loads. This TMDL will protect aquatic life uses by lowering instream water temperature by increasing shade, and by decreasing the loading of phosphorus and nitrogen into the water bodies.

During the research and data-gathering process for this study, we found additional waterbody segments that do not meet state water quality standards (see Table 2). This TMDL also addresses these segments.

Appendix A provides further details about water quality issues in the Little Spokane watershed.

As described above under **DO, pH, temperature, and nutrients** and detailed later in the **Instream DO and pH TMDL Analysis** section, the primary factors driving low dissolved oxygen and high pH are insufficient shade and excessive nutrients. For this reason, this TMDL uses **surrogate measures**. That is, rather than expressing load and wasteload allocations in terms of DO and pH, this TMDL expresses allocations in terms of shade, heat, and nutrient loads.

The sources of pollutants in the Little Spokane River watershed are detailed in the **Implementation Plan** section below, as well as the **Land use and potential pollutant sources** section of Appendix A. These sources include lack of riparian vegetation, sediment-linked nutrients from crop production and erosion, nutrients from livestock, stormwater, and septic systems, runoff from residential areas, groundwater nutrients, and permitted point sources such as the Spokane Hatchery.

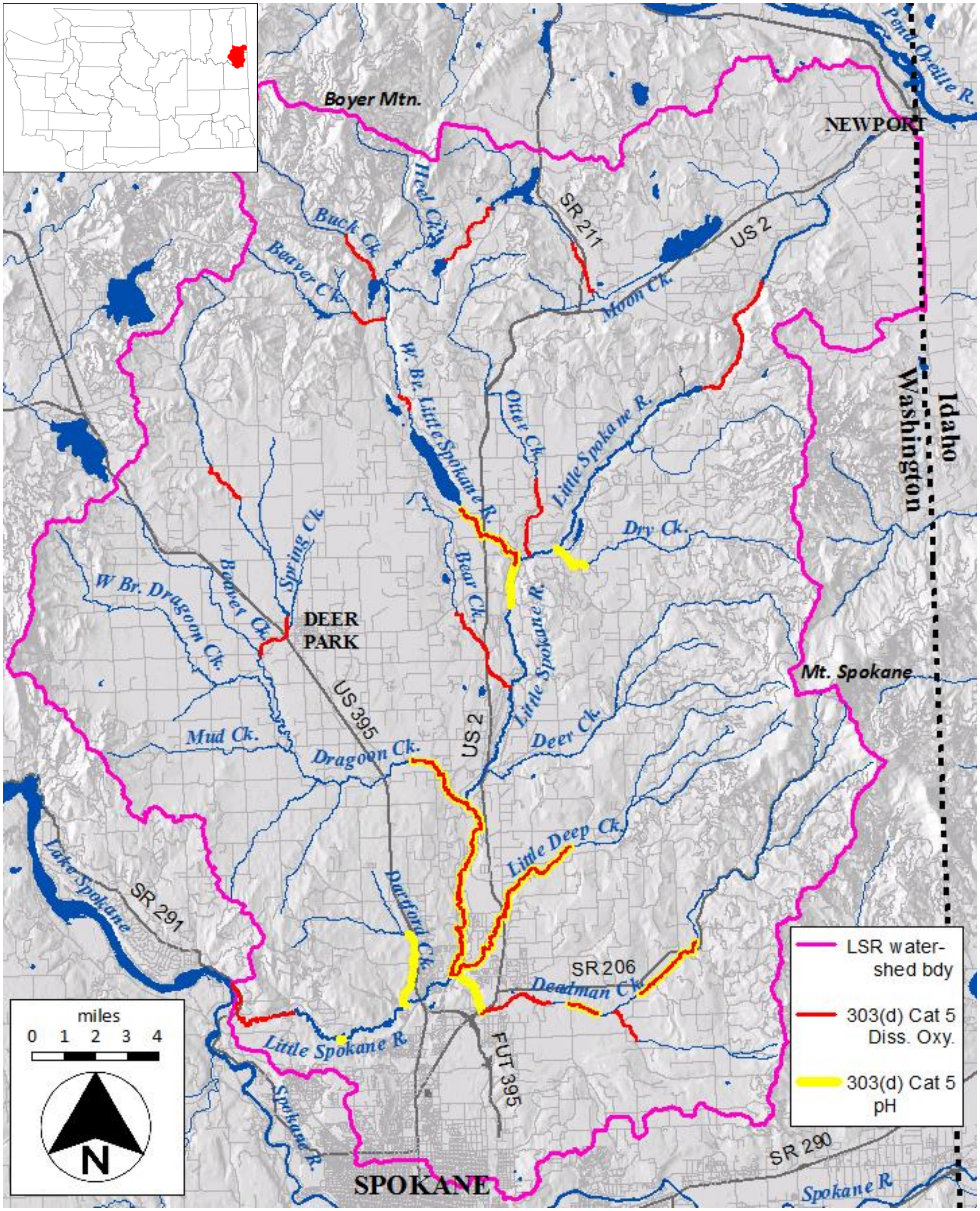


Figure 1. Study area for the Little Spokane DO-pH TMDL, also showing 303(d) listed water bodies for dissolved oxygen and pH.

Table 1. Study area waterbodies on the 2012 303(d) list for dissolved oxygen and pH.

Waterbody Name	Parameter	+NHD reach code	Assessment Listing ID
Little Spokane River (near Scotia)	DO	17010308000083	47875
Little Spokane River (near Milan)	pH	17010308000077	50436
Little Spokane River (Dragoon to Deadman Creeks)	DO, pH	17010308001158	47133, 50434
Little Spokane River (near mouth)	DO	17010308000018	42597
Dry Creek (above mouth at LSR)	pH	17010308000156	50373
Otter Creek (above mouth at LSR)	DO	17010308000365	47070
Moon Creek (near SR 211)	DO	17010308000099	47861
Little Spokane River, West Branch (between Sacheen and Trout Lakes)	DO	17010308006689	47863
Beaver Creek (above mouth @ West Branch)	DO	17010308000101	47869
Buck Creek (above mouth @ West Branch)	DO	17010308000142	47872
Little Spokane River, West Branch (near Fan Lake Road)	DO	17010308000088	47862
Little Spokane River, West Branch (Eloika Lake to mouth)	DO, pH	17010308000085	47073, 50379
Bear Creek (above mouth at LSR)	DO	17010308001818	47074
Dragoon Creek (near Spotted Road)	DO	17010308000125	8445
Dragoon Creek (Dragoon Lake to Spring Ck)	DO	17010308000119	47094
Dragoon Creek (Spring Ck to Beaver Ck)	DO	17010308000118	8443
Dragoon Creek (above mouth)	DO, pH	17010308000107	11368, 11370
Deadman Creek (near Heglar Rd)	DO, pH	17010308000038	42357, 50411
Peone Creek (Burnett Rd to Deadman Ck)	DO	17010308000033	47055
Deadman Creek (near Bruce Rd)	DO, pH	17010308000031	41981 50410
Deadman Creek (below Bruce Rd to SR 2)	DO	17010308001185	41982
Unnamed Creek (Spring Near Kaiser Outfall)	DO	Unnamed Creek (Spring Near Kaiser Outfall) 26N-43E-3	42359
Unnamed Spring (Trib to Deadman Creek)	DO	Unnamed Spring (Trib to Deadman Creek) 26N-43E-3	78112
Deadman Creek (SR 2 to Little Deep Ck)	pH	17010308000026	11388
Little Deep Creek (above mouth at Deadman Ck)	DO, pH	17010308000052	47097 50401
Deadman Creek (Little Deep Ck to mouth)	DO	17010308000025	11385
Dartford Creek (above mouth)	pH	17010308000151	50416
Griffith Spring (DS of hatchery, mouth at LSR)	pH	17010308001179	70444

Table 2. Study area waterbodies that are not on the current 303(d) list for DO and pH, but which do not meet state water quality standards.

Waterbody Name	Sampling Location(s)	Parameter	NHD reach code
Little Spokane River	Frideger Rd.	DO	17010308000081
Little Spokane River	Elk	DO	17010308000080
Little Spokane River	Deer Park – Milan Rd.	DO, (pH) [a]	17010308000077
Little Spokane River	Chattaroy	DO, pH	17010308007197
Little Spokane River	Dartford USGS gage	DO	17010308000024
Dry Creek	Near mouth (Milan-Elk Rd.)	DO, (pH) [a]	17010308000156
Deer Creek	Above Little Deer Ck.	DO	17010308000066
Deer Creek	Elk-Chattaroy Rd.; Mouth	DO	17010308000065
Spring Creek	Near mouth (Spring Ck. Rd.)	DO	17010308000397
Dragoon Creek	Abv W.B. Dragoon Ck.	DO	17010308000116
West Branch Dragoon Creek	Mouth	DO	17010308000477
Dragoon Creek	North Rd.	DO	17010308000110

[a] These locations are already listed for pH, but not DO.

Uses of the waterbodies

The Washington State water quality standards describe freshwater aquatic life use categories using key species (salmonid versus warm-water species) and life-stage conditions (spawning versus rearing). Ecology set criteria to protect different categories of aquatic communities, some of which are specified for individual rivers, lakes, and streams.

The Water Quality Standards for Surface Waters of the State of Washington Chapter 173-201A WAC (Ecology, 2006) designates these uses. WAC 173-201A-600(1)(a)(iii) specifies that the designated use of core summer salmonid habitat applies to "all feeder streams to lakes (reservoirs with a mean detention time greater than 15 days are to be treated as a lake for use designation)". Because the Little Spokane River is a tributary to Lake Spokane, this use applies to the Little Spokane River and all tributaries:

> *Core summer salmonid habitat – key identifying characteristics of this use are summer (June 15 - September 15) salmonid spawning or emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and sub adult native char. Other common characteristic aquatic life uses for waters in this category include spawning outside of the summer season, rearing, and migration by salmonids.*

The criteria for *core summer salmonid habitat* apply to the Little Spokane River and its tributaries year-round.

The Little Spokane River and its tributaries also have a *primary contact* recreational use. This designated use does not have DO and pH criteria associated with it, and so does not directly impact the allocations in this TMDL. However, efforts to improve DO and pH and to reduce nutrients and eutrophication will also benefit recreational uses.

Water Quality Criteria

Dissolved oxygen

Aquatic organisms are very sensitive to reductions in the level of DO in the water. The health of fish and other aquatic species depends on maintaining an adequate supply of oxygen dissolved in the water. Oxygen levels affect growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants. While direct mortality due to inadequate oxygen can occur, Washington State designed the criteria to maintain conditions that support healthy populations of fish and other aquatic life.

Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiratory requirements of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criterion is based on the lowest one-day minimum oxygen concentrations that occur in a waterbody.

The DO criterion for core summer salmonid habitat is summarized as follows [WAC 173-201A-200(1)(d)]:

> *The one-day minimum dissolved oxygen concentration shall not fall below 9.5 mg/L more than once every ten years on average. When DO is lower than the criterion (or within 0.2 mg/L of the criterion) due to natural conditions, then cumulative human-caused activities may not decrease the dissolved oxygen more than 0.2 mg/L.*

The criterion above is used to maintain conditions where a waterbody is naturally capable of providing full support for its designated aquatic life uses. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. When a waterbody is naturally lower in oxygen than the criteria, the state provides an additional allowance for further depression of oxygen conditions due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.2 mg/L decrease below that naturally lower (inferior) oxygen condition.

pH

The pH of natural waters is a measure of acid-base equilibrium achieved by the various dissolved compounds, salts, and gases. It is an important factor in the chemical and biological systems of natural waters. pH both directly and indirectly affects the ability of waters to have healthy populations of fish and other aquatic species. Changes in pH affect the degree of dissociation of weak acids or bases, which is important because the toxicity of many compounds is affected by the degree of dissociation.

While some compounds (e.g., cyanide) increase in toxicity at lower pH, others (e.g., ammonia) increase in toxicity at higher pH. While there is no definite pH range within which aquatic life is unharmed and outside which it is damaged, there is a gradual deterioration as the pH values are further removed from the normal range. At the extremes of pH, lethal conditions can develop. For example, extremely low pH values (<5.0) may liberate sufficient carbon dioxide from bicarbonate in the water to be directly lethal to fish.

Washington State established pH criteria in its water quality standards primarily to protect aquatic life. The criteria also serve to protect waters as a source for domestic water supply. Water supplies with either extreme pH or that experience significant changes of pH, even within otherwise acceptable ranges, are more difficult and costly to treat for domestic water purposes. pH also directly affects the longevity of water collection and treatment systems, and low pH waters may cause compounds of human health concern to be released from the metal pipes of the distribution system.

The pH criterion for core summer salmonid habitat is summarized as follows [WAC 173-201A-200(1)(d)]:

> *pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units.*

The criteria above are used to maintain conditions where a waterbody is naturally capable of providing full support for its designated aquatic life uses. When the pH is within the criteria range, the combined effects of all human activities may not exceed the range nor cause not more than a 0.2 units change. The standards recognize, however, that not all waters are naturally capable of staying within the fully protective pH criteria (discussed further below).

Natural background levels

The Water Quality Standards (Ecology, 2006) define "natural conditions" or "natural background levels" as "surface water quality that was present before any human-caused pollution." "Pollution" is defined broadly, and in the context of this study could include direct and indirect discharges of chemical contaminants, loss of riparian shade, alteration of flow regimes, and modification of the channel. These latter non-chemical factors are often termed "system potential," which is the term used for the instream DO and pH analysis.

For dissolved oxygen, the standards provide specific language regarding natural conditions:

> *When a water body's D.O. is lower than the criteria in Table 200 (1)(d) (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the D.O. of that water body to decrease more than 0.2 mg/L.*

The standards do not directly address natural conditions for pH. However, a small incremental change above or below the pH standard of 0.1 units has been allowed due to instrument error, otherwise defined as a measurable change. A previous TMDL (Carroll and Anderson, 2009) accounted for instrument error by applying a small incremental increase in pH of 0.1 above natural conditions when modeling showed natural conditions to exceed the upper threshold of 8.5. The basis of this approach was described as follows:

Ecology commonly uses a change in pH of 0.1 unit to represent a measurable change in pH in the field; thus, the TMDL target should be based at a minimum on keeping human-caused pH changes to less than 0.1 units.

Note that this pH change of 0.1 unit, which applies when natural pH conditions **exceed** 8.5, is separate from the allowed pH change of 0.2 units, which applies when pH is **within** the 6.5-8.5 range.

Narrative criteria for "natural and irreversible human conditions" are provided in WAC 173-201A-260(1)(a):

It is recognized that portions of many water bodies cannot meet the assigned criteria due to the natural conditions of the water body. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the natural conditions constitute the water quality criteria.

Given that true natural conditions refer to conditions that existed before western settlement and development began in the 1830s, it is virtually impossible to fully analyze all of the changes to the watershed and its hydrology since settlement began. The analysis provided in this report has estimated the effects of changes to shade, nutrients, groundwater inflows, surface water withdrawals, channel morphology, and riparian microclimate. We also analyzed the uncertainty around each of these factors. Although we attempted to be reasonably comprehensive in our approach, the final estimate of natural conditions still necessarily contains uncertainty. We detail these analyses in the **Natural conditions scenarios** and **Uncertainty analysis for natural conditions predictions** sections of Appendix G. In this document we use the terms "natural background" and "background" interchangeably to refer to this estimate of natural conditions. We also use the term "system potential," particularly when referring to natural riparian shade.

Targets

The numeric targets used in this TMDL to meet standards for DO and pH are heat loads for solar shortwave radiation, which we also present in terms of effective shade, as well as nutrient loads for total phosphorus (TP) and dissolved inorganic nitrogen (DIN). We establish load and wasteload allocations for TP throughout the Little Spokane watershed to meet the load allocation that was set for the mouth of the Little Spokane River in the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010). To meet DO and pH standards in the Little Spokane River and its tributaries, we establish load allocations for shade and heat throughout the watershed. We also establish load allocations for DIN in several locations where the Little Spokane River and its tributaries show nutrient sensitivity.

We express phosphorus allocations in this TMDL in terms of total phosphorus (TP) because: 1) this was the fraction utilized in the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010); and 2) modeling for this and other projects indicates that the less-bioavailable organic forms of phosphorus are labile, or readily converted into the more-bioavailable soluble reactive forms. We express nitrogen allocations in terms of dissolved inorganic nitrogen (DIN; equivalent to nitrate+nitrite+ammonia) because modeling indicates that the less-bioavailable organic forms of nitrogen are more recalcitrant, not readily converted to DIN.

Targets for the Little Spokane River mouth

In 2010, Ecology issued the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010). This TMDL addressed violations of the water quality standards for dissolved oxygen in the Spokane River and Lake Spokane, and established limits for the three pollutants affecting dissolved oxygen: ammonia (NH3-N), total phosphorus (TP), and carbonaceous biochemical oxygen demand (CBOD). The Little Spokane River enters the Spokane River at upstream end of Lake Spokane.

The *Spokane River and Lake Spokane DO TMDL* set load allocations at the mouth of the Little Spokane River for these three parameters. Table 3 provides an excerpt from Table 6a in Moore and Ross (2010).

Table 3. Seasonal Load Allocations for the Little Spokane River from the Spokane River DO TMDL

TMDL Season	2001 Flow (cfs)	TP Allocation Concentration (mg/L)	TP 2001 Load Allocation (lbs/day)	NH3-N Allocation Concentration (mg/L)	NH3-N 2001 Load Allocation (lbs/day)	CBOD Allocation Concentration (mg/L)	CBOD 2001 Load Allocation (lbs/day)
March–May	565	0.034	102.5	0.035	106.2	2.1	6409.3
June	426	0.023	53.9	0.005	11.5	2.1	4828.2
July--October	364	0.016	32.2	0.006	11.0	1.5	2867.8

(from: Moore and Ross, 2010; Table 6a)

Of these three pollutants, this TMDL for the Little Spokane River only addresses total phosphorus. The other two pollutants pertain mainly to municipal and industrial point sources. Sample results for these two pollutants (as ammonia nitrogen and BOD5) at the mouth of the Little Spokane River are typically below detection limits.

Targets within the Little Spokane River and tributaries

Ecology used the QUAL2Kw (Pelletier and Chapra, 2008) and River Metabolism Analyzer (RMA; Pelletier, 2013) water quality models to evaluate the effect of shade, nutrients, and several other factors on DO and pH in the Little Spokane River and its tributaries. We present the modeling and analytical procedure in the **Instream DO and pH TMDL Analysis** section. We found that even under natural conditions, streams in the Little Spokane River watershed will generally not meet numeric water quality criteria for DO and pH. Therefore, the shade/heat and nutrient targets in this TMDL are based on the 0.2 mg/L human allowance for DO and the 0.1 S.U. *de minimus* allowance for pH, as described above in the **Water Quality Criteria** section.

Ecology has determined that the most important factor that will lead to streams within the Little Spokane River watershed meeting DO and pH standards is the establishment of system potential shade. System potential shade will reduce water temperatures, allowing water to hold more dissolved oxygen and carbon dioxide. It will also reduce the amount of light reaching the water surface, which will help moderate algae growth. This finding is consistent with the goals of the *Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity Total Maximum Daily Load* (Joy and Jones, 2012).

Because shade is a key surrogate measure for improving DO and pH, this TMDL establishes explicit shade and heat targets. These targets overlap with those established in the *Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity Total Maximum Daily Load* (Joy and Jones, 2012). We discuss this further in the **Load Allocations** section below. The basic requirement in both TMDLs is the same, to establish system potential shade throughout the Little Spokane River watershed.

For most locations in the Little Spokane River and its tributaries, we found that DO and pH are not sensitive to nutrient concentrations. However, several stream reaches are sensitive to nutrients. This includes portions of the upper Little Spokane River mainstem, upper Dragoon Creek, South Fork Little Deep Creek, and Deadman Creek. For these locations, in addition to shade, this TMDL sets allocations for dissolved inorganic nitrogen (DIN). All of the nutrient-sensitive tributary reaches just named are nitrogen limited, and reducing only phosphorus in these locations would have no effect. The nutrient-sensitive portion of the upper Little Spokane River is a mix of N- and P- limited areas, but phosphorus is this reach is already at natural levels and cannot be reduced further.

We present shade/heat and nutrient target values in the **TMDL Allocations** section.

TMDL Allocations

TMDL Formula

A waterbody's **loading capacity** is the amount of a given pollutant that a waterbody can receive and still meet water quality standards. The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a waterbody into compliance with the standards.

The portion of the receiving water's loading capacity assigned to a particular source is a **wasteload** or **load** allocation. If the pollutant comes from a discrete (point) source subject to a National Pollutant Discharge Elimination System (NPDES) permit, such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a **wasteload allocation**. If the pollutant comes from diffuse (nonpoint) sources not subject to an NPDES permit, such as general urban, residential, or farm runoff, the cumulative share is called a **load allocation**.

The TMDL must also consider **seasonal variations**, **critical conditions**, account for **natural background conditions**, and include a **margin of safety** that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A **reserve capacity** for future pollutant sources is sometimes included as well.

Therefore, a TMDL is the sum of the wasteload and load allocations, natural background, any margin of safety, and any reserve capacity. The TMDL must be equal to or less than the loading capacity. The short-hand formula that describes the TMDL is:

$$LC=\sum WLA+\sum LA+NB+MOS.$$

Loading Capacity equals Sum of Wasteload Allocations plus Sum of Load Allocations plus Natural Background plus Margin of Safety.

Loading Capacity

This TMDL includes three sets of loading capacities, based on the two goals of the TMDL.

- To protect downstream DO and pH in Lake Spokane, the TMDL defines loading capacities for total phosphorus (TP), based on the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010).
- To meet water quality standards for DO and pH in streams throughout the Little Spokane River watershed, the TMDL defines loading capacities for for shade and heat.
- Also, to meet water quality standards for DO and pH in certain nutrient-sensitive streams, the TMDL defines loading capacities for dissolved inorganic nitrogen (DIN).

Loading Capacity for Total Phosphorus

Because DO and pH in the Little Spokane River and its tributaries are not sensitive to phosphorus (see the **Instream DO and pH TMDL Analysis** section), the loading capacity for phosphorus from the Little Spokane watershed is based entirely on protecting water quality downstream in Lake Spokane. Therefore, the loading capacity for phosphorus is simply the load allocation for the mouth of the Little Spokane River, specified in the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010). The March-May, June, and July-October seasons were specified by the *Spokane River and Lake Spokane DO TMDL*. The Spokane TMDL found that inputs during November-February do not impact DO in Lake Spokane.

Table 4 presents the loading capacity for TP. These are shown both in lbs/day (as defined in the *Spokane River and Lake Spokane DO TMDL*) and converted to kg/day, the units used throughout this report. The **Watershed Loading TMDL Analysis** section provides a breakdown or distribution of these loading values throughout the watershed, from which the load and wasteload allocations are derived.

Table 4. Loading capacity for total phosphorus (TP) for the mouth of the Little Spokane River

TMDL Season	TP Loading Capacity (lbs/day)	TP Loading Capacity (kg/day)	Reference 2001 Flow (cfs)
March – May	102.5	46.49	565
June	53.9	24.45	426
July – October	32.2	14.61	364

Loading Capacity for Shade and Heat

Loading capacities for shade and heat (Table 5) are designed to protect DO and pH standards for streams in the Little Spokane River watershed. For the vast majority of streams in the watershed, improving shade is the action that will have the single greatest impact. The loading capacities for shade and heat reflect a need to establish **system potential shade** throughout the watershed. System potential shade is the shade that would occur from **system potential riparian vegetation**, which is defined as that native vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

The *Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity Total Maximum Daily Load* (Joy and Jones, 2012) also established the need for system potential shade throughout the watershed, and presented loading capacities and load allocations for shade and heat. Because this is also key to addressing the DO and pH impairments emphasized in this DO/pH/TP TMDL, we are reiterating this need here. The basic requirement to establish system potential shade is the same between the two TMDLs. We discuss the overlap between the shade/heat allocations for this TMDL and the 2012 TMDL below in the **Load Allocations** section.

Table 5. Loading capacities for shade and heat for the Little Spokane River watershed

Waterbody	Applicable reach	System Potential Shade [a]	Heat Load Capacity (W/m^2) [a b]	Calc Method [c]
LSR	HW - Scotia	42%	165	WSW
LSR	Scotia - Chain Lk.	46%	154	WSW
LSR	Chain Lk. - Elk	56%	125	MS
Dry Ck.	Entire length	76%	68	WSW
Otter Ck.	Entire length	57%	122	WSW
Moon Ck.	Entire length	39%	173	WSW
WBLSR	Sacheen Lk. - Horseshoe Lk.	44%	157	WSW
Buck Ck.	Entire length	80%	55	WSW
Beaver Ck.	Entire length	90%	28	WSW
WBLSR	Horseshoe Lk. - Eloika Lk.	38%	174	WSW
WBLSR	Eloika Lk. - Mouth	39%	172	WSW
Bear Ck.	Entire length	65%	99	WSW
LSR	Elk - Chattaroy	37%	178	MS
Deer Ck.	HW - Little Deer Ck. conf.	84%	44	WSW
Deer Ck.	Little Deer Ck. conf - Mouth	58%	117	WSW
Dragoon Ck.	HW - Dahl Rd.	55%	128	WSW
Spring Ck.	Entire length	64%	101	WSW
Dragoon Ck.	Dahl Rd. - Burroughs Rd.	32%	191	WSW
WB Dragoon Ck.	Entire length	52%	135	WSW
Dragoon Ck.	Burroughs Rd. - North Rd.	30%	198	WSW
Dragoon Ck.	North Rd. - Mouth	43%	160	WSW
LSR	Chattaroy - N. LSR Dr.	34%	186	MS
Deadman Ck.	HW - St. Park Bdy	92%	24	WSW
Deadman Ck.	Park Bdy - Holcomb Rd.	79%	59	WSW
Deadman Ck.	Holcomb Rd. - Bruce Rd.	41%	166	WSW
S.F. Little Deep Ck.	Entire length	90%	28	WSW
Little Deep Ck.	Entire length	59%	116	WSW
Deadman Ck.	Bruce Rd. - Mouth	44%	158	WSW
Dartford Ck.	Entire length	85%	42	WSW
LSR	N. LSR Dr. - Mouth	10%	254	MS

[a] We calculated current and system potential shade and heat load capacity for August 1st, which represents the hottest part of the year and the most critical period for temperature.

[b] The heat load capacity represents daily average solar shortwave radiation entering the stream. We calculated this value for August 1st using Ecology's SolRad tool (Pelletier, 2012b), using a Ryan-Stolzenbach atmospheric transmission coefficient (ATC) = 0.75. This is the value used for QUAL2Kw model and for all other analyses for this TMDL. The total daily average solar shortwave radiation above the canopy, or for a stream with 0% shade, would be 282 W/m2. We calculated the heat load as (1-[system potential shade]) * [282 W/m2].

[c] WSW = Watershed-wide landscape shade analysis, described in Appendix I. MS = Mainstem LSR shade model used for the QUAL2Kw model, described in the **Climate and Shade Inputs** (Table G-10) and **Natural Conditions Scenarios > Shade** sections of Appendix G.

Loading Capacity for Dissolved Inorganic Nitrogen

Loading capacities for dissolved inorganic nitrogen (DIN) are designed to protect DO and pH standards for certain streams in the Little Spokane River watershed. The vast majority of streams in the Little Spokane River do not have a defined loading capacity for DIN. DO and pH impairments in these streams are not the result of nutrients, but rather of insufficient shade. However, for six stream reaches, five of which were nitrogen-limited and one of which was in a mixed-limitation area where natural phosphorus levels cannot be reduced, we found that nutrient reductions are needed. The DIN reductions needed are in addition to shade restoration.

Table 6 presents the loading capacities for DIN. Figure 2 provides a map showing where streams with DIN loading capacities are located. The **Instream DO and pH TMDL Analysis** section provides details of the calculation of these values.

The critical period for these instream DO and pH considerations is during warm, low-flow summer conditions. These loading capacities for DIN apply during May-November, which is the season when we observed dissolved oxygen saturation levels below 90 percent and above 110 percent at these six locations, indicating the potential for DO impairments linked to algae growth[2]. This is also the season when we observed pH values greater than 8.5 S.U. During December-April, cold temperatures and high flows restrict the ability of nutrient-driven algal growth to create impairments to DO and pH.

Table 6. Loading capacities for dissolved inorganic nitrogen (DIN), May-November.

Location ID	Applicable reach	Current conditions DIN (ug/L)	System potential DIN (ug/L)	TMDL DIN (ug/L)	7Q10 flow (cfs)	DIN Load capacity (kg/day)	% reduction needed
55LSR-37.1	Little Spokane R. between Chain Lake and Elk	29.4	13.9	16.5	33.6	1.36	44%
55LSR-33.2	Little Spokane R. between Elk and WBLSR confluence	335	55.6	281	45	30.9	16%
55DRA-19.6	Upper Dragoon Ck., abv Spring Ck.	146	11	24.5	0.58	0.035	83%
55SFLD-01.1	S.F. Little Deep Ck	107	11	94.3	0.10	0.023	12%
55DEA-13.8	Deadman Ck. from state park bdy to Holcomb Rd.	68	11	35.8	1.6	0.14	47%
55DEA-09.2	Deadman Ck. in Peone Prairie from Holcomb Rd. to Heglar Rd.	60.5	11	24.7	1.4	0.085	59%
All other tributary and mainstem LSR locations in the LSR watershed		Nutrient loading capacity not limited by instream DO and pH.					

[2] At one of these locations, Little Spokane River at Frideger Rd. (55LSR-37.1), we observed a DO saturation level *slightly* below 90% (88.7%) during December. However that location is downstream of a natural wetland, and this value is almost certainly the natural result of wetland processes, rather than nutrient-driven eutrophication.

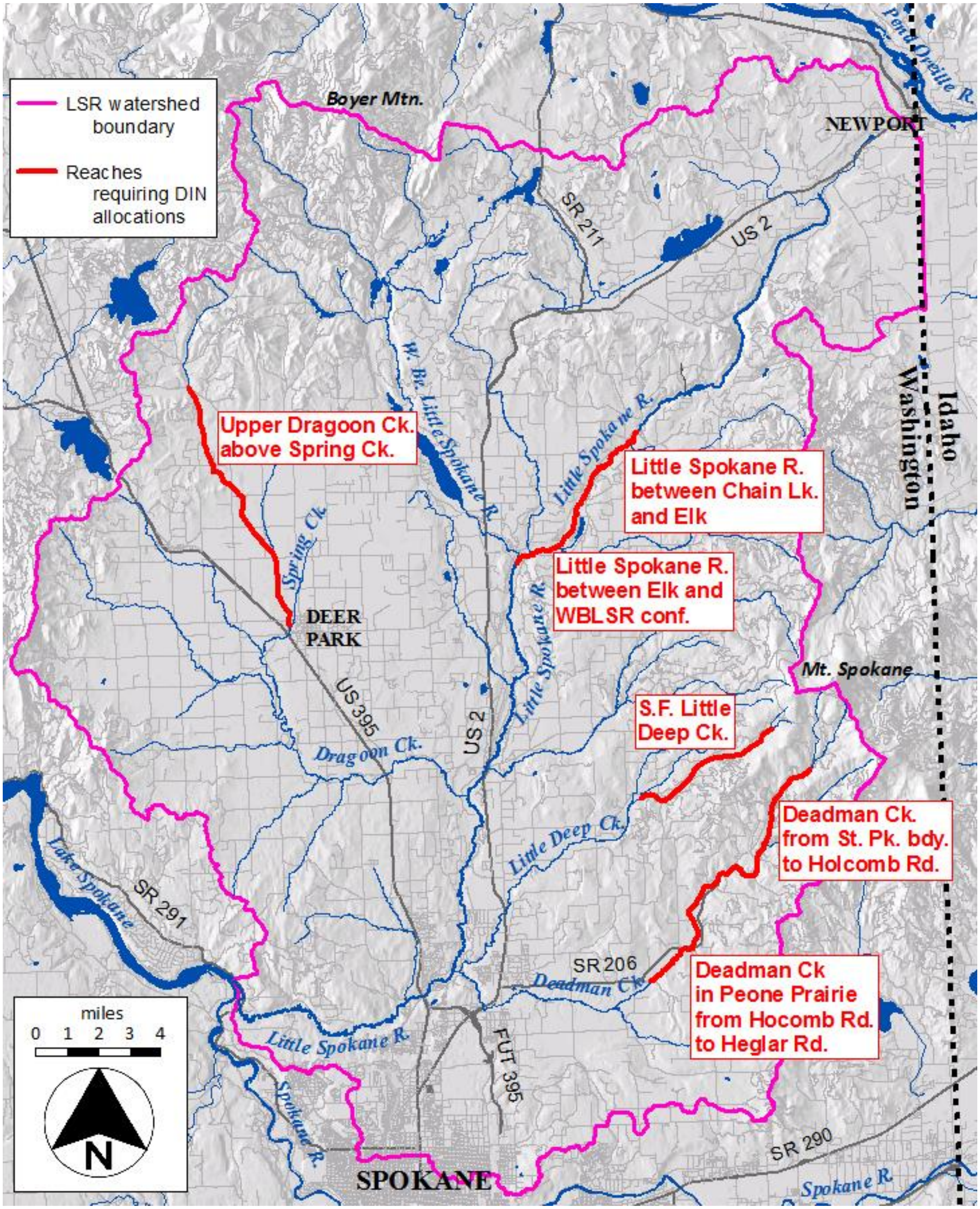


Figure 2. Reaches with defined loading capacities for dissolved inorganic nitrogen (DIN).

Wasteload allocations

Table 7 presents the wasteload allocations (WLAs) for National Pollutant Discharge Elimination System (NPDES) permitted point sources. Figure 3 shows the locations of point sources receiving WLAs. We present the WLAs for TP as loads in kg/day, along with the concentration and discharge that we used to calculate the load. We present the one WLA for DIN only as a load in kg/day, because it is essentially a **de minimis** allocation that applies to certain general permits, and a concentration would not be meaningful.
We are assigning WLAs to all permitted point sources that either have or may have a discharge to surface water. Some facilities discharge to ground, and these do not require a WLA. Table A-1 in Appendix A provides a complete list of NPDES permitted point sources in the Little Spokane River Watershed.

Appendix M presents the basis and calculation of WLAs.

The WLAs for TP apply during March-October, which is the critical TMDL season for the *Spokane River and Lake Spokane DO TMDL*. The WLAs for DIN apply during May-November, the critical period for DO and pH in the Little Spokane River and its tributaries. These seasonal determinations are described in more detail in the **Loading Capacity** section above.

The WLA for the Washington Department of Fish and Wildlife (WDFW) Spokane Hatchery will require an approximately 50% reduction in net total phosphorus loading. Spokane Hatchery is a significant contributor of anthropogenic phosphorus loading to the Little Spokane River, particularly during summer months. This will require Spokane Hatchery to adopt state-of-the-art effluent treatment. The **Watershed Loading TMDL Analysis** section and Appendix M provide additional details.

None of the permitted point sources in the Little Spokane River watershed are meaningful sources of heat pollution that could have any significant effect on DO and pH. With respect to the two continuously discharging sources, Colbert Landfill and Spokane Hatchery, the *Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity TMDL* (Joy and Jones, 2012) states:

> *Two regulated surface water discharges into the LSR originate from groundwater sources that are cooler than local receiving waters. The Colbert Landfill treats groundwater and discharges it at RM 19.7 (RKM 31.7). The effluent has had a maximum summer temperature of 13.3 ºC (Spokane County, 2010). The WDFW Spokane Fish Hatchery at RM 6.9 (RKM 11.1) discharges hatchery run water from Griffith Springs. The hatchery effluent at the main outfall and brood outfall consistently run at 12º to 13 ºC during the summer. These temperatures are cooler than the 7-DADMax 16 ºC criterion [water quality standard for temperature] for all water bodies in the LSR watershed.*
>
> *The effluent temperatures of these two sources are (1) lower than the receiving waters under critical conditions with mature system-potential shade in place and (2) provide localized cooling… Therefore, no alteration of effluent treatment [with respect to temperature] is needed.*

For stormwater sources, the intermittent nature and extremely low potential discharge flows mean that the potential for thermal impacts that could translate to DO and pH impacts is negligible. For example, given an extreme worst case scenario assuming 99th percentile daily rainfall and stormwater temperatures 5°C warmer than the receiving water (extraordinarily unlikely), we calculate that the heat load from either construction stormwater or Spokane County municipal stormwater would not exceed about ~0.02% (i.e. 2/10,000ths) of the total Load Capacity for solar heating.

The *Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity Total Maximum Daily Load* (Joy and Jones, 2012) established temperature WLAs for the point sources listed in Table 7, in order to comply with the statutory requirements of a temperature TMDL. The temperature WLAs from the 2012 TMDL serve to insure that future activities or expansions cannot result in measurable human impacts to stream temperature, and to encourage continued implementation of stormwater best management practices (BMPs).

Unlike the 2012 TMDL, this DO/pH/TP water quality improvement plan is not a temperature TMDL. The human impacts to temperature that influence DO and pH are essentially 100% nonpoint (mainly riparian vegetation removal). To the extent that point source temperature impacts could possibly impact DO and pH, the temperature WLAs established in the 2012 TMDL obviate this risk. For these reasons we are not including new temperature or heat WLAs for point sources. The temperature/heat WLA for all point sources in this TMDL is N/A. The shade/heat emphasis of this TMDL is on nonpoint impacts.

Table 7. Wasteload allocations for NPDES point sources in the Little Spokane watershed.

Permittee	Permit Number	Permit Type	TP (March-October) WLA (kg/day)	TP (March-October) Concen-tration (mg/L)	TP (March-October) Discharge (cfs)	DIN (May-November) kg/day (WLA)	Heat/ Temperature	Impaired stream reach [a]
WDFW Spokane Hatchery	WAG137007	Upland Fish Hatchery GP	0.51 net [b]	0.010 net [b]	21 [c]	N/A [d]	N/A	70444 (Griffith Springs; pH)
Colbert Landfill	WAD980514541	TCP Cleanup Groundwater	0.092	0.022	1.7	N/A	N/A	47133 (LSR; DO) 50434 (LSR; pH)
Spokane County Muni SW	WAR046506	Municipal SW Phase II Eastern WA GP	0.012	0.26	0.018	N/A	N/A	47133 (LSR; DO) 50434 (LSR; pH) 47097 (Little Deep Ck.; DO) 50401 (Little Deep Ck.; pH) 41982 (Deadman Ck.; DO) 11388 (Deadman Ck.; pH) Impaired but not listed (LSR @ Dartford USGS Gage; DO) 50416 (Dartford Ck.; pH)
Washington State Dept. of Transportation	WAR043000A	Municipal SW GP	0.0061	0.26	0.0096	N/A	N/A	47097 (Little Deep Ck.; DO) 50401 (Little Deep Ck.; pH) 11388 (Deadman Ck.; pH) Impaired but not listed (LSR @ Dartford USGS Gage; DO)
Spokane Recycling (Former Kaiser Site)	WAR304975	Industrial SW GP	0.0064	0.26	0.01	N/A	N/A	11388 (Deadman Ck.; pH)
Bubble allocation: • Industrial SW [e] • Construction SW • Sand & Gravel	WAR127295, WAR301800, Various Construction and Sand & Gravel	Industrial SW GP; Construction Stormwater GP; Sand and Gravel GP	0.044	0.095	0.19	N-sensitive streams [f]: 0.0040 Other streams: N/A	N/A	Can occur throughout watershed

[a] This indicates the 303(d) listed (Table 1) or impaired-but-not-listed (Table 2) reach to which the NPDES point source discharges, if applicable. Note that TP allocations are for the purpose of protecting water quality downstream in Lake Spokane, and the greatest impact of a TP discharge will not be to the reach where the discharge occurs. We present this information to assist with a U.S. Environmental Protection Agency (EPA) reporting requirement.

[b] We present the wasteload allocation and concentration for Spokane Hatchery as net loads and net concentrations, in accordance with usual practice for hatcheries. This means that the load and concentration represent only the amount of phosphorus the hatchery contributes. They do not include the phosphorus already present in the intake water from Griffith Spring.

[c] Spokane Hatchery has 8 separate outfalls. This discharge value represents the sum of all outfalls.

[d] A DIN wasteload allocation of N/A indicates that the applicable receiving stream reach(es) are not sensitive to nitrogen, and explicit limits are not needed. However, care should be taken not to allow degradation or backsliding.

[e] That is, all industrial stormwater sources **except** Spokane Recycling (Former Kaiser Site), which has its own WLA.

[f] N-sensitive stream reaches are the same reaches shown in Table 6: The Little Spokane River from Chain Lake to the W. Branch LSR confluence; Dragoon Creek upstream of Spring Creek; S. Fork Little Deep Creek; and Deadman Creek from the state park boundary to Heglar Rd.

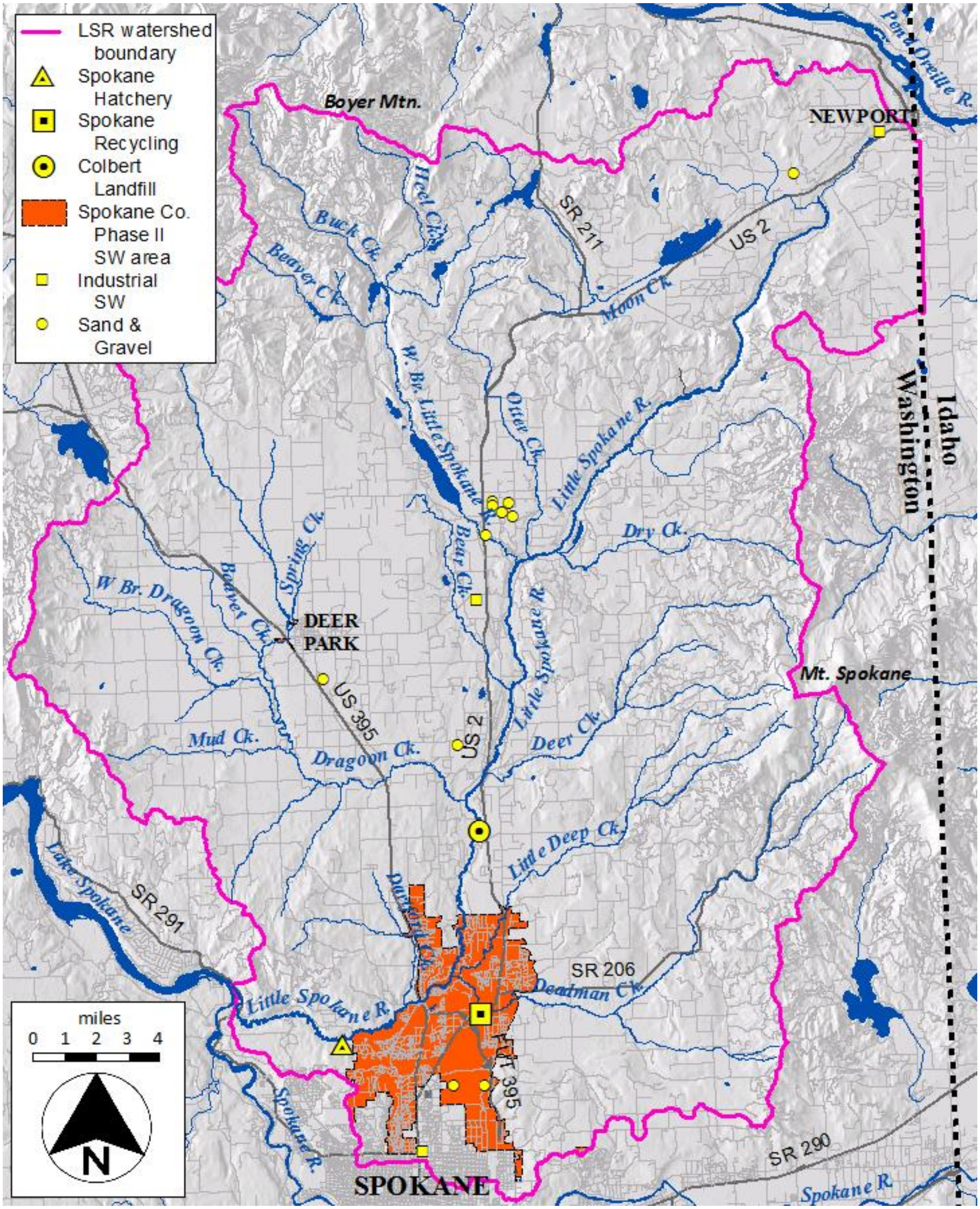


Figure 3. Point source discharges receiving wasteload allocations.

Construction stormwater permits change year by year with active construction projects, and are not shown. The Spokane County Phase II stormwater boundary also applies to WSDOT.

Load allocations

The load allocation is the portion of the TMDL assigned to existing and/or future nonpoint sources and natural background. We are defining load allocations for total phosphorus, shade/heat, and dissolved inorganic nitrogen.

Total phosphorus

Table 8 presents load allocations for total phosphorus throughout the Little Spokane River Watershed. The **Watershed Loading TMDL Analysis** section describes the methodology and calculation of these values. The load for each location includes the effect of all upstream loads as well. The watershed loading TMDL analysis explicitly considered the two continuously discharging point sources, Spokane Hatchery and Colbert Landfill. Because the total load at any location downstream of a point source will include that point source load as well as nonpoint and natural loads, the load allocations for all downstream locations account for the WLA load values from those two point sources.

Table 8. Load Allocations for nonpoint total phosphorus for the Little Spokane and tributaries.

Location	Load allocations for total phosphorus (kg/d) [a]									% reduction [b]					
	Mar-May			June			Jul-Oct			Mar-May		June		Jul-Oct	
	Natural	Human	Total	Natural	Human	Total	Natural	Human	Total	Human	Total	Human	Total	Human	Total
LSR@Scotia (55LSR-46.7)	1.43	*0.001*	1.43	1.68	*0.001*	1.68	0.86	*0.001*	0.86	N/A [c]	0%	N/A	0%	N/A	0%
LSR@Elk (55LSR-37.1)	2.06	0.09	2.16	3.12	0.11	3.23	1.21	*0.001*	1.21	0%	0%	0%	0%	N/A	0%
Dry Ck./Sheets Ck. (55DRY-00.4; 55SHE-00.6)	1.17	0.25	1.42	0.51	*0.001*	0.51	0.31	*0.001*	0.31	0%	0%	N/A	0%	N/A	0%
Otter Ck. (55OTT-00.3)	0.32	0.32	0.64	0.69	0.01	0.70	0.97	*0.001*	0.97	64%	47%	0%	0%	N/A	0%
Moon Ck. (55MOO-02.9)	0.14	*0.001*	0.14	0.09	*0.001*	0.09	0.04	*0.001*	0.04	N/A	0%	N/A	0%	N/A	0%
WBLSR@Harworth Rd. (55WBLS-17.7)	1.04	0.16	1.20	0.32	*0.001*	0.32	0.15	*0.001*	0.15	0%	0%	N/A	0%	N/A	0%
Buck Ck. (55BUC-00.3)	1.92	0.20	2.13	0.60	0.03	0.62	0.07	*0.001*	0.07	80%	28%	80%	15%	N/A	0%
WBLSR blw Horseshoe Lk. (55WBLS-11.1)	3.20	0.36	3.56	1.01	0.08	1.08	0.14	*0.001*	0.14	69%	19%	59%	9%	N/A	0%
Beaver Ck. (55BEAV-00.5)	0.78	0.33	1.12	0.05	*0.001*	0.05	0.01	*0.001*	0.01	0%	0%	N/A	0%	N/A	0%
WBLSR@Fan Lk. Rd. (55WBLS-07.7)	3.02	0.83	3.85	1.31	0.53	1.84	0.27	0.14	0.41	49%	17%	17%	6%	0%	0%
WBLSR@Eloika Lk. Rd. (55WBLS-03.1)	3.20	1.13	4.33	0.69	0.35	1.03	0.08	0.17	0.25	42%	16%	24%	10%	0%	0%
Bear Ck. (55BEAR-00.4)	0.43	0.03	0.46	0.16	0.01	0.17	0.08	*0.001*	0.08	0%	0%	0%	0%	N/A	0%
LSR@Chattaroy (55LSR-23.4)	8.49	2.35	10.84	5.60	0.43	6.03	2.27	0.12	2.39	66%	30%	20%	2%	0%	0%
Deer Ck. (55DEE-00.1)	3.35	0.38	3.73	0.50	*0.001*	0.50	0.01	*0.001*	0.01	80%	29%	N/A	0%	N/A	0%
Dragoon Ck.@Dahl Rd. (55DRA-17.0)	1.96	0.86	2.82	0.37	0.32	0.69	0.12	0.11	0.23	80%	55%	80%	65%	80%	66%
Spring Ck. (55SPR-00.4)	0.37	0.09	0.46	0.21	*0.001*	0.21	0.11	*0.001*	0.11	0%	0%	N/A	0%	N/A	0%
Dragoon Ck.@Hwy395 (55DRA-16.4)	2.43	1.00	3.43	0.23	0.32	0.55	0.16	*0.001*	0.16	78%	52%	80%	70%	100% [d]	68%
Dragoon Ck. abv. WBDR (55DRA-13.2)	2.74	1.08	3.82	0.72	0.30	1.02	0.28	*0.001*	0.28	79%	51%	81%	56%	100%	52%
WB Dragoon Ck. (55WBDR-00.1)	1.98	0.37	2.35	0.80	0.07	0.87	0.61	0.01	0.62	80%	39%	80%	25%	80%	5%
Dragoon Ck.@North Rd. (55DRA-04.3)	4.97	1.45	6.42	1.99	0.27	2.27	0.92	*0.001*	0.92	79%	46%	85%	41%	100%	24%
Dragoon Ck.@Mouth (55DRA-00.3)	5.46	1.62	7.08	1.78	0.25	2.03	1.00	*0.001*	1.00	79%	47%	86%	44%	100%	21%
LSR@N. LSR Dr. (55LSR-13.5)	18.81	4.75	23.56	8.54	0.76	9.30	4.29	0.04	4.33	72%	34%	69%	15%	98%	32%
Deadman Ck.@St. Park Bdy (55DRA-20.2)	1.09	0.02	1.11	0.58	*0.001*	0.58	0.17	*0.001*	0.17	80%	7%	N/A	0%	80%	0%
Deadman Ck.@Holcomb Rd. (55DEA-13.2)	3.36	0.33	3.69	0.78	0.04	0.81	0.24	0.01	0.25	80%	26%	80%	15%	80%	7%
Deadman Ck.@Bruce Rd. (55DEA-05.9)	4.41	0.80	5.21	0.97	0.21	1.19	0.32	*0.001*	0.32	81%	39%	89%	59%	100%	4%
Deadman Ck.@Shady Slope Rd. (55DEA-00.6)	4.55	1.09	5.64	0.58	0.17	0.75	0.50	*0.001*	0.50	81%	45%	92%	71%	100%	18%
Little Deep Ck. (55LDP-00.1)	1.93	0.35	2.29	0.16	*0.001*	0.16	0.12	*0.001*	0.12	80%	38%	N/A	0%	N/A	0%
Deadman Ck.@Mouth (55DEA-00.2)	6.49	1.44	7.93	0.74	0.17	0.91	0.62	*0.001*	0.62	81%	43%	92%	67%	100%	15%
Dartford Ck. (55DAR-00.2)	0.34	0.23	0.57	0.63	*0.001*	0.63	0.35	*0.001*	0.35	0%	0%	N/A	0%	N/A	0%
LSR@Mouth (55LSR-01.1)	34.46	11.54	46.00	15.77	7.98	23.75	10.08	3.64	13.71	76%	45%	52%	27%	48%	19%
LA for LSR@Mouth set by Spokane TMDL [e]			**46.49**			**24.45**			**14.61**						
Additional capacity [f]			0.49			0.70			0.90						

[a] Allocations for a human load of 0.001 kg/d, shown in italic, indicate a very small, nonmeasureable **de minimus** human load. These occur where either: 1.) no human load was estimated to exist under current conditions, and therefore there was no load to reduce; or 2.) prescribed reductions to human sources result in an apparent 100% reduction in human load at sampling location (see next footnote).

[b] Percent reductions do not exactly correspond with the human source reductions shown in Table 26. The reductions here represent the changes instream that are expected to result from those source reductions.

[c] A percent reduction of N/A means that no human load was estimated to exist under current conditions, and therefore there was no load to reduce. This generally occurred in the upper watershed during baseflow conditions, where the entire TP load was apparently geological, entering the stream via groundwater.

[d] A 100% reduction of human loads shown in this table does not mean a 100% reduction of human sources. Rather, at these locations, we expect the human source reductions shown in Table 26 (typically 80-90%) to result in natural TP loads instream, because of the effects of instream attenuation.

[e] The *Spokane River and Lake Spokane DO TMDL* expressed allocations in lbs/day. We convert them here to kg/day.

[f] We calculated the additional capacity shown here by subtracting the load at LSR mouth (55LSR-01.1; beige row) from the LA set by the Spokane TMDL (pink row). Therefore this is additional capacity **within** the LA for the mouth, not beyond it. The load value shown for LSR mouth (beige row) already includes the WLA loads from Colbert Landfill and Spokane Hatchery. (The watershed analysis accounted for those two point sources along with nonpoint sources.) The additional capacity is available for other small point sources, such as permitted stormwater, and for explicit Margin of Safety.

Shade and heat

Table 9 presents load allocations for shade and heat. These allocations are based on the need to establish system potential shade throughout the Little Spokane River watershed. Appendix I and the **Climate and Shade Inputs** and **Natural Conditions Scenarios > Shade** sections of Appendix G provide the details of our methods for calculating these values.

For the vast majority of streams in the watershed, improving shade is the action that will have the single greatest impact. This is true even of nutrient-sensitive streams where we define DIN allocations. (See the **Instream DO and pH Analysis > Model Scenario Results** section later in this document for more details.) Shade restoration provides two key benefits to DO and pH:

- Shade results in lower water temperatures. Lower water temperatures mean higher saturation points for dissolved gasses, leading to higher DO and lower pH. Also, most biological and metabolic processes occur more slowly at lower temperatures.
- Shade blocks light from reaching the stream. Aquatic algae and plants, like all photosynthetic organisms, depend on light for photosynthesis. Less light reaching the stream usually results in less biological productivity.

We present these allocations in two ways. First, we show the allocations as percent effective shade. This is defined as the percentage of solar shortwave radiation that is blocked from reaching the stream surface by vegetation and topography. Percent effective shade is a useful metric for implementation purposes. Second, we show the allocations as a daily heat load for solar shortwave radiation. This fulfills the statutory requirement that TMDL allocations be expressed as a daily pollutant load.

As noted above, the *Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity TMDL* (Joy and Jones, 2012) also established load allocations for shade and heat. Because we found temperature and light to be the most important elements contributing to DO and pH impairments in the Little Spokane River and its tributaries, it is necessary for us to specify shade and heat in this TMDL as well. Our natural conditions analysis differed from that in the 2012 TMDL, and as a result our system potential shade values vary somewhat from the 2012 values. The **Natural Conditions Scenarios > Shade** section of Appendix G provides a discussion of the reasons for the differing analysis. For implementation and compliance purposes, Ecology directs that wherever differing allocation values exist for the same stream reach, the more protective value should be used. We also note that from a practical standpoint, the on-the-ground implementation is identical. Both TMDLs require system potential shade, which means fully re-establishing native riparian vegetation along streams throughout the watershed.

Table 9. Load allocations for shade and heat for the Little Spokane River and tributaries.

Downstream sampling location	Waterbody	Applicable reach for shade allocations [a]	Current Shade [b]	System Potential Shade [b]	Shade Deficit [b]	Heat Load Allocation (W/m^2) [b c]	Calc Method [d]
LSR@Scotia (55LSR-46.7)	LSR	HW - Scotia	26%	42%	16%	165	WSW
LSR@Frideger Rd. (55LSR-39.5)	LSR	Scotia - Chain Lk.	28%	46%	17%	154	WSW
LSR@Elk (55LSR-37.1)	LSR	Chain Lk. - Elk	14%	56%	42%	125	MS
Dry Ck. (55DRY-00.4)	Dry Ck.	Entire length	46%	76%	30%	68	WSW
Otter Ck. (55OTT-00.3)	Otter Ck.	Entire length	36%	57%	21%	122	WSW
Moon Ck. (55MOO-02.9)	Moon Ck.	Entire length	33%	39%	6%	173	WSW
WBLSR blw Horseshoe Lk. (55WBLS-11.1)	WBLSR	Sacheen Lk. - Horseshoe Lk.	31%	44%	13%	157	WSW
Buck Ck. (55BUC-00.3)	Buck Ck.	Entire length	64%	80%	16%	55	WSW
Beaver Ck. (55BEAV-00.5)	Beaver Ck.	Entire length	73%	90%	17%	28	WSW
WBLSR@Fan Lk. Rd. (55WBLS-07.7)	WBLSR	Horseshoe Lk. - Eloika Lk.	23%	38%	16%	174	WSW
WBLSR@Eloika Lk. Rd. (55WBLS-03.1)	WBLSR	Eloika Lk. - Mouth	25%	39%	14%	172	WSW
Bear Ck. (55BEAR-00.4)	Bear Ck.	Entire length	52%	65%	13%	99	WSW
LSR@Chattaroy (55LSR-23.4)	LSR	Elk - Chattaroy	10%	37%	28%	178	MS
Deer Ck. abv Little Deer Ck. (55DEE-05.9)	Deer Ck.	HW - Little Deer Ck. conf.	68%	84%	17%	44	WSW
Deer Ck.@Mouth (55DEE-00.1)	Deer Ck.	Little Deer Ck. conf - Mouth	36%	58%	22%	117	WSW
Dragoon Ck.@Dahl Rd. (55DRA-17.0)	Dragoon Ck.	HW - Dahl Rd.	26%	55%	29%	128	WSW
Spring Ck. (55SPR-00.4)	Spring Ck.	Entire length	26%	64%	38%	101	WSW
Dragoon Ck. abv. WBDR (55DRA-13.2)	Dragoon Ck.	Dahl Rd. - Burroughs Rd.	17%	32%	15%	191	WSW
WB Dragoon Ck. (55WBDR-00.1)	WB Dragoon Ck.	Entire length	31%	52%	22%	135	WSW
Dragoon Ck.@North Rd. (55DRA-04.3)	Dragoon Ck.	Burroughs Rd. - North Rd.	14%	30%	16%	198	WSW
Dragoon Ck.@Mouth (55DRA-00.3)	Dragoon Ck.	North Rd. - Mouth	26%	43%	17%	160	WSW
LSR@N. LSR Dr. (55LSR-13.5)	LSR	Chattaroy - N. LSR Dr.	20%	34%	14%	186	MS
Deadman Ck.@St. Park Bdy (55DRA-20.2)	Deadman Ck.	HW - St. Park Bdy	77%	92%	15%	24	WSW
Deadman Ck.@Holcomb Rd. (55DEA-13.8)	Deadman Ck.	Park Bdy - Holcomb Rd.	59%	79%	21%	59	WSW
Deadman Ck.@Bruce Rd. (55DEA-09.2)	Deadman Ck.	Holcomb Rd. - Bruce Rd.	17%	41%	24%	166	WSW
S.F. Little Deep Ck. (55SFLD-01.1)	S.F. Little Deep Ck.	Entire length	78%	90%	12%	28	WSW
Little Deep Ck. (55LDP-00.1)	Little Deep Ck.	Entire length	38%	59%	21%	116	WSW
Deadman Ck.@Mouth (55DEA-00.2)	Deadman Ck.	Bruce Rd. - Mouth	29%	44%	16%	158	WSW
Dartford Ck. (55DAR-00.2)	Dartford Ck.	Entire length	56%	85%	29%	42	WSW
LSR@Mouth (55LSR-01.1)	LSR	N. LSR Dr. - Mouth	6%	10%	4%	254	MS

[a] These allocations also apply to tributaries that are not explicitly named in this table. For example, the allocation for Deadman Ck. from Holcomb Rd. – Bruce Rd. would apply to Peone Ck., the allocation for Dragoon Ck. from Burroughs Rd. – North Rd. would apply to Wethey Ck., etc.

[b] We calculated current and system potential shade, shade deficit, and heat load allocation for August 1st, which represents the hottest part of the year and the most critical period for temperature.

[c] The heat load allocation represents daily average solar shortwave radiation entering the stream. We calculated this value for August 1st using Ecology's SolRad tool (Pelletier, 2012b), using a Ryan-Stolzenbach atmospheric transmission coefficient (ATC) = 0.75. This is the value used for QUAL2Kw model and for all other analyses for this TMDL. The total daily average solar shortwave radiation above the canopy, or for a stream with 0% shade, would be 282 W/m^2. We calculated the heat load as (1-[system potential shade]) * [282 W/m^2].

[d] **WSW** = Watershed-wide landscape shade analysis, described in Appendix I. **MS** = Mainstem LSR shade model used for the QUAL2Kw model, described in the **Climate and Shade Inputs** (Table G-10) and **Natural Conditions Scenarios > Shade** sections of Appendix G.

Dissolved inorganic nitrogen

Table 10 presents load allocations for nonpoint dissolved organic nitrogen (DIN). These constitute the vast majority of the loading capacities presented in the **Loading Capacity** section, with a minimal fraction of the loading capacity reserved for the construction stormwater WLA. The load allocations for DIN apply during the May-November season.

Table 10. Load Allocations for nonpoint dissolved inorganic nitrogen (DIN) for the Little Spokane and tributaries.

Location ID	Applicable reach	Load Allocation (kg/day)	Concentration (ug/L) [a]	% reduction needed
55LSR-37.1	Little Spokane R. between Chain Lake and Elk	1.36	16.5 [b]	44%
55LSR-33.2	Little Spokane R. between Elk and WBLSR confluence	30.9	281 [b]	16%
55DRA-19.6	Upper Dragoon Ck., abv Spring Ck.	0.034	23.8	83%
55SFLD-01.1	S.F. Little Deep Ck	0.022	91.7	12%
55DEA-13.8	Deadman Ck. from state park bdy to Holcomb Rd.	0.139	35.4	47%
55DEA-09.2	Deadman Ck. in Peone Prairie from Holcomb Rd. to Heglar Rd.	0.084	24.5	59%
All other tributary and mainstem LSR locations in the LSR watershed		DIN limit not needed to protect instream DO and pH.[c]		

[a] The Load Allocations in this table are set to protect critical low flow (7Q10) conditions. The flow values used to calculate the loads are 7Q10 (or even lower). In higher flow years, it may be more appropriate to regulate to the concentration rather than the load.

[b] The Load Allocations for the Little Spokane River mainstem reaches, as presented, appear to be the same as the DIN load capacity. That is because the general permit bubble wasteload allocation for these reaches is so small in relative terms, as to constitute a rounding error.

[c] Although DIN limits are not needed in these other areas, care should be taken not to allow degradation or backsliding. I.e., there should not be an increase over current conditions.

Margin of safety

A margin of safety accounts for uncertainty about the pollutant loading and water body response and must be included in all TMDL projects to ensure water quality standards are met. This TMDL includes both an explicit (for TP) and implicit (for TP, shade/heat, and DIN) margin of safety.

Explicit margin of safety (TP)

We are retaining an explicit margin of safety (MOS) for total phosphorus (Table 11). The margin of safety is minimal during March-May, but is significant during July-October, which is the most critical time for downstream water quality issues in Lake Spokane.

We developed the explicit MOS by choosing a set of human TP nonpoint and point source reductions that would result in load allocations somewhat less than the loading capacity (see **Watershed Loading TMDL Analysis** section, and Table 26 in particular). This left a small amount of capacity (represented by the bottom pink row in Table 8) for other stormwater and general permit WLAs, which were not explicitly accounted for in the watershed loading analysis, and for an explicit MOS. We calculated the explicit MOS as:

Loading capacity (LA for LSR mouth from the Spokane TMDL)
– LA for LSR mouth (from this TMDL; includes Colbert Landfill and Spokane Hatchery WLAs)
– Other SW/GP WLAs

Explicit MOS

Table 11. Explicit margin of safety for TP.

	March-May TMDL season	June TMDL season	July-October TMDL season
Loading capacity (kg/day) [a]	46.49	24.45	14.61
LA for LSR mouth established in this TMDL (kg/day) [b]	46.00	23.75	13.71
Sum of all other stormwater and general permit wasteload allocations (kg/day) [c]	0.069	0.069	0.069
Explicit MOS (kg/day)	0.421	0.631	0.831
Explicit MOS (as % of loading capacity)	0.91%	2.6%	5.7%

[a] The loading capacity is the load allocation set for the mouth of the Little Spokane River in the Spokane River and Lake Spokane DO TMDL (Moore and Ross, 2010). In the Spokane TMDL it is expressed in lbs/day, here it is converted to kg/day.

[b] The load allocation for the mouth of the Little Spokane River established in this TMDL (not to be confused with the one established by the Spokane TMDL) is shown on the bottom full line of Table 8. We calculated this LA using the methodology detailed in the **Watershed Loading TMDL Analysis** section It is based on the human source reductions shown in Table 26. This LA and the watershed analysis from which it was calculated, explicitly includes the WLAs for Colbert Landfill and Spokane Hatchery. It does not include stormwater WLAs.

[c] That is, all WLAs except for Spokane Hatchery and Colbert Landfill.

Implicit margin of safety (TP, shade/heat, DIN)

In this TMDL report, we applied an implicit margin of safety for TP, shade/heat, and DIN by using conservative modeling and analytical assumptions as follows:

- The watershed loading analysis focused on developing new allocations and target loading reductions throughout the basin that meet the LA at the mouth. The *Spokane River and Lake Spokane DO TMDL,* which specified this LA, already had a Margin of Safety included.
- We addressed uncertainty qualitatively by developing implementation priorities at a sub-watershed scale starting with loads are of largest magnitude, clustered geographically, are found in multiple seasons, or are close in travel time to the mouth.
- For nitrogen-limited tributary streams, we estimated a natural condition DIN concentration of 11 ug/L by taking the 10th percentile of values observed at reference

streams. Since these streams have few human impacts, we could arguably have used the 50th percentile. Using the 10th percentile incorporates an extra degree of conservatism.

- River Metabolism Analyzer (RMA) models at some tributary sites calibrated to subsaturated DO conditions may over-represent the sensitivity of DO to nutrients. This may have resulted in more stringent allocations than would have been applied had this not been the case. (See the **Model sensitivity** section of Appendix H for complete explanation and discussion.)
- The analysis of hydromodification and channel morphology was conservative. Riparian and floodplain restoration efforts may provide more benefits for temperature, DO, and pH than assumed in this analysis.
- We designed the loading capacities to protect DO and pH in the Little Spokane River watershed by increasing shade and reducing DIN. Additional DO and pH improvement is expected from:
    - Improved channel morphology
    - Microclimate improvements due to riparian restoration
    - Any successful efforts to stabilize and restore summer baseflows

TMDL calculation

Table 12 presents the TMDL calculation for total phosphorus at the mouth of the Little Spokane River. Table 13 presents the TMDL calculation for dissolved inorganic nitrogen for each of the nutrient-sensitive reaches where a loading capacity was defined. Both TP and DIN are non-conservative pollutants, whose downstream transport is influenced by instream attenuation processes. We assessed loading of TP using a mass-balance approach, which is described in the **Watershed Loading TMDL Analysis** section. We assessed the local impact of pollutants including heat, TP, and DIN on instream DO and pH using mechanistic water quality models, as described in the **Instream DO and pH TMDL Analysis** section.

For shade/heat, the TMDL calculation is simple: the load allocation equals the load capacity. For each reach in Table 9, the value shown in the "heat load allocation" column represents both the load capacity and the load allocation. As discussed above in the **Wasteload Allocations** section, point sources are not significant contributors of thermal pollution in this watershed. Any possible heat contribution from stormwater would be so small relative to the load capacity for solar shortwave radiation as to constitute a negligible rounding error.

Table 12. TMDL calculation for total phosphorus load by season [a]

Description	March-May	June	July-October
Load allocation, accounting for upstream Spokane Hatchery and Colbert Landfill wasteload allocations [b] (kg/day)	46.00	23.75	13.71
Sum of all other stormwater and general permit wasteload allocations (kg/day)	0.069	0.069	0.069
Explicit Margin of Safety (kg/day)	0.421	0.631	0.831
Total allocations and MOS (kg/day)	**46.49**	**24.45**	**14.61**
Load Capacity (kg/day)	*46.49*	*24.45*	*14.61*

[a] The location is 55LSR-01.1 (Little Spokane River @ Mouth) and the applicable reach is the entire watershed.

[b] The watershed mass balance loading analysis (see **Watershed Loading TMDL Analysis** section) explicitly accounts for the loads from Colbert Landfill and Spokane Hatchery. The load calculations at all locations downstream of these points, including at the Little Spokane River mouth, include these point source loads.

Table 13. TMDL calculation for dissolved inorganic nitrogen (DIN) loads for July-October season

Location	55LSR-37.1	55LSR-33.2	55DRA-19.6	55SFLD-01.1	55DEA-13.8	55DEA-09.2
Applicable reach	Little Spokane R. between Chain Lake and Elk	Little Spokane R. between Elk and WBLSR confluence	Upper Dragoon Ck., abv Spring Ck.	S.F. Little Deep Ck	Deadman Ck. from state park bdy to Holcomb Rd.	Deadman Ck. in Peone Prairie from Holcomb Rd. to Heglar Rd.
Load allocation (kg/day)	1.36 [a]	30.9 [a]	0.034	0.022	0.139	0.084
Bubble GP wasteload allocation (kg/day) [b]	0.00038 [a]	0.00059 [a]	0.00096	0.00063	0.00081	0.00060
Total allocations (kg/day)	**1.36**	**30.9**	**0.035**	**0.023**	**0.14**	**0.085**
Load Capacity (kg/day)	*1.36*	*30.9*	*0.035*	*0.023*	*0.14*	*0.085*

[a] The total allocations for the Little Spokane River mainstem reaches, as presented, appear to be the same as the load allocations. That is because the general permit bubble wasteload allocation for these reaches is so small in relative terms, as to constitute a rounding error.

[b] Includes industrial stormwater (except for Spokane Recycling), construction stormwater, and sand & gravel.

Implementation Plan

Introduction

This Little Spokane River implementation plan was developed by Ecology and describes what needs to be done to improve water quality. It explains the roles and authorities of cleanup partners (those organizations with jurisdiction, authority, or direct responsibility for cleanup), along with the programs or other means through which they will address the water quality issues. It prioritizes specific actions planned to improve water quality and achieve water quality standards. TMDL reductions should be achieved by 2030. If effectiveness monitoring shows this not to be the case, adaptive management procedures described in this plan will be triggered and the implementation plan revised with new milestones and a load reduction completion deadline.

Point source wasteload allocations (WLAs) will be implemented through the administration of the National Pollution Discharge Elimination System (NPDES) Program. However, the Little Spokane Watershed Implementation Lead is tasked to work with permit managers to ensure that new TMDL-related requirements become permit conditions when permits are renewed. Phosphorous nonpoint load reductions will be achieved primarily by reducing or eliminating sediment-linked nutrient sources associated with land uses such as agriculture tillage practices, livestock grazing, as well as dissolved nutrient sources associated with urbanization and fertilizer application. Implementation actions that protect streambanks and restore riparian vegetation will improve riparian condition throughout the watershed. Carrying out these actions will also meet requirements specified in the 2012 Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity TMDL[3].

Watershed Land Use

Land use is often one of the most important watershed characteristics key to gaining an understanding of pollution sources (EPA, 2018). Land use determines the type, location, and relative severity of phosphorus pollution sources.

Most of the Little Spokane River watershed is primarily a rural landscape consisting of forested ridges, agricultural valleys, and small urbanized areas (Figure 5). The watershed also includes the northern portion of suburban Spokane. Livestock are mostly concentrated in the Dragoon Creek and Deadman Creek sub-watersheds. The residential, commercial, and industrial developments from the city of Spokane urban influence are mostly evident in the Lower Little Spokane River sub-watershed and along the lower Deadman and Little Deep Creek drainages.

[3] https://fortress.wa.gov/ecy/publications/documents/1110075.pdf

Map

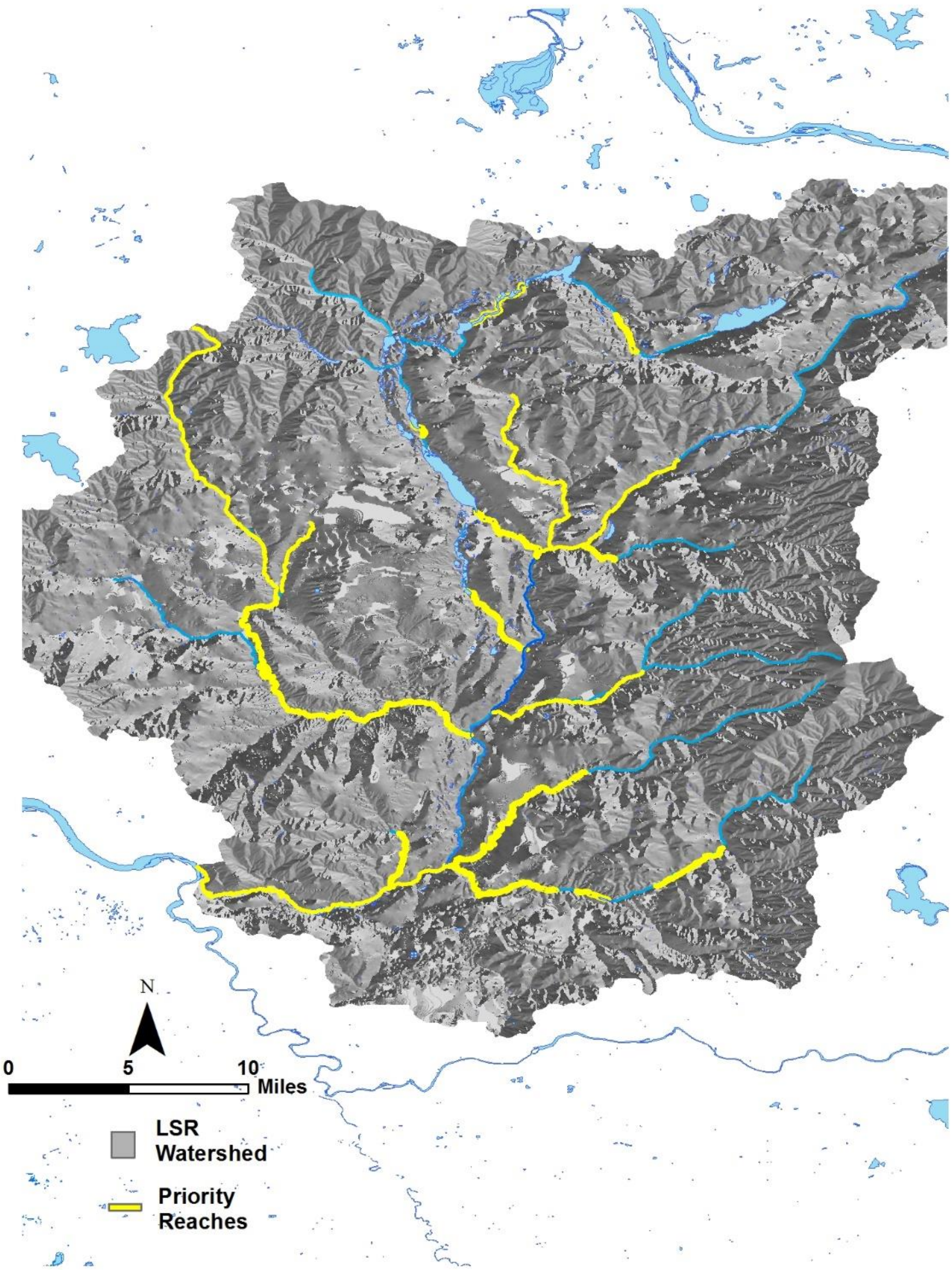


Figure 4. Map showing priority restoration reaches

Agricultural Areas

Agricultural land use comprises about 27 percent of the watershed area. This varies considerably throughout the watershed. Approximately 48 percent of the Dragoon Creek sub-basin and 35 percent of the Deadman Creek sub-basin are agricultural, as compared to 5 percent of the West Branch Little Spokane River sub-basin. Agricultural activities include orchards, hay, grain, rotational crops, and livestock. Historically, farming has had an impact on the Little Spokane River by removing riparian vegetation to raise crops.

Development over the past 150 years has changed the landscape and hydrology in the watershed. Before these changes, the Little Spokane River and tributaries were densely vegetated and unconfined. Many of the present day crop fields were forested and protected from heavy precipitation and runoff events, allowing overland flows to infiltrate before reaching surface waters. Numerous reaches of the Little Spokane River and tributaries have been straightened in agricultural fields to maximize harvestable acreage. The straightening of these channels reduces channel complexity and sediment storage, while increasing erosion, turbidity, and local flooding.

Agricultural producers often farm the land right up to the water's edge, eliminating riparian vegetation and forming a direct flow path for sediment and other pollutants. The riparian vegetation normally acts as a filter for pollutants, creates bank stability, reduces erosion, provides shade, and reduces stream temperatures. Furthermore, many farmers still use conventional farming practices that expose soils to high erosion rates.

The majority of the agricultural activity in the Little Spokane River watershed is comprised of small-scale local producers who have a direct connection to the watershed. Although most operations are of smaller scale, cumulatively, agricultural activity and landscape modification have substantial effects on water quality. The combined effects of all activities and modifications defines the hydrology of the agricultural landscape, and thereby, determines the amount, timing, and specific flow paths of water, sediment, and pollution moving through and out of the agricultural landscape.

The movement of water is the most important connection between agricultural activities and impacts on the quality of streams and rivers. Understanding the movement of water – amounts, timing, and pathways – is fundamental for making optimal agricultural management and policy decisions toward minimizing the impacts of agriculture on water quality.

Setbacks, riparian buffers, and improved tillage practices are primarily designed and implemented to minimize soil loss and prevent runoff of the sediment and nutrients into the stream by surface flow. These practices are effective because they slow down the water moving across the fields by surface flow and increase the volume of recharge.

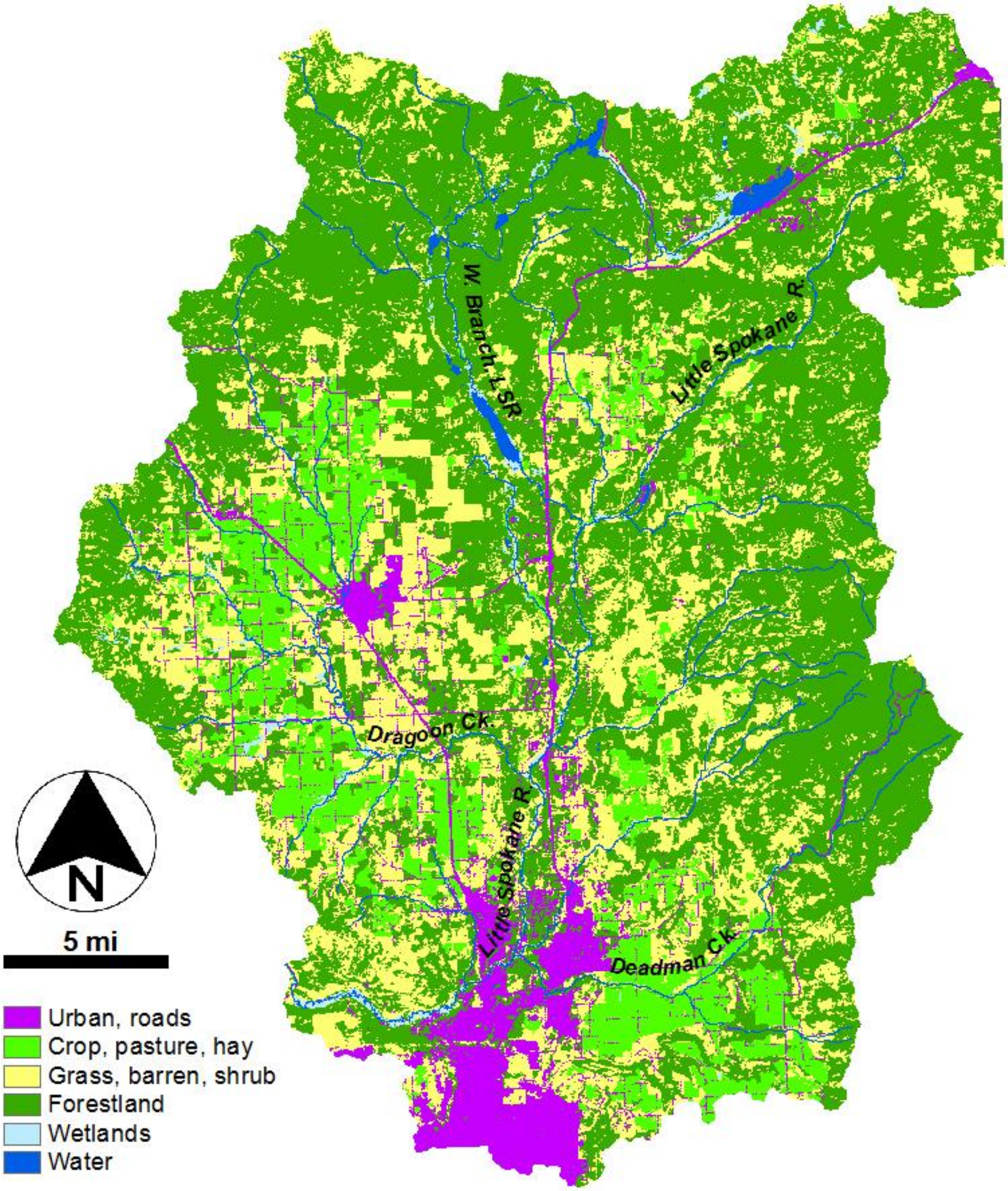


Figure 5. Map showing land use in the Little Spokane River watershed.

Source: National Land Cover Database, 2006 (USGS, 2006)

Residential Areas

Population growth and increased residential development have especially impacted the Lower Little Spokane River sub-watershed. Approximately 24 percent of the land in the watershed area below the confluence with Deadman Creek (the last 13 miles of the Little Spokane River) is designated urban. Under the Spokane County Comprehensive Plan, all land immediately adjacent to the Little Spokane River is designated Rural Conservation. Other than the urban areas surrounding Riverside, Mead, Colbert, Chattaroy, and Eloika, the remainder of the land in the Little Spokane River watershed in Spokane County is designated Rural Conservation, Rural Traditional, Forest Land, or Small Tract Agriculture. These designations have a minimum lot size of 10 to 20 acres. But if the land was divided into smaller lots prior to the adoption of the Comprehensive Plan, the lots are still available for development. North of the Spokane metropolitan area, there are a number of smaller residential areas, including Deer Park (population 3704), and Newport (population 2115), as well as small communities including Clayton, Chattaroy, Riverside, and Elk. In addition, residential development surrounds certain lakes, particularly Diamond and Sacheen.

Residential and commercial development within the watershed decreases the amount of land surface that is able to absorb moisture from rain and snowfall. Paved roadways and rooftops are impervious (impenetrable) surfaces that cause stormwater to run quickly off the landscape. Moisture is no longer stored within the topsoil and groundwater but instead enters the creeks and rivers quickly, causing flooding for short periods followed by reduced water flow over extended periods. Peak flows occur more frequently, increasing the erosive force and downstream sedimentation, as well as affecting groundwater infiltration and storage volumes. The city of Spokane, Spokane County, and Washington State Department of Transportation (WSDOT) have been issued stormwater permits for these urbanized areas.

Lawn and garden care in residential neighborhoods can impact the quality of the river by the misuse or overuse of chemical fertilizers and pesticides. These fertilizers and insecticides can run off to the river during rain events or with over-watering. Some property owners adjacent to the waterways dump lawn clippings and other vegetative debris next to, or in, the river where it is washed down during high-flow events.

Residential areas on the edge of urban development are frequently beyond the areas served by sewage waste treatment facilities. Septic systems are designed to remove the solids and allow the water to enter the soil, where nutrients should be retained by plants or soil particles. Improperly designed, poorly maintained, or failing septic systems increase pollutant delivery to surface water via contamination of shallow groundwater supplies or even surface runoff.

As population and development increase in the watershed, construction sites can pose problems by destabilizing soils and increasing sedimentation, causing changes in streamflows. These sites also compact the soil, creating less pervious surfaces that increase runoff that could result in flooding. The removal and degradation of existing riparian vegetation can cause channel instability, carrying eroded soils with attached nutrients to nearby waterways.

Forested Areas

About two-thirds of the land in the Little Spokane River watershed is forest. Forested land stabilizes hillsides, provides habitat for a variety of wildlife, and keeps streams cool. Logging, if not done properly, has the potential to destabilize soils and eliminate habitat. Logging activities close to wetlands can impact water quality. Along with possible wetland destruction, the construction of roads can be very damaging to streams, resulting in increased sedimentation. Nutrients are typically attached to sediment which erodes into streams.

Reforestation along streams in the Little Spokane River watershed is essential to not only decrease temperature so the water can hold more dissolved oxygen, but also to stabilize streambanks to reduce nutrient-laden sediment wasting to the streams. Streambank stability is largely a function of near-stream vegetation. Specifically, channel morphology is often highly influenced by land-cover type and condition by (1) affecting flood plain and instream roughness, (2) contributing coarse woody debris, and (3) influencing sedimentation, stream substrate compositions, and streambank stability. Decreased erosion is the benefit of stable streambanks.

Nonpoint Sources of Pollution

Nonpoint sources, particularly agricultural sources, are well known to be significant contributors of phosphorus to surface waters (Sharpley and Moyer, 2000; Sharpley et al., 1994; Daniel et al., 1998; Gitau, 2005). This TMDL's analysis shows that nonpoint sources are large contributors of phosphorus loading to the Little Spokane River watershed. Nonpoint load reductions will be essential to ensuring phosphorus reduction goals are met. This same analysis shows the highest nonpoint phosphorus loading originates from specific tributaries in the Little Spokane River sub-watersheds. Therefore, the primary focus for nonpoint phosphorus reductions will be tributaries in the Little Spokane River watershed including Deadman Creek, the headwaters and west branch of Dragoon Creek, Otter, Deer, and Little Deep Creeks.

A review of water quality sampling data, land uses, aerial imagery, and informal watershed assessments of the Little Spokane River watershed indicate the most likely nonpoint sources of dissolved phosphorus in the Little Spokane River watershed are as follows (in order of implementation importance):

Sediment-Linked Nutrients from Crop Production

Sediment-linked nutrients from agricultural operations during runoff events is a significant source of nutrients in Dragoon, Little Deep, and Deadman tributaries. These sub-watersheds, specifically the field erosion from crop production, are the main contributors of sediment and nutrients to the mainstem of the Little Spokane River during the wet season. More than a century of agricultural practices (upland tillage and riparian alterations) has accelerated flow during runoff, exacerbating erosion. Erosion is a natural process with loss rates dependent on factors such as soil characteristics, exposure (vegetative cover), slope, and the magnitude, intensity, and duration of precipitation and wind. Given these factors, the exposure of soil is a major determinant in the relative rates of erosion for a given crop and location. For this reason, tillage intensity and, in turn, the level of residue cover are critical factors in evaluating vulnerability to erosion especially during the harvest-to-planting period. Related to precipitation, residue shields the soil surface from direct impact of rain drops that can result in soil particle detachment, and the initiation of sheet erosion. Residue coverage also increases the surface complexity and, therefore, surface flow pathways, reducing surface runoff concentration, and facilitating its infiltration.

Lack of Riparian Vegetation

Solar heating from lack of riparian shade adversely effects water temperature, dissolved oxygen, and pH levels. Water temperature affects the physiology and behavior of fish and other aquatic life. Temperature can be the most influential limiting factor effecting the distribution and health of aquatic life, and it can be greatly influenced by human activities. The lack of riparian vegetation increases sediment in surface waters by 1) loss of filtration of sediment/nutrients and 2) loss of streambank integrity due to absence of root mass. The riparian zones within the Little Spokane River watershed have gone through significant modification. Agricultural, residential, transportation, and forest harvest uses have disturbed the native riparian vegetation and function. System-potential effective shade was compared to existing conditions in the Little Spokane River, resulting in an estimated 61 percent loss of natural riparian vegetation. Results in major tributaries had even more profound losses, such as 70 percent in Dragoon Creek and 93 percent in Little Deep Creek (Little Spokane River WQIR, 2012).

Nutrients from Livestock

The EPA has identified agricultural sources, including grazing and animal feeding operations, to be a key contributor of phosphorus (and nitrogen) to rivers and streams (EPA, 2017). Rau (2015b) cites direct animal access to streams, manure or fertilizer overspray or runoff, runoff from pastures, grazing areas, and heavy use areas as significant potential sources of nutrients to Washington's waters. The Little Spokane River does not have large concentrated animal feeding operations (CAFOs), but does have numerous smaller farms with cattle and horses having direct stream access. Access by farm animals results in direct inputs of animal wastes, degradation of stream side vegetation, and bank instability.

Nutrients from Stormwater

Relative to its size and proximity to the city of Spokane, there are few facilities in the Little Spokane River watershed with NPDES permits. However, nonpoint stormwater pollution from roadways, residential areas, and industrial sites can have profound concentrations of pollutants when stream buffers are not in place. Road salts, deicer, and auto fluids that accumulate on impervious surfaces can all have adverse effects to water quality. As urban areas grow, urban streams are forced to accommodate larger volumes of stormwater runoff that recur on a more frequent basis.

Channel Geometry and Function, Hyporheic Exchange

Many reaches in the Little Spokane River watershed lack channel complexity compared to reference reaches with similar characteristics such as geology, stream type, vegetation, and valley slope. Human activities have presumably reduced the amount of Large Woody Debris (LWD) recruitment, effectively reducing suitable fish habitat, adequate cover/shade, and sediment storage. Channel alterations have straightened reaches, reduced sinuosity, and increased flows during runoff which has accelerated erosion rates. Erosion due to sheer stress on streambanks lacking riparian vegetation exacerbates nutrient loading that often leads to over-widened very shallow reaches, resulting in increased water temperatures.

Nutrients from septic systems

Septic systems are known to be potential nutrient sources in rural areas (Withers et al., 2011; Withers et al. 2009) and the majority of the tributaries and some of the main stem of the Little Spokane River is serviced by on-site septic systems. Improperly maintained septic systems can fail and lead to pollutants entering waterways. Untreated or partially treated sewage can accumulate on the ground's surface and runoff into streams. Improperly treated sewage can also leach pollutants into ground water, which may travel to nearby streams. Generally, septic systems are considered an effective means of wastewater treatment provided they are designed, located, and maintained correctly (Withers et al., 2011).

Runoff and Erosion

Pollution of aquatic ecosystems is strongly influenced by watershed land use and the concentration and exposure of nutrients in watershed soils: Any factor that increases erosion or the amount of runoff will increase nutrient loads to downhill aquatic ecosystems.

Of particular concern is that large amounts of soil that can be mobilized by exceptional precipitation and erosion events or by changes in land management practices. Rainfall usually interacts with only a thin layer of surface soil before leaving as runoff (Sharpley, 1985). Erosion is generally associated more with particulate phosphorus than dissolved phosphorus (Sharpley et al., 1994) and therefore, this TMDL includes BMPs that address spring runoff and erosion.

Groundwater

As stated, research indicates that runoff and erosion are typically the primary transport pathways for dissolved phosphorus to reach surface water. However, during the dry summer months of focus in this TMDL, groundwater transport may become comparatively more important. Perhaps most important is not the quantity of phosphorus transported via groundwater relative to runoff/erosion, but the manner in which groundwater moisture and phosphorus content influence runoff/erosion transport. Duda and Finan (1983) found that large spring storms generated runoff where soil moisture was high. And Sharpley et al., (1993) state that a significant linear relationship has been demonstrated between soil phosphorus and dissolved phosphorus concentrations in runoff. In other words, shallow groundwater may significantly increase that phosphorus which is transported via runoff, especially in spring when soils are still wet.

Drainage

Phosphorus transport via man-made drainage networks may well be highly significant. Duda and Finan (1983) found pollutant delivery was enhanced where roadside and field ditches were common. Roads, highways, and bridges are conduits for pollution to nearby waterways during the wet season and storm events. Roadways adjacent to agricultural areas are likely to carry sediment to nearby waterways through drainage ditches if they are lacking vegetated buffers. Impervious surfaces such as parking lots and road construction sites tend to accumulate pollutants like petroleum over time, and can have direct flow paths to surface waters if BMPs are not in place.

Subsurface drainage may also be of importance to nutrient transport. Subsurface drainage systems, e.g., tile drains, are a common method of quickly drying agricultural soils prone to saturation. Sharpley et al.,, (1994) found that phosphorus losses can be significant when artificially drained, even when those soils are naturally poorly draining. Similarly, Duda and Finan (1983) found much higher levels of nutrients in agricultural watersheds with extensive artificial drainage. They also found substantial flow associated with tile drains following storms and visual indicators (e.g., algal blooms below tile drain outfalls) suggesting nutrient transport.

Best Management Practices

This TMDL classifies **nonpoint** corrective measures into three broad categories, prioritized as follows:

1) Source control
2) Transport treatment
3) Dissolved oxygen enhancement

The primary implementation focus is corrective measures, or best management practices (BMPs), that control and treat sources of total phosphorus and total suspended solids (TSS) and increase dissolved oxygen levels during the critical period. The Little Spokane River also fails state water quality standards for temperature, turbidity, and bacteria. Those parameters were addressed in a separate TMDL. Specific suites of BMPs are often needed to address the multiple water quality parameters and meet water quality standards.

In addition to suites of BMPs designed to control and treat sources of pollution, there are practices available that may enhance dissolved oxygen. These BMPs are considered important supporting practices. Dissolved oxygen enhancement BMPs will be most effective during the critical summer flows, but will also be beneficial during spring runoff and will vary in design based on factors such as flow, access, and risk to infrastructure. For example, the addition of instream log weirs for channel complexity and oxygen absorption would suffice as a multi-seasonal supporting BMP.

BMPs listed in Table 14 below are in order of priority (1 = highest priority) largely following the source, transport, and treatment priorities described above. The intent of this priority list is to inform implementation work plans and outreach with landowners as to ensure that priority BMPs are installed. The appropriate suite of BMPs will often include more than one of these priorities and be dependent on the severity of the site, location within the watershed, and land use activity. For example, BMPs that will reduce field erosion in ephemeral and intermittent streams may not be the same BMPs prescribed for livestock on a perennial tributary.

Natural Resource Conservation Service (NRCS) practice standard codes in the Field Office Technical Guide (FOTG) for agricultural activities are provided in the tables below. Implementation partners can quickly access reference information regarding the engineering/design of the BMP. NRCS codes provide important construction standards but are not considered state compliance standards for agricultural operations. Referencing NRCS codes should in no way be interpreted to imply that the NRCS requirements supersede Ecology's water quality guidance. Where discrepancies exist between Ecology and NRCS guidance, to comply with state water quality standards operators must follow Ecology's recommendations as expressed in this TMDL or implement practices that provide an equivalent level of protection. If NRCS requirements are more stringent, we encourage operators to follow those requirements..

In addition to the recommendations below, other BMP guidance may be helpful to implement actions needed to meet water quality standards in the watershed. Ecology's Clean Water Guidance for Agriculture is currently under development and will provide recommendations for a variety of different agricultural land uses. In addition, the Water Resources Inventory Area (WRIA) 55 watershed plan was recently updated. The purpose of the update was to offset impacts to flow from exempt well drilling and is primarily driven by water quantity needs rather than water quality. Yet, the plan also identifies non-water offset BMP strategies including floodplain and habitat restoration that would benefit water quality in the Little Spokane watershed.

Table 14. TMDL Implementation BMP Priorities

Implementation Priority	NRCS FOTG	BMP	Source Control	Transport Abatement	DO Enhancement
1	329, 345	Conservation tillage; no-till	✓	✓	
2	391	Riparian buffers	✓	✓	✓
3	590	Proper fertilizer application, nutrient management plan	✓		
4	472	Livestock exclusion	✓		
5	395	Stream habitat improvement and management			✓
6	N/A	On-site septic tank inspection, repair and maintenance (not NRCS funded)	✓		
7	554	Tile drain, drainage water management, and Road and Highway stormwater		✓	
8	449	Improved irrigation efficiency		✓	
9	666	Forest Stand Improvement	✓	✓	
10	N/A	Property acquisitions	✓	✓	

Recommended Primary BMPs for Agricultural Operations

Agricultural production is a significant source of pollution in the Little Spokane Watershed. Operations in the watershed must prevent the discharge of pollutants to state waters (90.48 RCW). Table 15 presents recommended BMPs that can prevent pollution delivered by agricultural sources. Persons engaged in agricultural operations who implement and maintain the recommended BMPs below will be presumed to be in compliance with the *Little Spokane River DO and pH TMDL* and the State Water Pollution Control Act (90.48 RCW). The current available science indicates the recommended BMPs are sufficient to meet water quality standards. But, Ecology recommended BMPs must be outcome oriented. If we determine through on-going implementation and effectiveness monitoring that water quality standards are not being met or we determine that more protective BMPs are needed for compliance, other recommendations may be made through the adaptive management process (see the Adaptive Management section of this report). If an agricultural operation is applying all of the listed BMPs and a violation of water quality criteria remains, the operator may be required to modify existing practices or apply further water pollution control measures selected or approved by Ecology, to achieve compliance with water quality criteria.

This TMDL recommends the practices listed by land use in Table 15 be implemented in combination as a holistic system, because they support each other. The sum benefits are greater than the individual BMP alone. Supporting BMPs should also be considered and are discussed later in this document. Alternative BMPs to Table 15 may be utilized if they provide equivalent protection.

Table 15. Agricultural BMPs for Preventing Pollution.

Suite of Livestock Practices	
Name of BMP	**Description of Agricultural Activity**
Riparian Buffer Code 391	For ephemeral streams, install a minimum 35-foot wide riparian buffer, measured horizontally from the top of the streambank. The buffer should include the reestablishment of streamside vegetation, sufficient to filter out pollutants before they reach the stream, and to stabilize stream banks. The buffer width may be increased, if needed For intermittent streams, install a minimum 35-foot wide riparian buffer, measured horizontally from the top of the streambank. This TMDL recommends a 50-foot-wide buffer to ensure water quality protection. The buffer should include the reestablishment of streamside vegetation sufficient to filter out pollutants before they reach the stream, and to stabilize stream banks. The buffer width may be increased, if needed. For perennial streams, install a minimum 50-foot-wide riparian buffer (75 feet wide, if fish bearing), measured horizontally from the top of the streambank.
Exclusion Fencing Code 382	Install exclusion fencing to prevent livestock access to all riparian buffers. Livestock should be excluded from flooded and flood-prone areas during periods of saturation. The use of hardened stream crossings should be used for all livestock movement across the riparian zones. Water gaps, with hardened access, may be used to water livestock in range pastures (not animal confinement or feeding areas).
Off-Stream Water Facility Code 614	Off-stream water facilities should be set back a minimum of 100 feet from all surface waters unless it can be demonstrated to Ecology's satisfaction that there is no suitable site more than 100 feet from surface waters. In the latter case, Ecology may approve a design plan to prevent contamination of State waters.

Table 16. Agricultural BMPs for Preventing Pollution.

Animal Confinement and Feeding Areas Code 472	Animal confinement and feeding areas should be set back a minimum of 100 feet from all surface waters unless it can be demonstrated to Ecology's satisfaction that there is no suitable site more than 100 feet from surface waters. In the latter case, Ecology must approve a design plan to prevent contamination of State waters. A 100-foot buffer zone should be established around all surface inlets and vents to subsurface drainage that are located within the boundaries of the animal confinement and feeding areas. All animal confinement and feeding areas should be sited away from locations that will concentrate runoff or increase the potential for polluted runoff to reach perennial surface waters such as steep slopes, unstable or erodible soils, natural or constructed drainages, or topography that concentrates runoff. All animal confinement areas should be hardened (stabilized) with compacted gravel, concrete, or similar material to allow for effective manure collection and to prevent erosion.
Dry Manure Management Code 590	Livestock manure should be collected, stored, composted and utilized in a manner that prevents contamination of State waters. Dry manure should be stored and composted in appropriately constructed manure management facilities. Manure management facilities should be set back a minimum of 100 feet from all surface waters unless it can be demonstrated to Ecology's satisfaction that there is no suitable site more than 100 feet from surface waters. In the latter case, Ecology should approve a design plan to prevent contamination of State waters. Manure collection, storage, and composting areas should never be constructed directly above or within a 100-foot horizontal distance of any surface inlet, manhole, or vent to subsurface drainage. This includes small-diameter tile in-field drainage, as well as large-diameter collector drains, that are completely buried. Manure storage facilities should be designed to provide adequate storage for all manure generated by the operation, be covered, and installed on an impermeable surface. All manure collection, storage, and composting areas should be sited away from locations that will concentrate runoff or increase the potential for polluted runoff to reach perennial surface waters such as steep slopes, unstable or erodible soils, natural or constructed drainages, or topography that concentrates runoff. Clean water should be diverted from entering manure collection, storage, and composting areas through the use of gutters, berms, roofs, or other means of conveyance to prevent contact with manure. All manure should be utilized in a manner that prevents contamination of State waters. Application of dry manure to fields should be consistent with the Nutrient Application BMPs listed below in the section labeled **Cropland Practices**.
Stream Crossing Code 578	Stream crossing are stabilized areas or bridges constructed to provide travel for livestock and prevent discharges of pollution to surface water. Stream crossing should be installed as part of a suite of BMPs if livestock need to access both sides of a stream.
Heavy Use Area Protection Code 561	Heavy Use Area Protection is used to stabilize a ground surface that is frequently and intensively used by livestock. Heavy Use Area Protection should be included as part of a suite of livestock practices if intensively used areas increase the risk of polluted run-off.

	Table 17. Agricultural BMPs for Preventing Pollution.
Liquid Manure Management Code 590	Livestock manure should be collected, stored and utilized in a manner that prevents contamination of State waters. Liquid manure should be stored in appropriately designed and constructed waste storage lagoons. Manure storage lagoons should be set back a minimum of 100 feet from all surface waters unless it can be demonstrated to Ecology's satisfaction that there is no suitable site more than 100 feet from surface waters. In the latter case, Ecology should approve a design plan to prevent contamination of State waters. Manure storage lagoons should never be constructed directly above or within a 100-foot horizontal distance of any surface inlet, manhole, or vent to subsurface drainage. This includes small-diameter tile in-field drainage, as well as large-diameter collector drains, that are completely buried. Manure storage lagoons should be designed, constructed and maintained following the most current guidance provided by the WSDA and other appropriate environmental and resource agencies. Clean water must be diverted from entering manure storage lagoons through the use of gutters, berms, roofs, or other means of conveyance to prevent contact with manure. All liquid manure should be utilized in a manner that prevents contamination of State waters. Application of liquid manure to fields should be consistent with the Nutrient Application BMPs listed below in the section labeled **Cropland Practices**.
Suite of Cropland Practices	
Riparian Buffer FOTG 391	For ephemeral streams, install a minimum 35-foot wide riparian buffer, measured horizontally from the top of the streambank. The buffer should include the reestablishment of streamside vegetation, sufficient to filter out pollutants before they reach the stream, and to stabilize stream banks. The buffer width may be increased, if needed For intermittent streams, install a minimum 35-foot wide riparian buffer, measured horizontally from the top of the streambank. This TMDL recommends a 50-foot-wide buffer to ensure water quality protection. The buffer should include the reestablishment of streamside vegetation sufficient to filter out pollutants before they reach the stream, and to stabilize stream banks. The buffer width may be increased, if needed. For perennial streams, install a minimum 50-foot-wide riparian buffer (75 feet wide, if fish bearing), measured horizontally from the top of the streambank.
Conservation Tillage FOTG 329	Implement reduced tillage practices that achieve a minimum residue coverage of 60 percent. The residue coverage expectation is based on the minimum observed from harvest to the time of planting, or a soil Tillage Intensive Rating (STIR) of 30 or less as determined by the Natural Resources Conservation Service (NRCS).

Fertilizer Management Code 590	**Suite of Cropland Practices** Operations should only apply the amount of fertilizer needed and consider timing of application to reduce or eliminate the potential for run-off to surface water. A comprehensive nutrient management plan is recommended that incorporates precision ag practices that use technology for nutrient placement.
Irrigation Water Management	Irrigation systems should only apply the amount of irrigation water needed by the crop and in a manner that limits waste, prevents surface losses of nutrient and soil, and prevents nutrient leaching. In no event should runoff occur when using any irrigation method, including runoff into subsurface drainage through inlets, vents, and manholes. Rill irrigation should be eliminated, whenever possible.
Tile Drain Management	Tile drainage should be eliminated when possible to reduce drainage intensity. Controlled drainage or drainage water management, such as riparian buffers to filtrate pollutants, set-backs from surface waters at end of tile locations, and winter cover crops

Riparian Buffers

Riparian buffers are native woody vegetation zones along streams that serve to protect or "buffer" surface waters from adjacent and upland anthropogenic impacts. The vegetation and associated organic litter provide physical resistance to surface flow, thus slowing runoff velocities and allowing for the deposition of particulates like sediment and sediment-bound nutrients (Lee et al., 2003). In addition, the chemical and biological process associated with forested riparian ecosystems transform nutrients and chemicals transported via runoff (Snyder et al., 1998; Lee et al., 2003), reducing or making more benign that which is delivered to surface waters. Buffers are important for all land uses in the watershed including agriculture. Riparian buffers are deemed an effective and relatively cost effective BMP frequently recommended to remove or reduce sediment and nutrients associated with agricultural runoff (Lim et al., 1998; Daniels and Gilliam, 1996; Smith, C.M., 1988; and Younos et al., 1998).

The establishment of healthy riparian buffers, along with conservation tillage practices, will be the most effective strategy to reduce nutrient pollution during runoff in the Little Spokane River watershed. Healthy riparian buffers benefit the watershed in a multitude of ways throughout the landscape as well as throughout the year. During spring runoff, riparian buffers are essential for filtering sediment from agricultural runoff, effectively leaving the soil on the landscape. Riparian buffers slow down spring flows by creating roughness on slopes, which in turn reduce sheer stress, greatly reducing erosional forces. Once established, riparian buffers create a seed sink promoting the propagation of additional vegetation. Riparian buffers can be so effective at slowing down flows in intermittent streams, ephemeral drainages, and ditches that flows will percolate and infiltrate into the soil, recharging groundwater.

Riparian buffers that include native vegetation such as willow (*Salix spp*.), red osier dogwood (*Cornus sericea*), and Douglas hawthorn (*Crataegus douglasii*) are a key component for perennial and intermittent streamside bank restoration. The streamside vegetation provides resiliency to erosion and scour by establishing a robust root network. Once established, the vegetation will become dense and effectively create surface tension and drag, slowing down high flows and allowing suspended sediment to deposit. During the hot summer months, the established vegetation will provide additional shade and reduce stream temperatures. Riparian buffers intercept direct flow paths to surface waters, by creating roughness on the landscape and filtering out sediments and debris of overland flows during heavy precipitation and rapid snow melting events. Native vegetation is vital to the complex macro-invertebrate food web, which support native fish species.

The phosphorus removal performance of buffers varies depending on site conditions (e.g., soil types, slope, and climate) but also on buffer size and composition. Research literature reviewed reported large ranges of effective buffer widths but the majority demonstrated similar effective widths. On the high end, Young et al., (1980) found buffer strip lengths of 36 m (118 ft) to be sufficient to reduce nutrient levels to 'acceptable levels'. On the low end, Lim et al., (1998) found no reduction in phosphorus concentration in runoff from buffer strips more than 6 m (20 ft) wide. However, Abu-Zreig et al., (2003) found short filters, 5 m wide (16 ft) were not effective at removing phosphorus, and instead found best phosphorus removal with 15 m (50 ft) wide buffers. Similarly, Schmitt et al., (1999), Srivastava et al., (1996), and Lowrance et al., (2001) found optimal phosphorus reduction performance around 15 m to 20 m (65 ft). Consistent with these latter, mid-range, findings (which represents the majority of papers reviewed), this TMDL adopts 50 ft as the minimum buffer width necessary (on perennial and seasonal streams) to achieve assigned phosphorus reductions. (Table 16).

Table 18. Minimum buffer widths and recommended buffer widths for broader water quality protection and funding eligibility purposes

Waterbody Type	Minimum Widths	Recommended Widths
Large perennial or seasonal streams	50 ft	75 ft
Small ephemeral drainages and ditches	35 ft	50 ft

Larger (minimum 75 ft) buffers are highly recommended to be protective of other water quality parameters (e.g., temperature) and to be consistent with Ecology's 319/Centennial funding eligibility criteria designed to protect aquatic life. This also approximates the buffer width reviewed in the literature cited above.

The effectivity and cost efficiency of riparian buffer installment throughout the Little Spokane watershed make this BMP action vital to the success of this TMDL. Perennial, intermittent streams, small ephemeral drainages and ditches, especially in agricultural landscapes, should be a primary focus for riparian buffer installation to address nutrient pollution from runoff. Here are detailed management recommendations for implementing buffers:

- Buffers must be wide enough to provide maximum possible dissolved phosphorus filtration/treatment.
- Have a minimum 50 ft on all mainstem channels and/or perennial, fish-bearing streams.
- A 75 ft buffer width (on perennial and seasonal streams) is strongly recommended so as to be protective of other, more restrictive water quality parameters (e.g., temperature) and to be consistent with 319/Centennial funding eligibility criteria.
- Buffers as low as 35ft may be acceptable on small conveyances (e.g., ditches, canals) and ephemeral side channels/depressions.
- TMDL implementation partners are encouraged to use best professional judgement and consider local site conditions (e.g., soils, slope) when determining if buffer widths should be larger. For example, buffer widths may need to be larger in order to address faster flow off steep slopes, saturated soils, or a significant pollutant source such as livestock feeding.
- TMDL implementation partners should give thought to the species composition and structure of riparian buffers to mimic natural recolonization.
- Only native species indigenous to the specific reach are recommended for planting.
- Native vegetation (willow/cottonwood/alder/hawthorn) planted along waters' edge will be effective to increase bank stability and shading.
- Dense grasses and other herbaceous vegetation is generally more effective at nutrient removal than trees (Schmitt et al., 1999). Therefore, a mix of grasses, forbs, shrubs, and trees is recommended.
- Dense herbaceous vegetation such as sedges are very effective when placed perpendicular to the flow in swales, ephemeral and small intermittent channels.
- Trees are necessary to address other pollution problems, such as temperature exceedances.
- Buffer vegetation can be installed in a variety of forms such as: fascines, vegetative sod mats, woven in beaver dam analogs (BDAs), and post-assisted log structures (PALS), intermixed with coir fabrics.
- Buffers must preferably be actively maintained (e.g., weeded, replanted) until the riparian forest becomes self-sufficient, typically five to ten years after planting. In order to ensure on-going water quality protection, buffers must remain in place. Ecology combined Centennial /319 funding often requires 10 years of maintenance.
- Buffers may need to be combined with livestock exclusion fencing to ensure riparian vegetation is protected from disturbance.
- TMDL implementation partners should note that specific buffer widths are required to be eligible for Ecology 319/Centennial funding. These widths are based on stream type and salmonid presence. Supporting BMPs such as manure storage structures and livestock off-stream watering facilities are only eligible when coupled with riparian buffers.

Conservation Tillage

Conservation tillage refers to farming practices that largely eliminate conventional plowing and maintain crop residues. These alternate practices aim to reduce soil disturbance and thus promote soil health and reduce loss of topsoil through erosion. Conservation tillage, especially no-till, is gaining popularity in dryland wheat, barley, and legume rotations. Studies show that conservation tillage, particularly no-till agriculture, significantly reduces sediment delivery to surface waters (Norton, 2008; McIsaac et al., 1995; and King et al., 2015a). Delivery of nutrients associated with sediment are reduced. Thus, conservation tillage practices are often recommended for water quality enhancement purposes.

Remarkable improvements in erosion control have been achieved over the last 30 years, mostly through the reduction in tillage (Kok et al., 2009). However, erosion remains an ongoing threat to the resources, environment, and agricultural economy of the region (Schillinger et al., 2010), emphasizing the need for conservation tillage practices.

Winter wheat – summer fallow systems in low precipitation zones of the inland PNW have lost more than 60 percent of soil organic matter (SOM) from topsoil (Brown and Huggins 2012; Ghimire et al., 2015; Machado 2011; Rasmussen and Smiley 1997). Similarly, a study on high precipitation regions of the Palouse has shown that conversion of native prairie to wheat cropping systems using intensive inversion tillage has caused substantial loss of organic matter pools including 56 percent of soil organic carbon, 79 percent of particulate organic carbon, 50 percent of microbial biomass carbon, and 28 percent of mineralizable carbon (Purakayastha et al., 2008).

Soil organic matter comprises organic materials in various states of decomposition, such as tissues of living soil organisms, plant and animal residues, and excretions from plant roots and soil microbes. Increasing SOM is a prerequisite for sustainable agricultural production and is essential for long-term sustainability of agricultural systems. It promotes soil aggregation, increases soil water and nutrient holding capacity, and serves as a sink for sequestration of atmospheric carbon.

The impacts of soil erosion to aquatic resources can be significant. Furthermore, many farmers still use conventional tillage practices that expose soils to high erosion rates. Rain on snow events are common in the basin and readily mobilize soils and exacerbate nutrient runoff to surface waters. Sediment, and attached nutrients and toxicants, adversely impact the physical habitat, chemical, and biological attributes of receiving waters. Tillage and residue management practices that minimize erosion address the following pollutants: sediment, nutrients, pathogens, and pesticides (toxicants).

When tillage and residue management practices are being used to protect water quality, producers should try to minimize soil loss from fields and maximize the retention and enhancement of SOM.

These objectives are achieved through tillage practices that minimize surface soil disturbance to the maximum extent while maintaining protective surface and subsurface crop residue. Collectively, tillage and residue management practices are considered a source control practice because they can prevent erosion from occurring. Tillage can protect water quality by controlling the transport of pollutants at the source. Erosion is influenced by multiple factors including rainfall intensity and duration, soil texture, field topography, tillage methods and soil vegetative cover. Many of these factors cannot be controlled. However, producers can increase erosion control in their fields through conservation tillage methods and residue management.

Table 17 demonstrates the typical dryland crops rotations including winter wheat (WW); chemical fallow (ChF); chickpea (CP); spring pea (SP); summer fallow (F). Adapted from Williams et al., 2014.

Table 19. Cover, Runoff and Erosion in No-till and Conventional Tillage

Tillage	Cropping systems	Ground cover (%)	Runoff (Inches)	Soil erosion (tons/acre)
No-till	WW-ChF-WW-CP/SP	73	1.46	0.10
Conventional	WW-F	44	3.15	4.90

The NRCS uses the soil tillage intensity rating (STIR) metric to provide a relative indication of tillage-based soil disturbance. The STIR value utilizes the speed, depth, surface disturbance percent and tillage type parameters to calculate a tillage intensity rating for the system used in growing a crop or a rotation. STIR ratings show the differences in the degree of soil disturbance between systems. Lower numbers indicate less overall disturbance to the soil layer.

Common Eastern Washington Conservation Tillage Systems

No-till/Direct Seed

- Producers plant directly into crop residue that has not been tilled.
- Planting is completed using a no-till hoe or disk drill.
- Chemical fallow leaves the soil undisturbed from harvesting to planting.
- There is no full width tillage, and fertilizing and planting are generally accomplished in two to three passes.

Strip-till

- The soil is tilled and crop residue is removed from narrow strips where the crop is to be planted.
- The residue-covered area between the strips is left undisturbed.

Ridge-till

- Planting is completed in a seedbed prepared on ridges, with furrows protected by crop residue in between the ridges.

Mulch-till

- Tillage is completed with chisels, field cultivators, sweeps, or blades.
- No primary inversion tillage implements are used.

Reduced tillage practices, cropping intensification and diversification, crop residue retention, and application of organic amendments can enhance soil health.

Figure 6. Fine-grained soil from conventional tillage (left) and coarse-grained soil from reduced tillage (right) (Photo Credit: Rajan Ghimire)

To protect water quality, producers should use a conservation-based tillage system that achieves:

- A **minimum residue coverage of 60 percent.** The residue coverage expectation is based on the minimum observed from harvest to the time of planting; or
- **A STIR of 30 or less** based on NRCS guidance and calculation tools. (In some areas of the state higher residue crops, because of site specific factors (e.g., soils, annual rainfall, etc.), cannot achieve the recommended residue levels. In those cases, producers should utilize conservation tillage systems that meet the STIR recommendation).

Fertilizer Application

Organic fertilizers are those derived from animal waste. Inorganic fertilizers, sometimes referred to as synthetic fertilizers, are of mineral or chemical origin and are often manufactured in industrial processes. In the agricultural areas of the Little Spokane River watershed, the latter is likely most commonly used. Research suggests that total phosphorus losses from organic fertilizer is generally greater and often contains more dissolved phosphorus than inorganic fertilizer (King et al., 2015a). While the fertilizers used are usually mineral and not manure in origin they still have the potential to impact receiving waters. For these reasons inorganic fertilizer usage and management is prioritized in this TMDL.

Commercial nitrogen fertilizers are a cost-effective means of supplementing soil-supplied nitrogen for plant growth and are typically necessary for sustaining high crop yields. However, it has been documented that improper or excessive use of nitrogen fertilizer can lead to nitrate pollution of ground or surface water. Although proper nitrogen rates are the most critical components of nitrogen management, there are other tools that should also be considered. Proper calibration and maintenance of fertilizer equipment is essential to get uniform distribution of fertilizer at the correct rate. Crop rotation can be beneficial by minimizing total fertilizer and pesticide needs. Both urban and rural fertilizer applicators can minimize water quality issues by implementing BMPs for fertilizer use.

Precision agriculture has been described as the use of the right input in the right amount at the right time and in the right location (Mulla, 2013). Improved precision agriculture technologies allow producers to measure multiple interacting variables and to potentially use this information to maximize their profits, use resources efficiently, and minimize environmental damage. Some examples of precision agriculture include crop zone mapping with soil testing, flow metering, auto-steer on spray equipment, and variable application rate technology. Important precision agriculture considerations include:

- Precision agriculture is a site-specific management approach that uses technology to manage field variability and achieve specific goals such as crop yield, percentage of protein, and nitrogen use efficiency.
- Precision agriculture assumes that variability in the major factors that affect crop yield and quality can be accurately measured at scales relevant to farm management and that the resulting information can be used to improve the efficiency of crop input use.
- If the above assumptions are met, precision agriculture strategies might result in a win-win-win scenario with improved crop yields and quality, higher economic returns, and decreased environmental impacts from excessive inputs.
- Precision agriculture technologies provide the ability to monitor crop and field variability and help diagnose agronomic problems that occur across fields and years.
- Decisions about adoption of precision agriculture involve the consideration of economic, agronomic, technical, environmental, and social factors.

In order to meet the water quality objectives in this TMDL, appropriate fertilizer application will be important. Fertilizer application should emphasize the following:

- Timing of fertilizer application is critical.
    - Applicators should avoid periods of intense rain and colder temperatures (i.e., winter) when biological activity is reduced.
    - Avoid applying nutrients to fields with conditions that are likely to lead to runoff or nutrient losses such as frozen or saturated soils, over field tile drains during

saturated conditions, when significant precipitation is predicted, or when flooding or field inundation is likely.

  - Specific attention should be paid to avoiding ‘first flush’ events, i.e., the first two rainfall events following a dry spell.
  - A minimum three-day window *between* application and the first runoff event is highly recommended.

- Fertilizer applied too close to surface waters increases the risk of transport via runoff.
  - A minimum 50 ft buffer between the fertilizer application area and surface waters is deemed appropriate for TMDL. For most annual crop production, application location will match seeding location. Therefore, crop buffers will match fertilizer application buffers.
- Fertilizer should be applied at “agronomic rates” using soil testing and following a nutrient management plan.
  - Regular phosphorous testing of soil is important to prevent over application and soil phosphorus saturation (Daniel et al., 1998 and Sharpley et al., 1993).
  - Research suggests that if fertilizers are applied at agronomical acceptable rates, based on soil testing, significant phosphorus losses are unlikely to occur (Sims et al., 1998).
  - Apply nutrients at amounts that can be utilized by the crop in a single growing season and apply those nutrients at times where crops are most likely to utilize applied nutrients.
  - Nitrogen is often the focus of fertilizer application, but most fertilizers do not contain nitrogen and phosphorous in equal ratios. And as nitrogen is often the agricultural focus, phosphorus is often over-applied (Sharpley et al., 1993).
- Records maintenance helps to demonstrate that applications of nutrients to cropland are within acceptable agronomic rates. These records may include:
  - Soil sampling results
  - Nutrient analysis of fertilizer and all other sources
  - Nutrient application records including, but not limited to:
    - Crops grown
    - Total amount of nutrients applied
    - Date, method, and nutrient sources of each application
    - Weather conditions leading up to nutrient applications
    - Amount of irrigation water applied to each field each year

- Adjust nutrient applications when soil sampling demonstrates that crops are not utilizing applied nutrients.
  - When soil tests demonstrate elevated soil phosphorus, apply nutrients based on the phosphorus crop removal rate for the planned crop(s) in a single growing season, and develop a long-term strategy to reduce soil phosphorus levels over time using crop rotations and limiting the use of phosphorus until soil levels are reduced.
  - When soil tests demonstrate crops are not utilizing nutrients as planned, evaluate and adjust application rates.
- Conservation District and NRCS staff can assist landowners in development of a tailored nutrient management plan and phosphorus reduction strategy. When making referrals, TMDL implementation partners should emphasize the importance of **dissolved** over total phosphorus.
- Fertilizer placement in soil may be important.
  - By placing fertilizer in the root zone rather than simply spreading it on the soil surface, phosphorus runoff may be reduced and phosphorous uptake by plants and soil productivity may be increased (Sharpley and Halvorson, 1994).
  - However, mixing of soil and fertilizer through, for example, tillage may exacerbate transport via erosion, and cause additional environmental problems (e.g., increased sediment delivery to surface waters).

Livestock Exclusion

Livestock manure is one of the primary sources of phosphorus in agricultural watersheds and much of this TMDL's emphasis is on preventing or reducing leachate and associated transport. Therefore, it is important to prevent uncontrolled livestock access to riparian areas. Restricting access will help to:

- Prevent livestock from defecating and urinating in the riparian corridor.
- Protect native riparian vegetation from grazing and trampling, in turn protecting the transport control and possible treatment benefits associated with riparian buffers.
- Reduce/eliminate streambank erosion (and phosphorus inputs) associated with livestock access.
- Reduce compaction of soils and provide for infiltration of runoff.
- Maintain narrow and deep stream channels. Livestock access often results in the widening and shallowing of streams.

Well-constructed, permanent fencing is usually the most effective livestock exclusion tool. It's important to position fencing far enough from surface waters to prevent manure impacts. Fencing and riparian buffers are typically implemented in combination. Fences should be located at minimum 50 ft from perennial and intermittent streams for phosphorus control purposes. It should be noted that 75 ft buffers are typically required for 319/Centennial funding program eligibility purposes along perennial fish bearing streams in Eastern Washington.

Tile Drain Management

Drainage can increase crop yields and give farmers more control over field operations such as earlier planting and increased crop choices (King et al., 2015a). Subsurface drainage, or tiling, was once achieved via concrete or clay pipe and restricted to random wet spots, but since the 1970s, pipes are increasingly made from plastic tubing and used in a systematic fashion to drain whole fields (King et al., 2015a). Agricultural ditches may also convey phosphorus to surface water.

While runoff and erosion appear to be the primary phosphorus transport pathways, research suggests that tile drains can also be a significant source of phosphorus, and in particular dissolved phosphorus to surface waters (Duda and Finan, 1983; Smith et al., 2015; King et al., 2015a; King et al., 2015b; and Gentry et al., 2007). Tile drains alter the hydrologic regime such that vertical movement of nutrients through soil is facilitated, providing direct connection to surface waters (King et al., 2015b). Transport distance to surface water is shortened and natural evapotranspiration processes are bypassed (Smith et al., 2015) increasing total water yield (King et al., 2015a). In addition, phosphorus losses from tile drains appear greatest in spring (King et al., 2015b) with dissolved phosphorus dominating the total phosphorus loss at this time (Schelde, et al., 2006).

Phosphorus losses from subsurface drainage is often difficult to control because it's usually hidden and it bypasses the usual suite of nonpoint BMPs. Because the scale of the problem in the Little Spokane River isn't yet fully understood, and because fixes are inherently difficult and expensive, this TMDL deems tile drain management to be a lower priority at this time.

Tile drain management recommendations include:

- Controlled drainage or drainage water management
- Set-backs from surface waters of end of tile locations
- Riparian buffers to filtrate pollutants at end of tile locations
- Reduce drainage intensity
- Winter cover crops
- Nutrient retention basins
- Two-stage ditches

Irrigation Efficiency

Limited residential lawn, annual crop, and hay irrigation occur in the Little Spokane Watershed. Given the primary transport pathways for phosphorus are runoff and erosion, actions that would serve to reduce water surficial flow from irrigation could help to reduce phosphorus inputs to surface waters (Sharpley et al., 1993). As stated previously, during the dry summer months of concern in this TMDL, irrigation may be a transport factor in that it supplements reduced precipitation. Agricultural irrigation is typically a costly, energy intensive endeavor, so savings through efficiency projects are often of agricultural/economic benefit as well. Most water wastage is the result of over-irrigation or faulty irrigation equipment. The Farm Journal AgWeb (2019) and Irrigation Association (2019) recommend the following practices:

- Use qualified professionals to plan and help manage irrigation systems.
- Identify the soil type and its soil water characteristics to manage the water supply.
- Understand crop water needs to know when and how much water should be applied.
- Use a consistent method of irrigation scheduling.
- Scheduling can reduce energy use by 7 to 30 percent.
- It can also ensure crops are not under or over-watered.
- Select appropriate irrigation methods that will efficiently deliver water to the crop.
- Adopt and apply innovative technology to improve water management.
- Buried pipes rarely leak and are less maintenance intensive.
- Maintain irrigation equipment.
- The average life expectancy of a sprinkler head is about seven to ten years.
- The diameter of the sprinkler head nozzle is very important for uniform water application; the nozzle diameter can grow with use, especially if there is sand or grit in the water.
- Replace broken sprinkler heads as soon as possible.
- Do a "can test" to check the uniformity of the application pattern.
- Repair all leaks on the center pivot as soon as detected.
- Above ground pipelines frequently have worn gaskets and up to 30 percent of the water can be lost before it gets to the discharge point.
- Replace leaking gaskets and plug any holes in the pipeline.
- Maintain accurate records to facilitate better decisions on crop inputs.
- Anticipate water shortages and have planned strategies to respond.

A potential source of funding assistance for irrigation efficiency work may be obtained through Streamflow Restoration efforts. The Streamflow Restoration law (Chapter 90.94 RCW) was passed and signed in January 2018 in response to the Hirst decision, a 2016 Washington State Supreme Court decision. The law clarifies how counties should issue building permits for rural homes that use a permit-exempt well for a water source. The law requires local planning groups in the 15 watersheds to develop projects and actions that offset the impacts of new permit-exempt domestic water use. The plans must result in a net ecological benefit. The law also sets aside $300 million over 15 years to support these actions, distributed through a competitive grant program. Implementation partners should consider referrals to Ecology's Water Resources Program and/or the Conservation Commission and Conservation District staff on a case-by-case basis as circumstances dictate.

Recommended Supporting BMPs

Streambank Protection

Large woody debris can protect streambanks from erosion and provide sediment storage that will promote riparian vegetation growth. Instream large woody debris (weir-grade control structures) can also redirect flows to the center of the channel (thalweg), alleviating sheer stress to vulnerable streambanks. All of the restoration techniques described below will have multiple benefits to the Little Spokane River during the most critical seasons (spring runoff and summer low flow) by:

- Increasing channel/bank stability during high flows
- Increased shade, lowering stream temperatures during low flows
- Creating turbulence, increasing dissolved oxygen during low flows

Potential streambank treatments for the Little Spokane River watershed include bioengineering. Bioengineering is an in-stream restoration technique consisting of live plant material and biodegradable coconut fiber fabrics (coir). Bioengineering treatments create bank conditions that support the establishment of woody vegetation:

- Provides bank protection in order to allow bank vegetation to become established.
- Suitable for low to moderate stress banks with low curvature.
- Promotes rapid development of desired woody vegetation.
- The development of woody vegetation along the streambank provides floodplain stability, and provides a source of seeds to promote the establishment of desired vegetation communities in the floodplain.
- Materials are composed of biodegradable fabrics and native materials. Short-term streambank stability provided by fabric and long-term stability provided by rooted woody vegetation supports desired disturbance regimes and relatively low erosion rates.
- Short-term performance is dependent on toe stability as well as smooth transitions to stable upstream and downstream tie-in points. Placement of healthy woody vegetation cuttings to a depth to ensure contact with the water table throughout the growing season is critical. Long term performance is dependent on development of dense root mass.

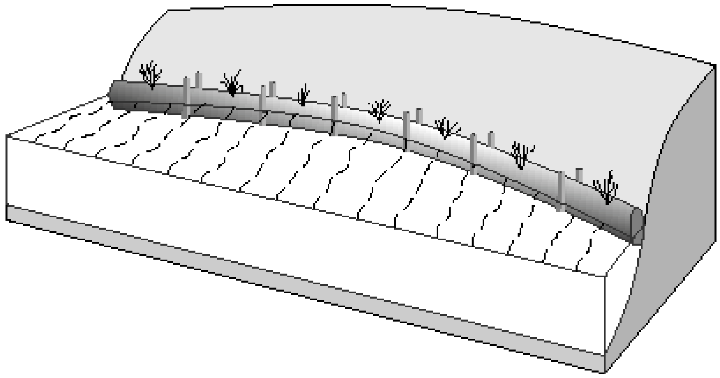


Figure 7. Bank bioengineering technique with erosion control fabric with plantings at toe of slope. (Source – NRCS FOTG)

Simple and inexpensive treatments to help reduce erosion and slow runoff include BDA and PALS. These structures consist of posts driven into the ground, perpendicular to the flow, with or without vegetation woven between the posts. The structures are designed, in this case, to slow down runoff flows in intermittent and ephemeral channels/swales without causing diversion:

- Creates a semi-permeable flow obstruction to provide sediment storage
- Creates a seed bank for future vegetation growth
- Once established, structures will promote infiltration
- Provides channel complexity and aggradation
- The structure is composed of native materials
- Very economically feasible
- Minimal land disturbance to install

Fascines are a restoration technique consisting of brush bundles and live plant material. Depending on the application and availability of materials, fascines may also include woody debris and/or wetland sod mats.

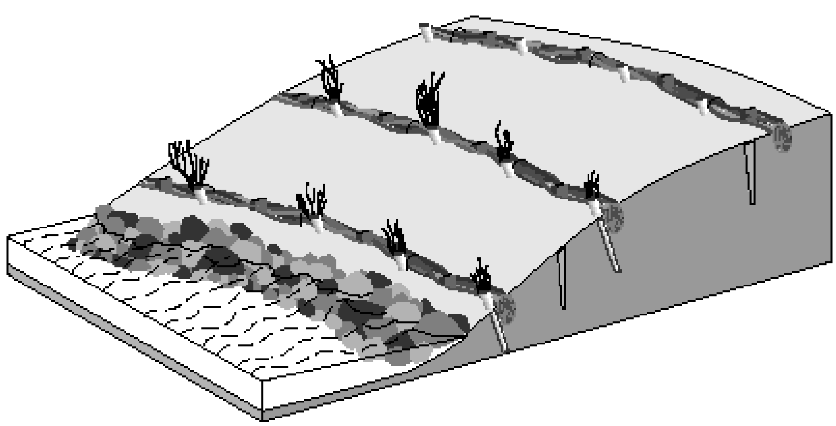


Figure 8. Bank bioengineering technique with erosion control fabric with fascines installed on a streambank (Source – NRCS FOTG)

Fascines can be a successful and economic application used in a variety of riparian zones. Some considerations include:

- Fascine treatments create a rough, complex, and vegetated bank margin.
- Fascines are designed to function on moderate stress banks with low to moderate curvature.
- Timing of installation is critical for vegetation survival with measurable results in three years.
- Brush and vegetation provide cover and hydraulic complexity. Fascines promote the rapid development of woody vegetation on streambanks and riparian zones.
- Woody vegetation on the streambank provides instream cover, shade for temperature reduction, large wood recruitment over time, fish refuge during high flows, organic matter inputs, and supports emerging aquatic insects.
- Over time they provide microsites to support natural recruitment of early successional species of desired vegetation community types. The elevation of the structure allows floodplain connection.
- Fascines provide bank margin roughness similar to natural bank conditions. Structure stability supports desired disturbance regimes and relatively low erosion rates.
- Maintaining adequate backfill ballast is critical to counteract buoyancy of native vegetation. Placement of ballast at or below bankfull elevation, and placement of healthy woody vegetation in contact with the water table throughout the growing season is critical for rapid vegetation establishment.

Log weirs are large woody structures strategically placed in the channel to provide grade control, channel complexity, and bank protection. Log weirs can:

- Redirect high flows away from vulnerable streambanks
- Create pool development, effectively deepening and cooling the channel (thalweg)
- Create turbulence on slow-moving warm reaches during critical summer flows augmenting dissolved oxygen
- Provide additional cover for thermal refuge
- Be economically feasible to implement

Large wood jams are structures consisting of logs and brush buried into the streambank and projecting out into the channel. Large wood jams are intended to emulate natural accumulations of large wood along the bank margins.

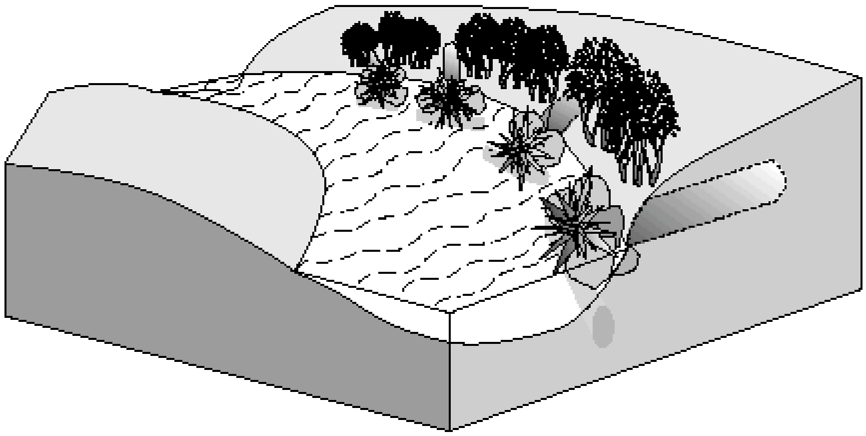


Figure 9. Bank bioengineering technique with large wood jam installed in streambank (Source – NRCS FOTG)

Large wood jams can be expensive and may not be appropriate for many locations. At the same time, wood jams can be beneficial in larger perennial streams. Some considerations include:

- Development of hydraulic conditions that maintain a deep pool
- Creating stable conditions to support development of desired vegetation community types during high flow
- Designed to function on a high stress bank with moderate to high curvature
- Providing channel complexity pool development, pools provide planform variability and foster point bar development
- The structure is composed of native materials
- Creating complex hydraulics such as eddies, turbulence, and secondary flow circulation during critical low flow periods
- Wood provides instream cover and shade for temperature reduction
- Promoting pool formation that improve hyporheic flow; residual pools provide low velocity holding habitat and over-wintering habitat for fish

Attention to detail of how the structure is tied into existing features or other bank structures is critical for long-term stability. Maintaining adequate backfill ballast is critical to counteract the buoyancy of wood. Structure performance is dependent on structure size and use of adequately-sized wood with intact root wads. Excavation of the pool in conjunction with the structure is recommended. The structure will tend to recruit additional large wood. Over time, the structure will decompose or become abandoned. Integrating mature shrub transplants or plantings on the floodplain surface behind this structure creates rooting structure for long-term bank stability.

Recommended Non-Agricultural BMPs

On-site Septic Tank Inspection, Repair, and Maintenance

Failing on-site septic systems (OSS) are likely contributing to nutrient delivery to tributaries of the Little Spokane River. As discussed, research suggests that in agricultural areas, livestock manure and fertilizer application are usually more significant sources. In addition, runoff and erosion are the primary phosphorus transport pathways.

This TMDL still deems septic inspection, maintenance, and repair work a valuable component of TMDL implementation. In the dry summer months, septic sources will likely become relatively more significant, as river flows are lower and septic inputs are independent of runoff (Jarvie et al., 2006). Transport via shallow groundwater movement may increase slightly during the dry summer months as soils dry out, serving to further increase the significance of septic sources. Finally, OSS improvements in the rural Little Spokane River watershed will provide additional assurance that load reductions are met, should implementation fail to address all agricultural sources. Therefore, proactive septic inspection and repair work will need to be part of the suite of BMPs implemented.

Local health districts are typically chiefly responsible for oversight of OSS. In the identified tributaries of interest in this TMDL, Spokane County Public Health is the agency charged with this oversight. Due to resource constraints, and the difficulties of verifying failure, corrective actions are typically conducted on a complaint response basis, or where source-tracing data point to a specific parcel.

The Spokane Conservation District and Spokane County Public Health provides detailed guidance on proper OSS management, summarized here:

- Regularly inspect and maintain septic systems. The frequency of maintenance depends on the type of system, ranging from three months to three years.
    - Gravity systems should be inspected every three years; pressure distribution systems, proprietary systems, mound and sand filter systems annually.
    - Contacting a certified On-site System Maintainer (OSM) is recommended to inspect and monitor systems.
- Pump septic tanks every three to five years. A general rule of thumb is the more people using the system, the more frequent pumping needs to be.
- Using less water may increase the life of a septic system. Using too much water is a frequent factor in failed systems.
- Repair all leaky faucets and toilets.
- Use "low flow" fixtures on faucets and shower heads.
- Spread laundry washing throughout the week and wash full loads.
- Dishwashers and washing machines should not be run at the same time.
- Nothing except toilet paper should be flushed into a septic system.

- Don't drain large volumes of water into a septic system. Large volumes of water can "drown" a drainfield and chlorine can destroy important bacteria in a septic tank and drainfield.
- Drain hot tubs and swimming pools away from the system, especially the drainfield.
- Direct water from land and roof drains away from the drainfield.
- Landscape with care. Grass is the best cover for a septic tank and drainfield. Other plants with very shallow root systems can also be used for landscaping.
- Keep septic tank lids easily accessible.
- Have "risers" installed to make septic tank pumping and monitoring visits easier and less time-consuming.
- Contact a certified professional for septic repairs.
- Don't use a garbage disposal. Garbage disposals add solids and grease which can build-up quickly and clog or choke a drainfield.
- Don't put household chemicals down the drain
- This includes chemicals such as paint products, drain and floor cleaners, motor oil, antifreeze, and pesticides. These chemicals destroy bacteria in a system that are necessary to break down solids.
- Don't park cars and trucks on a drainfield or septic tank
- This will prevent soils from being packed down and pipes from breaking.
- Don't use septic tank additives. They may be harmful by adding extra solids to the system that can clog a drainfield. The chemicals can also pollute ground and surface water.

With the exception of Spokane County Public Health staff and Spokane Conservation District, most TMDL implementation partners likely will not be directly involved in septic repair and/or septic compliance efforts. However, TMDL partners are encouraged to be on the lookout for signs of septic failure during site visits and look for opportunities to ask landowners about their septic systems and provide associated technical assistance. Septic repair or replacement can be expensive but funding is available through the Spokane Conservation Districts On-Site Septic System (OSS) Program. The program is designed to provide financial assistance to property owners in the form of loans and grants. Implementation partners should consider referrals to the Spokane Public Health if they find the following:

- Bad odors around the drainfield area, especially after heavy water use or rainfall
- Very wet spots with lush green grass growth over the drainfield or septic tank areas
- Standing water in the drainfield area
- Plumbing or septic tank back-ups
- Slow draining fixtures
- Gurgling sounds in the plumbing systems

Stormwater Management

Stormwater drainage, particularly roadside, highway and bridge drainage, can provide a direct pathway of pollutants to nearby surface waters. During spring runoff, farming in the road right-of-ways and ditches that run parallel to agricultural landscapes create a conduit for pollutants. Water often flows from highway and bridge impermeable surfaces directly to surface waters without any deflection or filtration. Furthermore, winter month pollutants such as magnesium chloride and sand are often used to deice roads and bridges and can flow to surface water. During the dry seasons these impermeable surfaces accumulate pollutants such as petroleum products, construction debris, and road residue. Thunderstorm events wash these pollutants off of the impermeable surfaces. They can contain very high pollutant concentrations compared to the low flow conditions in the streams.

Washington State Department of Transportation (WSDOT) manages properties and infrastructure (roads, ditches, culverts, right-of-ways) within the Little Spokane Watershed that include US 395, US 2, SR 206, and SR 291. An unspecified and difficult to proportion pollutant load from WSDOT-managed properties and infrastructure is captured in several of the load allocations in the watershed, including the Deadman Creek load allocations.

When stormwater discharges that transport phosphorus over natural background levels to listed receiving waters are found from sources within WSDOT's right-of-way and control, WSDOT will apply BMPs from their Stormwater Management Plan (SWMP) or perform remediation to correct the situation.

For run-on sources of sediment and phosphorus identified by WSDOT that are from outside of WSDOT's right-of-way, WSDOT will notify Ecology and work cooperatively with parties involved in their resolution. To address sediment associated with adjacent erosion (run-on), including delivery that results from farming activities, WSDOT will work cooperatively with Ecology, the local jurisdiction, and other parties involved to prevent sediment from entering area waterways. At a minimum, WSDOT should address sediment and phosphorus sources that contribute to the Deadman Creek load allocations by:

- Spending one day annually performing a Highway 206 evaluation with Ecology staff
- Documenting problem road infrastructure and run-on pollution sites
- Collaborating with Ecology on developing a map of the problem sites
- Referring sites to Ecology (letter or e-mail) for follow-up
- Adaptively managing with Ecology as needed

Spokane County stormwater is regulated under the Eastern Washington Phase II Municipal Stormwater NPDES and State Waste Discharge General Permit (hereafter referred to as the Municipal Stormwater Permit). The permit requires the implementation of these stormwater management elements:

- Public education and outreach
- Public involvement and participation

- Illicit discharge detection and elimination (IDDE)
- Construction site and post-construction stormwater runoff control
- Operation and Maintenance
- Program management effectiveness studies

As a result of the TMDL findings and in conjunction with the Municipal Stormwater Permit, Spokane County will conduct activities to locate and reduce potential sources of sediment and nutrients to its municipal separate storm sewer system (MS4). As part of its IDDE Program, Spokane County will investigate potential sources of pollutants in drainage basins contributing the highest loadings and concentrations.

The second priority will be an investigation of all storm sewers draining to the Little Spokane River mainstem. Investigations will identify and map of the MS4 conveyances to the mainstem Little Spokane River within the permit boundary.

As a result of the TMDL findings, Ecology will require Spokane County to implement the following actions under the Municipal Stormwater Permit:

1. Inventory and inspect all municipal stormwater outfalls to the Little Spokane River and its tributaries.
2. Inventory, inspect, and perform maintenance on the stormwater facilities/systems that discharge to the outfalls identified in #1 above.
3. Using the results of the inventories and inspections from #1 and #2 above, develop a map of the MS4 for each outfall drainage area that, at a minimum, includes all stormwater assets/features (manholes, catch basins, curb inlets, pipes, swales, etc.), locations of known and suspected illicit connections of sanitary sewer, and locations of known and suspected sources of phosphorus to the MS4.
4. Develop and implement a lawn fertilizer, pet waste, and household product education program for residents of Spokane County within the LSR watershed.
5. Consider, during SEPA review, the potential for projects to increase runoff and sources of phosphorus, and the need for mitigation measures to reduce these adverse impacts to the MS4 and surface waters.
6. Field assess each outfall to the Little Spokane River and its tributaries during the critical period (May-November) to identify/detect illicit discharges. For each outfall drainage area investigated under the IDDE program, Spokane County shall submit to Ecology with the annual report summarizing:
    i. If samples are taken during field assessment, report dates and concentration results of water quality monitoring at outfalls discharging to the Little Spokane mainstem and tributaries for parameters of concern in this TMDL.
    ii. A description of summarizing actions taken to reduce phosphorus pollution, including any business inspections conducted, outreach and education efforts, and any other efforts made to reduce phosphorus loadings to receiving surface water bodies.

Spokane County also manages many miles of paved, gravel, and summer dirt roads outside of the Phase II NPDES permit boundary. In order to reduce sediment and nutrient laden run-off, the county should properly maintain and manage right-of-ways and roadside ditches. For these areas it will be important for Spokane County to work cooperatively with Ecology and other parties involved on strategies to prevent sediment from entering Little Spokane River watershed waterways.

Forest Practices

The state's forest practices regulations will be relied upon to bring waters into compliance with the load allocations established in this TMDL on private and state forest lands. This strategy, referred to as the Clean Water Act Assurances, was established as a formal agreement to the 1999 Forests and Fish Report.[4]

The state's forest practices rules were developed with the expectation that the stream buffers and harvest management prescriptions were stringent enough to meet state water quality standards for temperature and turbidity, and provide protection equal to what would be required under a TMDL. As part of the 1999 agreement, new forest practices rules for roads were also established. These new road construction and maintenance standards are intended to provide better control of road-related sediments, provide better stream bank stability protection, and meet current best management practices.

To ensure the rules are as effective as assumed, a formal adaptive management program was established to assess and revise the forest practices rules, as needed. The agreement to rely on the forest practices rules in lieu of developing separate TMDL load allocations or implementation requirements for forestry is conditioned on maintaining an effective adaptive management program.

Consistent with the directives of the 1999 Forests and Fish agreement, Ecology conducted a formal 10-year review of the forest practices and adaptive management programs in 2009.[5]

Ecology noted numerous areas where improvements were needed, but also recognized the state's forest practices program provides a substantial framework for bringing the forest practices rules and activities into full compliance with the water quality standards. Therefore, Ecology decided to conditionally extend the CWA assurances with the intent to stimulate the needed improvements. Ecology, in consultation with key stakeholders, established specific corrective milestones for program accomplishment and improvement. These corrective milestones were designed to provide Ecology and the public with confidence that forest practices in the state will be conducted in a manner that does not cause or contribute to a violation of the state water quality standards.

In 2019 Ecology granted a two-year extension to the Assurances (until December 31, 2021). This extension was provided to allow time to address deficiencies in the rules to protect small non-fish-bearing headwater streams that were identified in several research studies through the adaptive management process. In order to extend the Clean Water Act Assurances beyond 2021,

[4] http://www.dnr.wa.gov/Publications/fp_rules_forestsandfish.pdf
[5] https://fortress.wa.gov/ecy/publications/SummaryPages/0910101.html

Ecology will need to see the program is on a clear path to making rule changes that will support cool, clean water in fishless headwater streams.

Property Acquisition

Perhaps the most protective BMP available to implementation partners is property acquisition for permanent conservation as it provides the greatest level of protection. When combined with restoration activities, acquisitions can be powerful water quality improvement tools. Ecology's 319/Centennial and Floodplains-by-Design funding programs provide funding for property acquisitions. The former emphasizes acquisitions for water quality improvement purposes, while the latter emphasizes flood protection. Washington's Recreation and Conservation Office (RCO) also provides funding for property acquisitions, primarily to protect and restore habitats and for salmon recovery purposes. While the Floodplains-by-Design and RCO programs aren't water quality focused, there's often overlap between those programs' goals and water quality improvement needs. One of the chief challenges with property acquisitions is that opportunities for purchase may be limited and purchase costs are often high. For these reasons this BMP is deemed the lowest priority for TMDL implementation purposes. Nonetheless, implementation partners are encouraged to be on the lookout for acquisition opportunities.

Organizations that Implement the TMDL

Washington Department of Ecology

Ecology has authority under the federal Clean Water Act by the EPA to establish water quality standards, administer the NPDES wastewater permitting program, and enforce water quality regulations under Chapter 90.48 RCW. Ecology responds to complaints, conducts inspections, and issues NPDES permits as part of its responsibilities under state and federal laws and regulations. Ecology's primary tools for implementing the nonpoint (unpermitted) BMPs include proactive technical and financial assistance. Ecology may use formal enforcement, including fines, if proactive compliance is unsuccessful. Ecology also works with many valuable implementation partners described below to complete the work described within the TMDL implementation plan.

Spokane County Conservation District and Pend Oreille Conservation Districts

The conservation districts have authority under Chapter 89.08 RCW to develop farm plans, protect water quality, and to provide animal waste management information, education and technical assistance to residents on a voluntary basis. Individual properties identified as a source of pollution through Ecology watershed evaluations or from complaints will normally be referred to the local conservation district for assistance. The conservation districts also implement programs, such as the regional conservation partnership program (RCPP), designed to improve water quality and habitat. These programs are available to interested landowners within the Little Spokane watershed. In addition, the conservation districts seek and receive grant funds that will assist landowners to implement BMPs that improve riparian health and protect water quality to the Little Spokane River and its associated tributaries.

Natural Resources Conservation Service (NRCS)

NRCS works closely with conservation districts to implement farm plans and agricultural BMP programs. NRCS is one of the primary entities for technical assistance and financial support to assist in the implementation of agricultural and livestock BMPs throughout the watershed.

Spokane and Tri-County Health Departments

The health departments regulate on-site sewage systems in the watershed in accordance with Chapter 246-272 WAC. When the department receives a complaint about a failing system, the department verifies the failure and assists the landowner with coming into compliance with Chapter 246-272 WAC. In addition, the health departments are often involved in the investigation of complaints about agricultural animal waste.

Spokane County, Pend Oreille County, Stevens County, and City of Spokane

The Little Spokane River falls under the requirements of the Shoreline Management Act (SMA) (RCW 90.58). The SMA is administered principally by local governments through locally developed Shoreline Master Programs (SMPs), and Ecology provides technical and financial assistance for the development and implementation of the SMPs.

Ecology reviews and approves the SMPs, and with the local governments has the authority for compliance and enforcement of the SMA and SMPs. Local governments review projects in their jurisdiction for compliance with local SMPs and the SMA through a permit process. The SMA specifically lists protecting water quality as a purpose of the SMA (RCW 90.58.020). Local governments must periodically update their SMPs and must integrate them with their Growth Management Act provisions, including critical area ordinances. As of June 2011, the plan was still being developed.

Pacific Northwest Direct Seed Association (PNDSA)

The PNDSA is a producer-led, non-profit group that promotes conservation tillage practices. They also manage the Farmed Smart program that looks to certify farms that implement specific conservation tillage and other water quality and air quality protection practices. They will likely be a partner in the portions of the Little Spokane watershed where dryland crops are produced adjacent to surface water.

Washington Department of Natural Resources (WDNR)

The WDNR will implement the Clean Water Act Assurances forest practices regulations, including the additional milestones specified in the 2009 and 2019 assessment of these regulations.

Washington State Department of Agriculture (WSDA)

The WSDA protects water quality from livestock nutrient discharges and helps to maintain a healthy agricultural business climate. Dairy Nutrient Management is a water quality program administered by Washington State Department of Agriculture under Chapter RCW 90.64, Dairy Nutrient Management Act.

Washington State Department of Fish and Wildlife (WDFW)

The Washington Department of Fish and Wildlife is dedicated to preserving, protecting, and perpetuating the state's fish, wildlife, and ecosystems while providing sustainable fish and wildlife recreational and commercial opportunities.

Friends of the Little Spokane River

Dedicated to preserving and sustaining the unique character of the Little Spokane River Valley, including its open space and natural setting. They ensure the protection of the area's ecosystem including water quality, wetlands, priority habitat and wildlife, and dwindling native vegetation.

Washington State University Extension (WSU)

The Washington State University Extension program offers field programs and training opportunities to students and partners who are conducting research that is changing the way water is used and managed across Washington State.

Washington State Department of Transportation (WSDOT)

The WSDOT is the steward of a multimodal transportation system and responsible for ensuring that people and goods move safely and efficiently. They will partner to ensure we are minimizing pollutant-loading from their road infrastructure and right-of-ways.

Spokane Tribe

The Spokane Tribe of Indians are of the Interior Salish Group, dedicated to preserve, protect, manage, and enhance the long term sustainability of the natural resources for present and future generations through an interdisciplinary process by developing and implementing best management practices.

Spokane RiverKeeper

The RiverKeeper is a Spokane non-profit organization advocating for the restoration and preservation of the river's health and aesthetic integrity. The organization is active in promoting conservation tillage and riparian improvements in tributaries of the Spokane River, including the Little Spokane.

The Lands Council

The Lands Council is a Spokane non-profit organization dedicated to the preservation and revitalization of Inland Northwest forests, water, and wildlife through advocacy, education, effective action, and community engagement. They fund stream improvements such as planting of native trees and shrubs, and installation of Beaver Dam Analogs (BDAs).

Priorities and Timeline

This plan is designed to see TMDL implementation that will lead to attainment of water quality standards within 20 years. Assuming this TMDL is approved/adopted in 2020, we plan to see TMDL implementation completed by 2040. Some pollutants will take longer to reach water quality standards than others. For example, it may take up to 50 years to reach the temperature standards because of the time it takes to grow plants and trees that will provide shade to the streams. If monitoring data shows that water quality standards have not been attained by 2040, this implementation plan will be revised and a new implementation timeline established (see **Adaptive Management** section). This TMDL proposes an annual implementation schedule based on the TMDL-BMP compliance actions established earlier (see **Best Management Practices** section).

Prioritizing Implementation

Several studies have underscored the importance of concentrating implementation resources on sensitive source areas within a watershed, rather than implementing general strategies over a broad area (Sharpley et al., 1993 and Sharpley et al., 1994). In addition, EPA (2018) states that environmental response to implementation will be most rapid when targeted in those areas that have the greatest influence on water quality and related problems. Therefore, prioritization is a key component to any successful implementation strategy. This TMDL attempts to prioritize implementation systematically, at increasingly finer scales, starting at the watershed level, then within sub-watersheds or tributaries, finally ending at the individual parcel level. The goal is to provide an efficient strategy for Ecology implementation. Furthermore, it provides implementation partners a clear roadmap to take the information presented previously, and apply it at the site level in a way that first addresses the most significant sources in the most effective and efficient manner possible.

The watershed loading analysis later in this document (Chapter 4) describes the need for nutrient reductions in the Little Spokane River in order to protect and restore the watershed as well as reduce nutrient loading to Lake Spokane.

The majority of the BMPs being proposed in this TMDL will address the parameters in a twofold aspect, for example, during spring runoff the establishment of riparian buffers will slow and filter overland flows, and provide streambank protection from erosion. During the summer months, riparian buffers will filter sediments from storm events, and once established, provide additional streamside shade, effectively cooling water temperatures. During spring runoff the addition of large wood will provide bank protection and direct erosive flows towards the center of the channel (thalweg). In the summer months, large wood structures will create turbulence that increases dissolved oxygen as well as provide in-channel shade to reduce temperature. In fact, these same suites of BMPs will help implement the *Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity TMDL* (February 2012) through restoration and protection of riparian areas.

Areas located "near in time" to the mouth of the Little Spokane River have more potential to contribute nutrient loads to Lake Spokane within the same averaging season. In setting priorities for nutrient load reductions, sources closer in time to the mouth will be given greater weight.

There is considerable opportunity to improve dissolved oxygen and pH in the Little Spokane River and its tributaries by enhancing riparian zones. There are many locations in the Little Spokane River watershed where riparian vegetation has been removed or degraded, and the current amount of stream shade is less than system potential shade (Joy and Jones, 2012). Restoring system potential shade will improve dissolved oxygen and pH by reducing water temperatures and limiting solar radiation. The mainstem Little Spokane River channel has numerous reaches that have also been straightened, resulting in the lack of channel complexity and loss of floodplain connectivity.

As the TMDL analysis suggests, the nutrient loading from spring runoff is substantial in the Little Spokane watershed. The analysis identified six diffuse nonpoint source locations that are recommended as the highest priorities for load reductions:

- Runoff and unidentified sources of loading to the mainstem Little Spokane River in the lower river (RM 13.5 – above Deadman Creek, to RM 1.1 – near the mouth)
- Deadman Creek runoff, groundwater, and unidentified sources
- Dragoon Creek headwaters (upstream of Spring Creek, RM 17.0)
- Runoff to the mainstem Little Spokane River above Deadman Creek
- Other small tributary sources (Otter, Deer, and Little Deep Creeks)
- West Branch Dragoon and other Dragoon Creek runoff sources

Watershed Scale

As mentioned earlier, land use is often one of the most important watershed characteristics key to gaining an understanding of pollution sources (EPA, 2018). Practices aimed at increasing the productivity of land cannot ignore the need to implement sound watershed management practices. Conversely, watershed actions aimed at reducing erosion, sedimentation, and other water related problems cannot ignore the importance of upland management strategies that diversify and increase income generation through the production of agricultural and natural resources. This TMDL attempts to incorporate a management philosophy that both benefit the tract of land and the water quality criteria downstream.

Sub-watershed Scale

This section attempts to prioritize reaches within the three priority tributaries including Deadman Creek, Dragoon Creek, and Little Deep Creek. Our modeling analysis predicts dissolved oxygen impacts due to nutrients in these sub-watersheds. The sub-watersheds have been identified as significant human-induced contributors of nutrients affecting dissolved oxygen and pH.

The Deadman sub-watershed in its upper reaches is a bedrock driven, narrower valley type, consequently having a steeper profile compared to the mid to lower reaches. Due to the narrow valley type, dwellings are relatively close to Deadman Creek and some are likely contributing nutrients (year-round) through septic systems. Improperly maintained septic systems can fail and lead to pollutants entering waterways. Untreated or partially-treated sewage can accumulate on the ground's surface and runoff into streams. Improperly treated sewage can also leach pollutants into the ground water, which may travel to nearby streams.

The middle reaches of the Deadman sub-watershed are low gradient, primarily agriculturally driven landscapes. As mentioned earlier, the ephemeral and intermittent streams in these sub-watersheds are significant sources of sediment and nutrients and may require additional supporting BMPs. Again, addressing the source of the pollution with the suite of BMPs that include conservation tillage and riparian restoration to slow and capture seasonal runoff will be a vital initial approach. When the strategies mentioned above have been implemented, additional BMPs such as beaver dam analogs (BDAs), post assisted log structures (PALS), and bioengineering techniques, all in conjunction with riparian vegetation are recommended to follow.

The lower reaches of the Deadman sub-watershed gradually steepen and are mostly dominated again by residential areas where septic systems may again be contributing nutrients. These lower reaches will also benefit from riparian buffers as well as supporting BMPs, including in-stream bioengineering techniques such as installing large woody debris (LWD) and bioengineering bank stabilization techniques.

The Dragoon Creek (above Spring Creek), water quality issues are primarily driven by agricultural practices. For livestock grazing activities, the suite of livestock BMPs will be needed. The ephemeral and intermittent streams in this sub-watershed are significant sources of sediment and nutrients and may require specific supporting BMPs that may not be as effective in perennial systems. For example, all agricultural landscapes will benefit from primary suites of

BMPs that include conservation tillage practices and riparian buffers. However, in certain landscapes such as seasonal channels, additional BMPs such as fascines and sedges planted in strips perpendicular to flow paths may provide additional benefits.

Upper Little Deep Creek is comprised of a mosaic of land use types ranging from forestland, agriculture, livestock, and residential. For this sub-watershed, a multifaceted BMP approach that considers land use will be most effective. Again, in agricultural crop production areas, it will be recommended to implement the conservation tillage and riparian buffers suite of BMPs. For livestock grazing, the suite of livestock BMPs will be needed. Where channels may be showing instability, it will also be advantageous to incorporate instream stability structures such as log weirs and bioengineering techniques.

Reach or Parcel Scale – Watershed Evaluations

The primary tool Ecology uses to implement non-point BMPs in TMDL watersheds are called watershed evaluations. Ecology staff use a combination of visual cues (e.g., denuded riparian areas, eroded banks, crop gully formation, unconfined livestock, livestock manure, sheet and rill erosion) documented from public right-of-ways to identify parcels for technical assistance. Properties may be classified as a high priority based on the pollution risk. Ecology staff will perform watershed evaluations annually for the next 10 years in the Little Spokane Watershed. Each evaluation identifies the priority parcels for implementation during the following time period. The watershed evaluations are typically performed in early spring (March or April) and in the fall in some years (September or October).

Ecology contacts landowners who need to take steps to protect surface water. Landowners are provided information on the suites of BMPs identified in this TMDL. They are given an opportunity to proactively seek technical and financial assistance from Ecology and its partners. Ecology staff will work with the partners and landowners to design and implement the projects. Staff will ensure the suites of BMPs are implemented in ways that are adequate to protect surface water.

Despite the best efforts of Ecology and partners in the watershed, some landowners may be unwilling to perform the steps needed to protect water quality at their property. It then becomes Ecology's responsibility to evaluate whether their activities are causing or have the potential to cause pollution in violation of the state's Water Pollution Control Act (RCW 90.48). In these situations, Ecology can pursue enforcement steps needed to gain compliance.

Properties within each specific stream reach are prioritized based on proximity to surface water. Parcels that fall within 100 feet of surface water are considered a priority for implementation purposes. Parcels further from surface water are less likely to be significant contributors of nutrients and sediment, unless drainages serve as a direct conduit. Ecology does not assume that all parcels close to surface water cause pollution. Only watershed evaluation work can make this determination.

BMP Recommendations by Reach

For the purposes of this implementation strategy, the mainstem Little Spokane River and sub-watershed tributaries have been mapped based on the dominant land use (Figure 10). Geographic Information Systems (GIS) analyses were used to overlay a stream layer on top of a land use layer. Due to the many different land use types in the Little Spokane River watershed, only the three major (agricultural, forested, and residential) land uses were used to depict the surface water in each land use type.

A color coded table (Table 18) was developed to help implementation partners select the appropriate supporting BMPs based on land use and stream type. For example, if a stream is colored yellow in the map, a partner would know that it lies within an agricultural landscape. Referring to Table 15 above (Primary Agricultural BMPs) and Table 18 below (supporting BMPs), the partner would know the recommended BMPs include riparian buffers, conservation tillage, and nutrient management and well as supporting BMPs including Beaver Dam Analogs (BDA), Post Assisted Log Structures (PALS), and fascines.

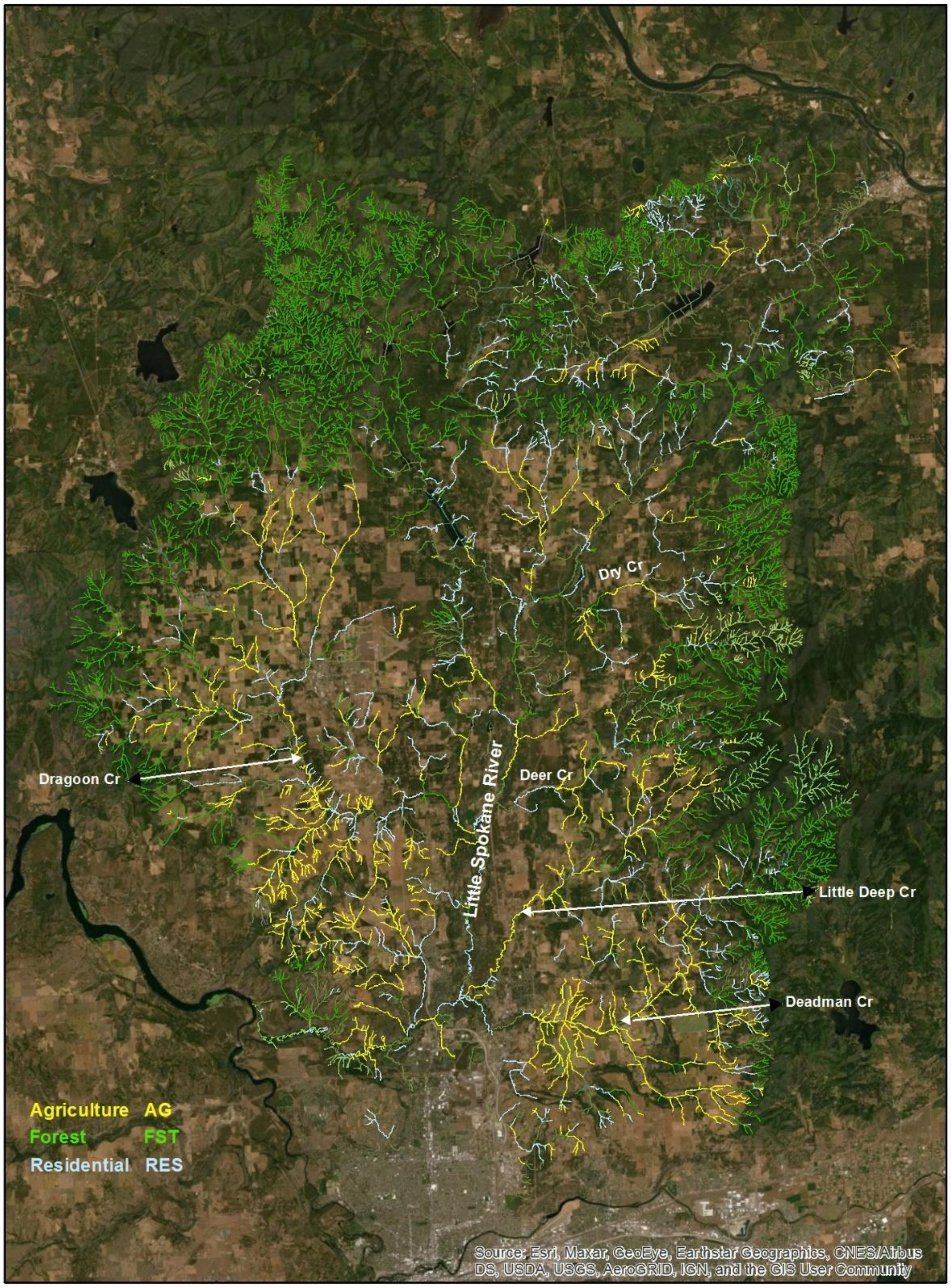


Figure 10. Map of streams and the dominant land use

In addition to residential, urban, and agricultural areas, Table 18 includes recommendations for supporting BMPs for buffers within the forested portions of the watershed. These recommendations are for activities other than timber harvest. For harvest activities, it will be important for landowners to follow the buffer requirements described in the Washington State Forest Practices Rules. The **Best Management Practices** section above provides information on the implementation of forest practices rules.

Local rules implemented as part of the Growth Management Act (GMA) and Shoreline Management Act (SMA), such as critical area ordinances, may require larger stream buffers for specific actions. It is important for implementation partners to refer to local ordinances and install the most protective buffer or land use setback.

Table 20. Recommended Supporting BMPs by land use and stream type

Land use	Stream type	Buffer width	Supporting BMPs	Waterbody Type
AG	Ephemeral	35'	Perpendicular vegetative strips	All riparian zones including swales, ditches, and unnamed 1st and 2nd order channels
AG	Intermittent	50'	BDAs, PALS, Fascines	Unnamed 1-4 order channels
AG	Perennial	75'	Log Weirs & Large Woody Debris	Perennial streams
FST	Ephemeral	FPA*		All riparian zones including swales, ditches, and unnamed 1st and 2nd order channels
FST	Intermittent	FPA*	BDAs, PALS, Fascines	Unnamed 1-4 order channels
FST	Perennial	FPA*	Log Weirs & Large Woody Debris	SF Little Deep, NF Little Deep, Little Deer Cr, Deer Cr, Cottonwood Cr, Little Spokane R
RES	Ephemeral	35'	BDAs, PALS, Fascines	All riparian zones including swales, ditches, and unnamed 1st and 2nd order channels
RES	Intermittent	50'	BDAs, PALS, Fascines	Unnamed 1-4 order channels
RES	Perennial	75’	Log Weirs & Large Woody Debris	Deer Creek, Dragoon Creek, Mid/lower Deadman Cr, Little Deep Cr, Little Spokane R

***Buffers described in the Forest Practices Act RCW**

TMDL Implementation Annual Schedule

Figure 11 below proposes a TMDL implementation schedule for the next 10 years. Actions in the schedule are assigned in priority order, starting with the highest priority reaches in the Little Spokane River watershed described above. The purpose of basing annual assignments on priority reaches was to ensure work begins first on addressing the largest number and/or most significant sources of pollution, facilitating the most rapid load reduction progress possible. Permit renewal and GMA and SMA process reminders are also incorporated into the schedule.

Each year's assigned BMP implementation should be interpreted as start dates. It's unlikely that all work within a given reach will be identified, outreach completed, and BMPs fully installed within one calendar year. This is especially true of the highest priority reaches with the largest number of pollution problems. In reality, the following years will see not only the start of work in another priority reach, but also continued work in proceeding priority reaches (Figure 11). This will result in a gradual increase in implementation workload, which should be mitigated somewhat by the fact that implementation partners will become progressively more experienced and effective at their work. Work in lower priority reaches should be easier and faster to complete.

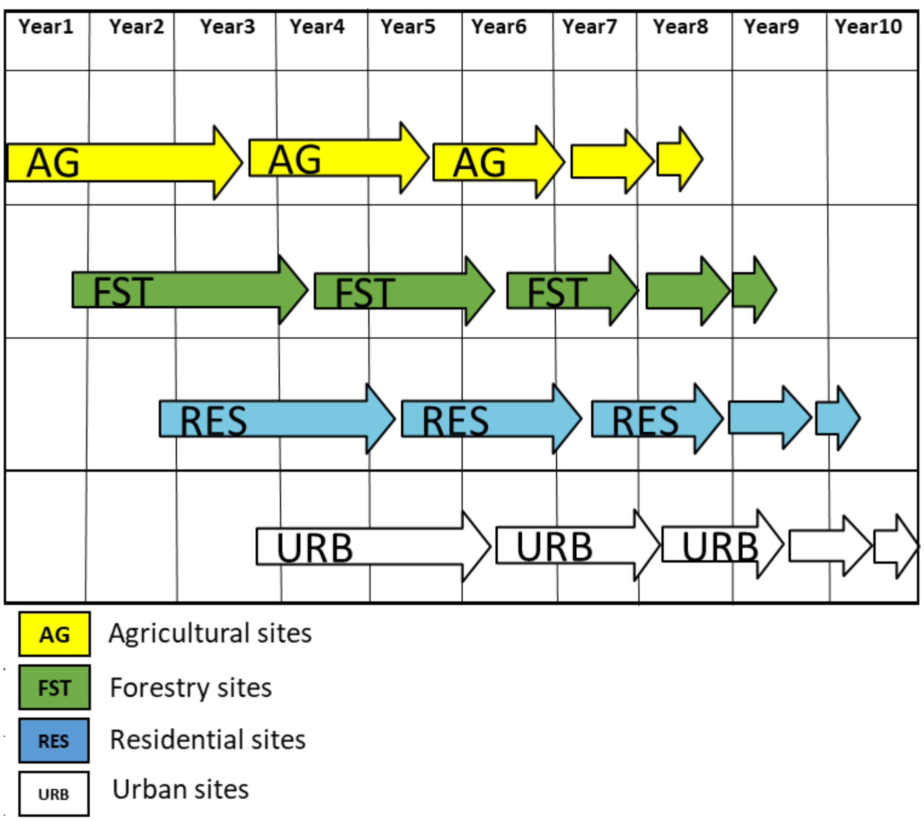


Figure 11. Conceptual implementation schedule for priority reach work

As mentioned earlier in the implementation plan, point source WLAs will be largely self-implementing through the administration of the NPDES program. However, the Watershed Implementation Lead will need to work with permit managers to ensure that new TMDL-related requirements become permit conditions when permits are renewed. For this TMDL, the primary point-source focus will be the Spokane Hatchery. Below is a depiction of how the TMDL timeline and hatchery facility renovations may be coordinated.

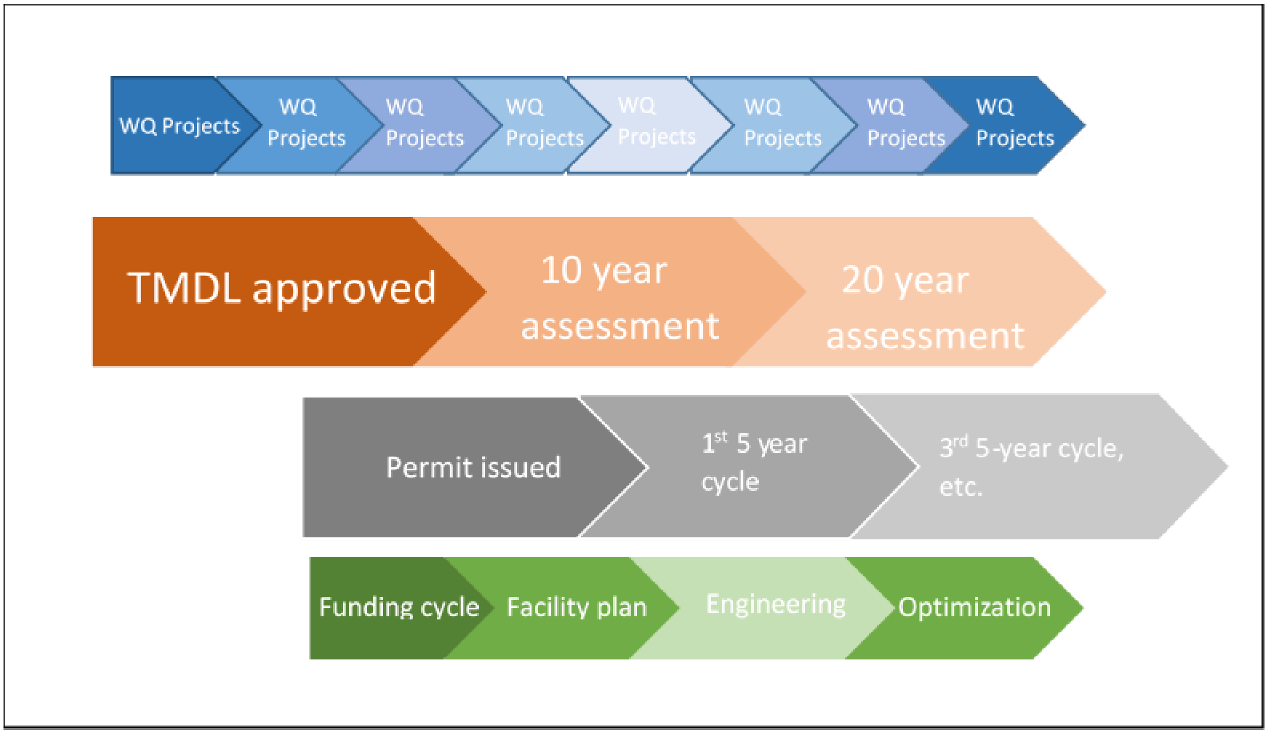


Figure 12. TMDL timeline and permit cycle

Costs

There are almost certainly economic benefits of TMDL implementation in terms of aquatic and human health, property value and flood protection. However, it is important to understand the financial costs associated with implementation of the TMDL. It also helps implementation partners develop sound budgets and ensure that appropriate funding requests are made. The costs may help prioritize grant funding resources in the future.

Table 19 below is a rough estimate of TMDL implementation costs for non-point BMPs. The table only captures core work. It does not include the relatively smaller costs associated with actions such as drainage and irrigation efficiency.

Table 21. TMDL cost estimates for core implementation

Nonpoint BMPs	Unit cost	Acres	BMP Cost
Conservation Tillage	$500 per acre	10,000	$5,000,000
Nutrient Management	$28 per acre	5,000	$140,000
Livestock Exclusion Fence	$8 per foot	75,000	$600,000
Riparian Buffers	$2000 per acre	3000	$6,000,000
Supporting Riparian BMPs	$3,000 per structure	200	$600,000
OSS repair/replacement	$18,500 per repair	50	$925,000
		Total Cost	$ 13,265,000

Potential Funding Sources

Table 22. Agency information for prominent funding sources

Natural Resource Conservation Service	Conservation Programs www.nrcs.usda.gov/programs	These programs help people reduce soil erosion, enhance water supplies, improve water quality, increase wildlife habitat, and reduce damage from flooding.
Natural Resource Conservation Service	Emergency Watershed Protection www.nrcs.usda.gov/programs/ewp/index.html	NRCS purchases land vulnerable to flooding to ease flooding impacts.
Natural Resource Conservation Service	Wetland Reserve Program https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=STELPRDB1049327 http://teams/...	Landowners may receive incentives to enhance wetlands in exchange for retiring marginal ag land.
Washington State Conservation Commission	Washington State Conservation Districts https://www.scc.wa.gov/	Various environmental program grants.
Washington State Department of Ecology	Centennial Clean Water Fund, Section 319, and State Revolving Fund https://ecology.wa.gov/About-us/How-we-operate/Grants-loans/Find-a-grant-or-loan/Water-Quality-grants-and-loans	Facilities and water pollution control related activities; implementation, design, acquisition, construction, and improvement of water pollution control.

Washington State Public Works Board	[Public Works Trust Fund](http://pwb.wa.gov/programInfor1.aspx?ActiveView=0) http://pwb.wa.gov/programInfor1.aspx?ActiveView=0	Administered by the Public Works board, this funding provides financial assistance to local government and private water systems.
US Department of Agriculture	Farm Service Agency-Conservation Reserve Program https://www.fsa.usda.gov/programs-and-services/conservation-programs/index	Assists agricultural producers to protection sensitive lands.
US Department of Agriculture	Rural Development Rural Housing Repair and Rehabilitation https://www.rd.usda.gov/about-rd/agencies/rural-housing-service	Loans to low-income rural residents to repair, improve, or modernize a home or remove health and safety hazards (e.g., failing on-site septic systems).

Outreach

Public Involvement in TMDL Development

Ecology identified key stakeholders in the Little Spokane watershed early in the process and sought feedback. It was understood early that the Spokane Hatchery operated by the WDFW was the primary point-source discharge within the Little Spokane watershed. Given the age of treatment infrastructure of the facility, Ecology and WDFW recognized significant upgrades would be needed to meet the high level of treatment the WLA would specify once it was calculated. As a result, discussions began early with WDFW staff regarding the TMDL study. Ecology staff also met with the Spokane and Pend Oreille County Conservation Districts early in the process to identify the water quality issues throughout the watershed and to discuss nonpoint best management practices (BMPs) and other solutions.

As the draft implementation strategy was being finalized in late 2019 and 2020, Ecology reached out to key implementation partners and stakeholders including the Spokane County Conservation District, WDFW, the Spokane RiverKeeper, Lands Council, Friends of the Little Spokane, and Avista Utilities. Listening sessions were scheduled with each of these key partners to get their initial feedback on the various components of the draft TMDL and implementation plan.

Promoting Implementation of Nonpoint Actions

Outreach and education efforts are intended to aid in implementing this TMDL so that the Little Spokane River will meet its state water quality standards and provide the water quality needed to support beneficial uses, including support for populations of redband trout and other native fish species. The Department of Ecology's relationship to education and outreach has primarily been to administer a competitive grant program that invests millions annually in water quality improvement projects and public education to support those efforts. Ecology's eastern region staff work directly with landowners to provide technical assistance on the best management practices (BMPs) described in the **Nonpoint** section of this plan. Staff also work with community partners to develop projects and identify Ecology funding to support their implementation.

The following nonpoint priorities were identified to focus outreach efforts on achieving on-the-ground water quality outcomes. Understanding that our target audiences may have differing levels of awareness, or that past efforts may have moved them closer to the adoption of desired behaviors, a group of efforts may be selected and implemented in a consecutive manner while others may be singular, independent efforts.

Priority 1 - Enhance Awareness

- Awareness of water quality problems and causes
- Awareness of agricultural BMPs to address the water quality problems
- Awareness of financial assistance programs through Ecology, SCCD, other sources
- Awareness of the Farmed Smart certification program and benefits

Priority 2 - Shift Attitudes

- Build trust with communities, rural residents, and agricultural producers
- Acknowledge water quality impacts caused by land use
- Recognize individual responsibility to protect water quality
- Spread knowledge of BMPs that protect water quality, and their application(s)
- Recognize that BMPs for water quality protection can support sustainable agricultural production
- Expose stakeholders to conservation farming practices and benefits

Priority 3 – Promote Behavior Adoption

- Ecology-producer site visits
- Ecology-producer conversations
- BMPs implemented
- Producers enrolled in BMP programs

Tracking Progress

A monitoring program for evaluating progress is an important component of any implementation strategy. Monitoring is needed to keep track of what activities have or have not been done, to measure the success or failure of target pursuit actions, and to evaluate improvements in water quality. Monitoring should also be done after water quality standards are achieved (compliance monitoring) to ensure that standards continue to be met.

Tracking Nonpoint BMP Implementation

As BMP projects are put into place, progress will be tracked by the granting or funding agency. Progress will be tracked using numeric criteria to the extent possible (e.g., feet or acres of planting, feet or miles of fencing, number of off-site watering facilities, etc.). Stormwater permit holders are responsible for meeting the monitoring requirements of their permits. Organizations conducting restoration projects or installing BMPs are responsible for monitoring plant survival rates and maintenance of improvements, structures, and fencing.

Beginning when this TMDL is approved, Ecology will perform watershed evaluation work in the Little Spokane watershed and prioritize nonpoint pollution sites. Ecology will track the progress at each priority site and record the following information:

- Number of sites evaluated annually
- Number of sites identified as priorities for contact
- Number of Ecology site visits to discuss issues identified with the landowners
- Number of priority sites addressed by Ecology
- Number of priority sites addressed by implementation partners
- Number of site visits where previously implemented BMPs are not maintained adequately
- Number of sites brought into compliance without the use of enforcement tools
- Number of recommendations for enforcement
- Number of enforcement actions (and what type) taken by Ecology
- Number of sites brought into compliance after the use of enforcement tools
- For sites contacted that were not brought into compliance, an explanation of why not for each one

Water Quality Monitoring

A TMDL must include water quality monitoring to measure achievement of targets and progress toward meeting water quality standards. This effectiveness monitoring also provides evidence that BMPs are having the desired benefit. Effectiveness monitoring results will be used to evaluate interim targets and whether water quality standards are being achieved. Ecology would like to perform this monitoring 10 years after the water quality implementation plan is approved. The ability of Ecology to conduct the monitoring in 10 years depends on the availability of resources. If the streams are found to not meet the interim targets and/or water quality criteria, an adaptive management strategy (see below) will be adopted and future effectiveness monitoring will need to be scheduled.

Ecology will be responsible to ensure appropriate water quality monitoring is conducted. Depending on resources, conservation districts will be encouraged to partner in the monitoring efforts. Where appropriate, photo monitoring and other forms of documenting progress will likely be utilized. If resources are available, a riparian habitat evaluation will be initiated. Riparian condition is a key indicator of nonpoint pollution.

A quality assurance project plan (QAPP) will be prepared for all monitoring work. The QAPP will follow Ecology guidelines (Lombard and Kirchmer, 2004), paying particular attention to consistency in sampling and analytical methods.

Adaptive Management

Natural systems are complex and dynamic. While we have recommended practices in this chapter that are known to be effective, the way a natural system will respond to changes in human management activities is often unknown and can only be described as probabilities or possibilities. Adaptive management involves testing, monitoring, evaluating applied strategies, and incorporating new knowledge into management approaches that are based on scientific findings. In the case of TMDLs, Ecology uses adaptive management to assess whether the actions identified as necessary to solve the identified pollution problems are the correct ones and whether they are working. As we implement these actions, the system will respond, and it will also change. Adaptive management allows us to fine-tune our actions to make them more effective, and to try new strategies if we have evidence that a new approach could help us to achieve compliance.

Full TMDL implementation and point source targets should be achieved by 2040. The goal will be to meet standards by 2050-2070, due to the lag between nonpoint implementation and full water quality benefit. The targets in this TMDL are described in terms of percent reductions, concentrations, and implementation activities. As described above in the **Outreach** section, partners will work together to monitor progress towards these goals. The effectiveness monitoring goal will be to perform extensive sampling in 2030 if resources are available. Ecology can then evaluate successes, obstacles, changing needs, and make appropriate adjustments to the implementation strategy as needed.

Ecology will use adaptive management when water monitoring data show that the TMDL targets are not being met or implementation activities are not producing the desired result. A feedback loop (Figure 13) consisting of the following steps will help guide adaptive management:

Step 1. The activities in the TMDL implementation plan are put into practice.

Step 2. Programs and BMPs are evaluated for technical adequacy of design and installation. Evaluation will be made by agencies with appropriate expertise with Ecology acting as a facilitator as well as a contributor.

Step 3. Ecology evaluates effectiveness of the activities by assessing new monitoring data and comparing it to the data used to set the TMDL targets.

Step 3a. If the goals and objectives are achieved, the implementation efforts are adequate as designed, installed, and maintained. Project success and accomplishments should be publicized and reported to continue project implementation and increase public support.

Step 3b. If not, then BMPs and the implementation plan will be modified or new actions identified. The new or modified activities are then applied as in Step 1.

Additional monitoring may be necessary to better isolate the nutrient sources so that new BMPs can be designed and implemented to address all sources of nutrients to the streams. It is ultimately Ecology's responsibility to insure that implementation is being actively pursued and water standards are achieved.

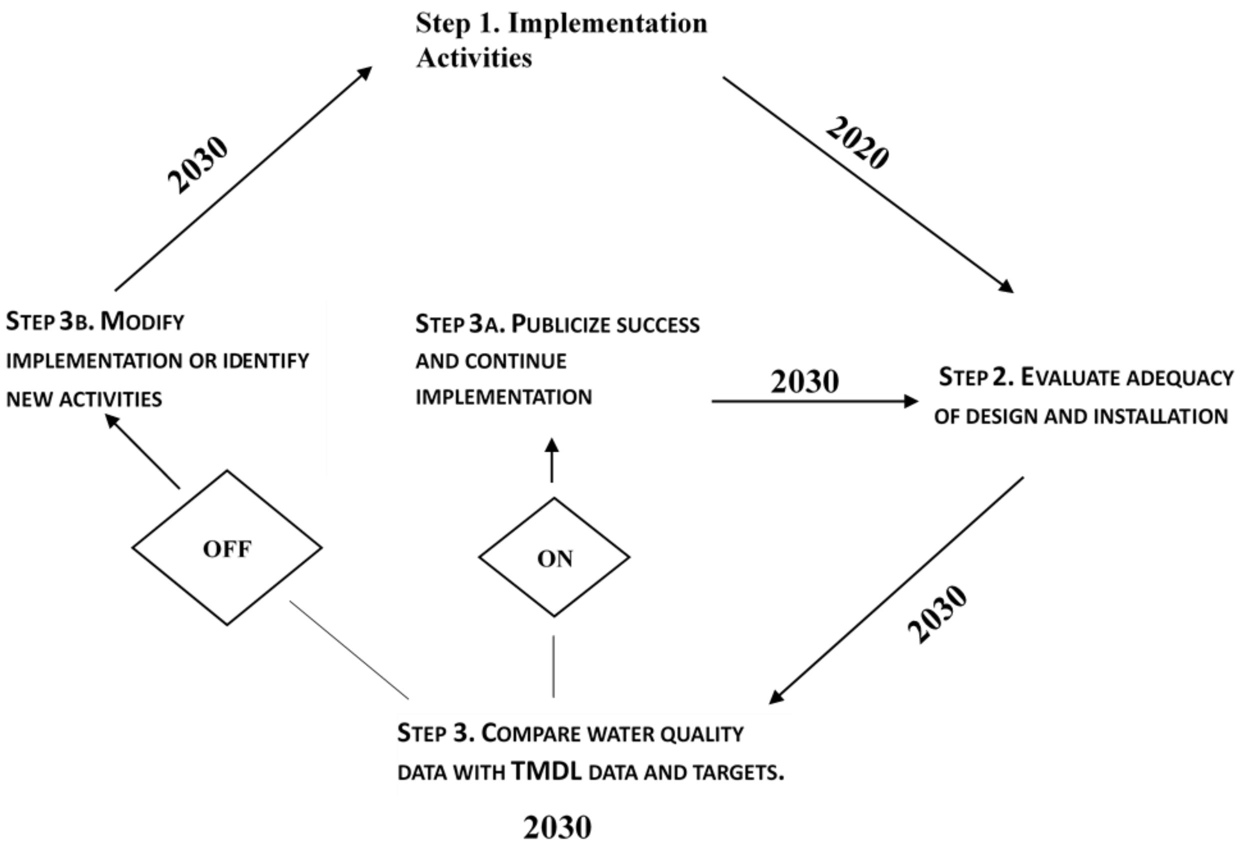


Figure 13. Adaptive Management flow chart showing a 10-year decision making process.

Reasonable Assurance

When establishing a TMDL, reductions of a particular pollutant are allocated among the pollutant sources (both point and nonpoint) in the water body. In the Little Spokane River TMDL, both point and nonpoint sources exist for dissolved oxygen and pH TMDLs (and related implementation plans) must show "reasonable assurance" that the nonpoint sources will be reduced to their allocated amount. Education, outreach, technical and financial assistance, permit administration, will all be used to ensure that the implementation goals of this TMDL are met in 20 years. Ecology has legal authority to issue administrative orders under RCW 90.48.120 requiring persons who contribute nonpoint source pollution (including temperature pollution) to implement best management practices if proactive compliance is unsuccessful. Ecology has additional authority under RCW 90.48.144 to issue penalties for failure to comply with an administrative order.

Ecology believes that the following activities already support this TMDL and add to the assurance that dissolved oxygen and pH in the Little Spokane River will meet conditions provided by Washington State water quality standards. This assumes that the activities described below are continued and maintained.

The purpose of the Little Spokane River TMDL for dissolved oxygen and pH is to set WLAs and LAs to help the waters of the basin meet the state's water quality standards. Ecology believes the work described in this plan provides reasonable assurance that the Little Spokane River TMDL goals for dissolved oxygen and pH will be met in 30 years. Meaning, when implementation is completed in 20 years (2040), it will take an additional 10 years (2050), for dissolved oxygen and pH goals to be met watershed wide.

The ability to meet specific interim targets and milestones will depend on full compliance with the TMDL and the State Water Pollution Control Act from all applicable landowners and stakeholders in the watershed. Some pollutants will take longer to reach water quality standards than others. For example, it may take up to 50 years to reach the temperature standards required from the previous Little Spokane River TMDL because of the time it takes to grow plants and trees that will provide shade to the streams. Turbidity will require establishing functioning riparian areas, streambank stabilization, and other measures throughout the watershed.

Tables 8 and 10 show reduction targets for dissolved inorganic nitrogen and total phosphorous. These targets were set using the scientific approach described in the **Technical Study and Analysis** section. Once implementation is well underway and effectiveness monitoring performed, it will become clearer whether the table is accurate. If adjustments are deemed necessary, they should be made according to the adaptive management strategy described above.

Technical study and analysis

Study Goals and Objectives

Two Quality Assurance Project Plans (QAPPs – Joy and Tarbutton, 2010; Stuart and Pickett, 2015), specified the goals and objectives for this project. We provide a summary here.

Study goals

Conduct a TMDL study with the ultimate goals of:

- Meeting the load allocation for phosphorus at the mouth of the Little Spokane River, established in the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010).
- Bringing the Little Spokane River and its tributaries into compliance with dissolved oxygen and pH water quality standards.

Study objectives

The twin goals of this TMDL dictated a need for two parallel TMDL analyses. We performed a watershed loading analysis to assess the phosphorus reductions needed to meet the load allocation for the mouth of the Little Spokane River. We performed an instream DO and pH analysis to assess the nutrient reductions and other changes needed to meet water quality standards within the LSR watershed. The objectives pertaining to these analyses were as follows:

Objectives for watershed loading study/analysis

- Collect one year of nutrient, suspended sediment, streamflow, and other related data at approximately monthly intervals and for storm events from a network of sites distributed throughout the Little Spokane River watershed.
- Assess watershed nutrient loading using monthly data collected throughout the watershed.

Objectives for instream DO and pH study/analysis

- Conduct two synoptic water quality surveys along the mainstem Little Spokane River during the low-flow season (July – August) to generate data needed for the QUAL2Kw water quality computer model.
- Collect diel dissolved oxygen and pH data at locations throughout the Little Spokane River and its tributaries.
- Assess nutrient impacts to dissolved oxygen and pH in the middle and lower Little Spokane River using the QUAL2Kw model framework.
- Use the River Metabolism Analyzer (RMA) model to assess nutrient impacts to dissolved oxygen and pH in tributaries and in the upper portion of the Little Spokane River.

- Sample each of five lakes once during late summer for epilimnion and hypolimnion nutrients, and collect temperature, dissolved oxygen, and pH profiles, to assist in understanding the role of lakes in nutrient transport, especially in the West Branch Little Spokane River.

Data Sources

We used a wide variety of data types and sources to provide the information needed to complete both the watershed loading analysis and the instream DO and pH analysis. These include data collected by Ecology as well as data collected by other organizations and agencies. Figure 14 (next two pages) shows maps of the locations where data were collected.

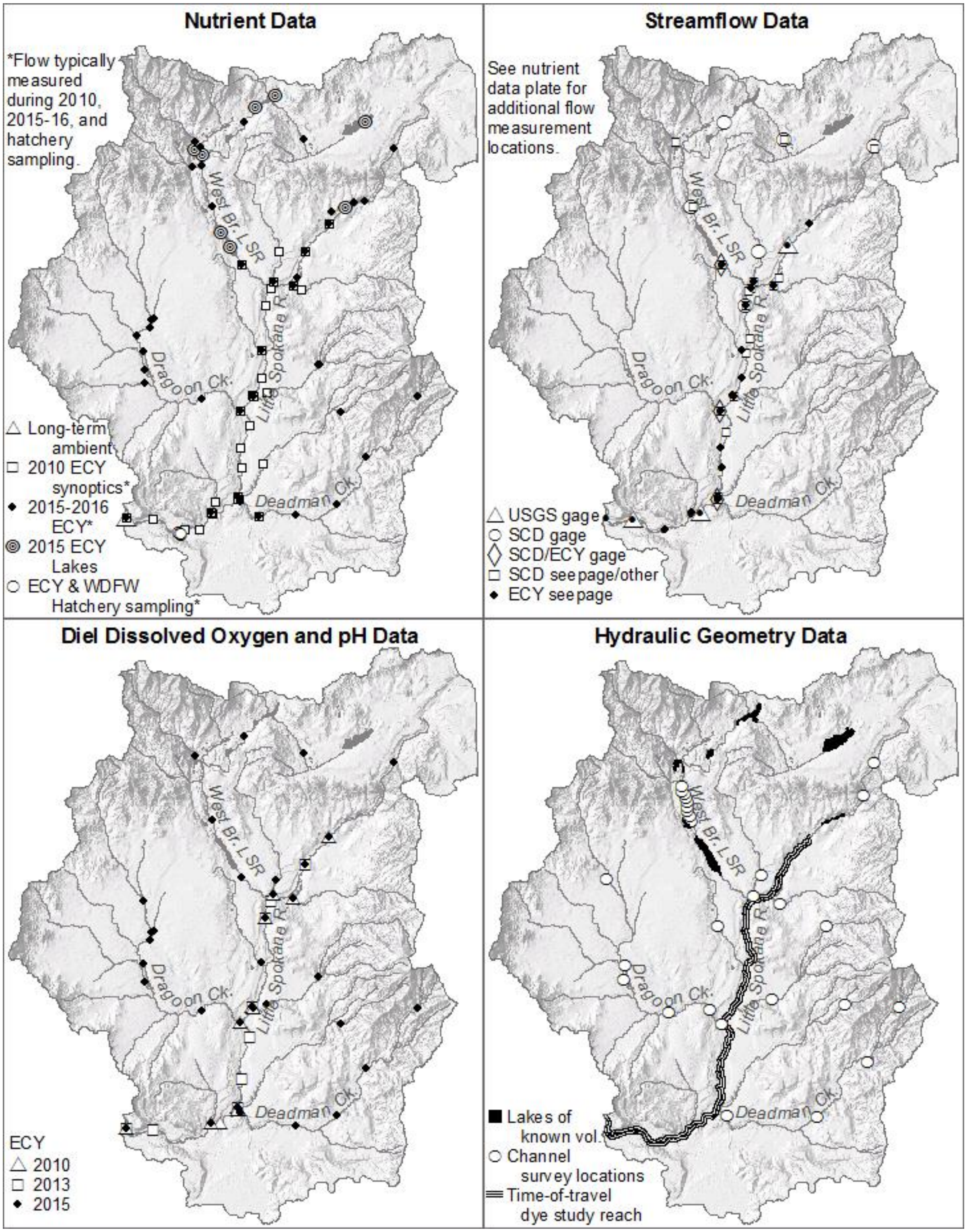
Ecology TMDL data collection

Ecology collected field data in the Little Spokane watershed over three separate field monitoring studies during 2010, 2013, and 2015-2016. These data collection efforts followed Quality Assurance Project Plans (QAPPs) and QAPP addendums (Joy and Tarbutton, 2010; Tarbutton, 2013; Stuart and Pickett, 2015). Each of these data collection efforts had a different emphasis:

- The 2010 data collection focused on summertime conditions in the mainstem Little Spokane River, to provide the data necessary to develop a QUAL2Kw model.
- The 2013 effort was a brief follow-up to the 2010 data collection, and focused on resolving river time-of-travel and flow balance data gaps in the mainstem Little Spokane River.
- The 2015-2016 data collection was a year-long effort focused on quantifying nutrient loading from various parts of the Little Spokane watershed during different seasons of the year. This effort also had a focus on assessing conditions in tributary streams.

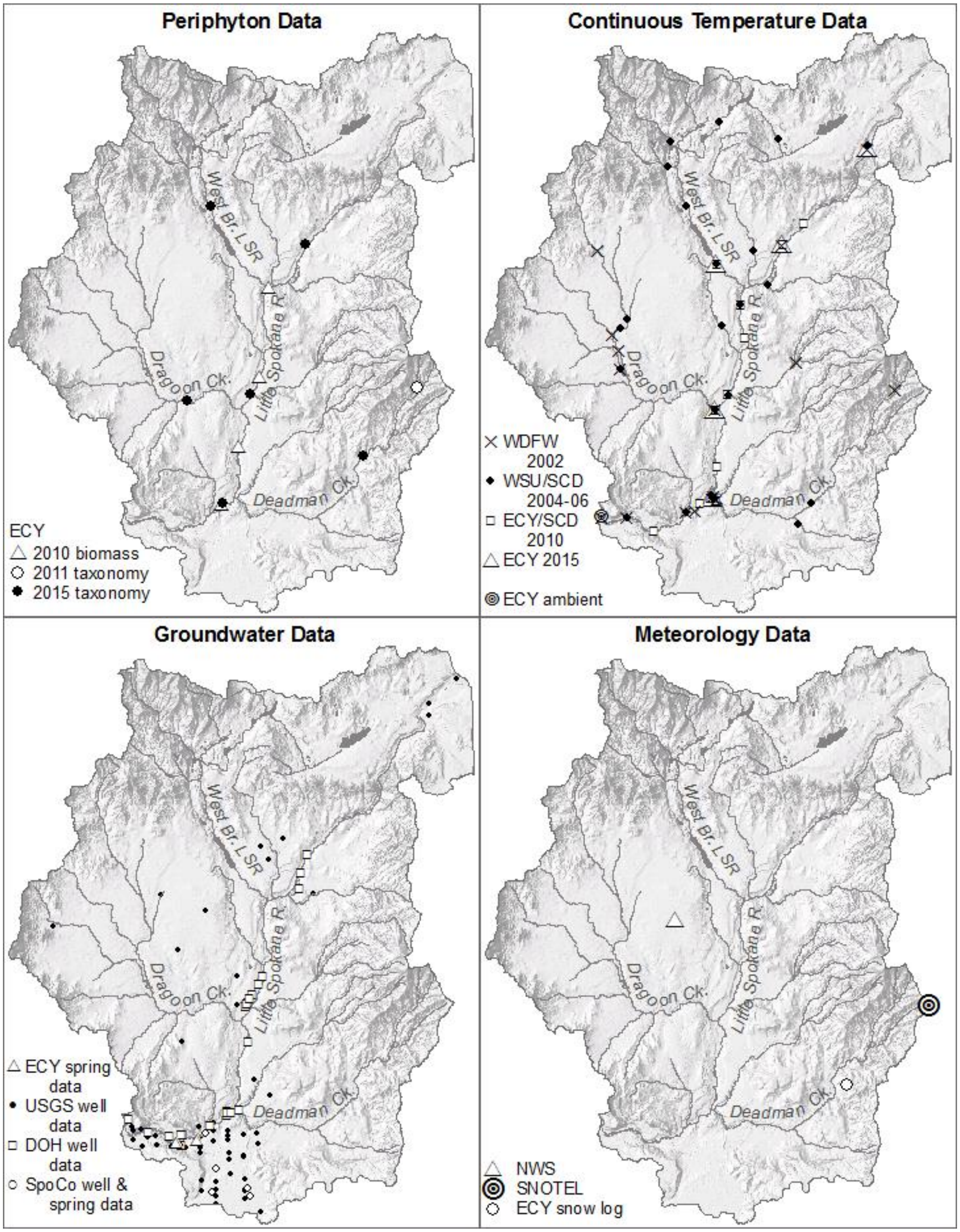
Table 21 lists all of the sampling locations used by Ecology during the 2010, 2013, and 2015-2016 data collection efforts. Data collected during 2010 are available in a separately published data summary report (Stuart, 2012). Appendix D presents data collected during 2013 and 2015-2016. Ecology data are also available online through the Environmental Information Management (EIM) database[6]; search study ID “jjoy0007”.

[6] https://www.ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database



ECY=Department of Ecology; WDFW=Washington Dept. of Fish and Wildlife; USGS=U.S. Geological Survey; SCD=Spokane Conservation District

Figure 14. Monitoring locations for the Little Spokane DO-pH TMDL



ECY=Department of Ecology; WDFW=Washington Dept. of Fish and Wildlife; WSU=Washington State University; SCD=Spokane Conservation District; USGS = U.S. Geological Survey; DOH=Washington State Dept. of Health; SpoCo=Spokane County; NWS=National Weather Service; SNOTEL=Natural Resources Conservation Service Snow Telemetry.

Figure 14, continued. Monitoring locations for the Little Spokane DO-pH TMDL

Table 23. Ecology TMDL sampling locations.

Study Specific Location ID	Sampling Location	Latitude	Longitude	2010 Nutrients	2015-2016 Nutrients	2015 Lakes	2010 Diel Hlab	2013 Diel Hlab	2015 Diel Hlab	2010 Periphyton	2015 Periphyton	2013 Seepage/Flow	2010 Temperature	2015 Temperature
55LSR-46.7	LSR @ Scotia	48.1059	-117.1528		X				X					X
55LSR-42.3	LSR @ Chain Lk inlet	48.0599	-117.1948		*									
55LSR-39.5	LSR @ Frideger Rd	48.0407	-117.2437	X	X		X		X			X	X	
55LSR-37.5	LSR @ Elk Park	48.0226	-117.2730								X		s	X
55LSR-37.1	LSR @ Elk	48.0166	-117.2770	X	X			X	X					
55LSR-33.2	LSR @ E Eloika Rd	47.9849	-117.3248	X				X		X		X		
55LSR-31.8	LSR @ Deer Park-Milan Rd	47.9695	-117.3339	X			X	X	X			X	s	
55LSR-29.5	LSR abv Bear Ck	47.9404	-117.3299										s	
55LSR-25.4	LSR @ Riverway Rd	47.9040	-117.3435	X						X		X		
55LSR-23.4	LSR @ Chattaroy	47.8894	-117.3553	X	X		X	X	X		X	X	s	
55LSR-19.8	LSR @ Colbert Landfill outfall	47.8618	-117.3610					X						
55LSR-18.0	LSR @ LSR Dr in Buckeye	47.8426	-117.3746	X						X		X		
55LSR-16.0	LSR @ E Colbert Rd	47.8239	-117.3741	X				X				X	s	
55LSR-13.5	LSR @ N LSR Dr	47.7983	-117.3817	X	X		X	X	X			X		X
55LSR-13.2	LSR abv Deadman Ck	47.7960	-117.3837										X	
55LSR-11.7	LSR @ Pine River Park (upper)	47.7913	-117.3984								X		X	
55LSR-11.5	LSR @ Pine River Park (lower)	47.7900	-117.4002							X				
55LSR-11.0	LSR @ Dartford USGS Gage	47.7847	-117.4049				X							
55LSR-10.3	LSR @ N Dartford Dr	47.7836	-117.4144	X										
55LSR-07.5	LSR @ W Waikiki Rd	47.7700	-117.4525	X								X		
55LSR-06.8	LSR blw Griffith Spring	47.7688	-117.4625										X	
55LSR-03.9	LSR @ Rutter Pkwy (Painted Rocks)	47.7809	-117.4952	X				X						
55LSR-01.1	LSR @ Mouth	47.7832	-117.5297	X	X		X	X	X					
55CHA-00.2	Unnamed trib to Chain Lake @ Mouth	48.0592	-117.2091		*									
55JON-00.5	Jones Ck (Camden Ck?) @ Mouth	48.0515	-117.2394		*									
55REFL-NOUT	Reflection Lk @ North outlet	48.0029	-117.2836		Q									
55SHE-00.6	Sheets Ck @ Reflection Lake outlet	47.9930	-117.2889		X									
55DRY-01.2	Dry Ck @ Dunn Rd	47.9823	-117.2846	X	Q									
55DRY-00.4	Dry Ck @ Mouth	47.9865	-117.2951	X	X		X		X			X		
55OTT-02.7	Otter Ck @ Elk-to-Highway Rd	48.0174	-117.3133	X										
55OTT-02.0	Otter Ck @ 3rd Valley Rd xing	48.0090	-117.3112		Q									
55OTT-01.4	Otter Ck @ 2nd Valley Rd xing	48.0041	-117.3173						X					
55OTT-00.3	Otter Ck @ Mouth	47.9903	-117.3212	X	X		X		X			X		
55MOO-02.9	Moon Ck @ Hwy 211	48.1180	-117.2737		X				X					
55WBLS-17.7	WBLSR @ Harworth Rd	48.1354	-117.3526		X				X					
55WBLS-12.4	WBLSR @ Horseshoe Lk inlet	48.1142	-117.4115		*									
55BUC-00.3	Buck Ck @ Mouth	48.1192	-117.4181		X				X					
55WBLS-11.1	WBLSR blw Horseshoe Lk	48.0979	-117.4114		X									
55BEAV-00.5	Beaver Ck (WBLSR trib) @ Mouth	48.0969	-117.4230		X									
55WBLS-07.7	WBLSR @ Fan Lk Rd	48.0607	-117.3994		X				X		X			
55FAN-00.3	Fan Lk outlet	48.0561	-117.4038		Q									
55WBLS-03.1	WBLSR @ Eloika Lk Rd	48.0071	-117.3627	X	X				X			X	s	X
55BEAR-03.7	Bear Ck @ Deer Park-Milan Rd	47.9644	-117.3716		Q									
55BEAR-00.4	Bear Ck @ Mouth	47.9297	-117.3416	X	X				X			X		
55DEE-05.9	Deer Ck abv Little Deer Ck	47.9139	-117.2653		X				X					
55LDR-00.1	Little Deer Ck @ Mouth	47.9138	-117.2645		X									
55DEE-03.2	Deer Ck @ Bruce Rd	47.8946	-117.3043		Q									
55DEE-01.4	Deer Ck @ Elk-Chattaroy Rd	47.8908	-117.3366	X					X					

Study Specific Location ID	Sampling Location	Latitude	Longitude	2010 Nutrients	2015-2016 Nutrients	2015 Lakes	2010 Diel Hlab	2013 Diel Hlab	2015 Diel Hlab	2010 Periphyton	2015 Periphyton	2013 Seepage/Flow	2010 Temperature	2015 Temperature
55DEE-00.1	Deer Ck @ Mouth	47.8883	-117.3536	X	X		X		X			X		
55DRA-19.6	Dragoon Ck @ Montgomery Rd	47.9894	-117.4947						X					
55DRA-17.0	Dragoon Ck @ Dahl Rd	47.9603	-117.4872		X				X					
55SPR-00.4	Spring Ck @ Spring Ck Rd	47.9622	-117.4831		X				X					
55DRA-16.4	Dragoon Ck @ Hwy 395 nr Deer Park	47.9537	-117.4878		X				X					
55BEAV2-00.1	Beaver Ck (Dragoon trib) @ Mouth	47.9471	-117.5075		*									
55DRA-13.2	Dragoon Ck abv WB Dragoon Ck	47.9320	-117.4985		X				X					
55WBDR-00.1	WB Dragoon Ck @ Mouth	47.9157	-117.4983		X				X					
55MUD-00.7	Mud Ck @ Mouth (@ Monroe Rd)	47.9039	-117.4981		*									
55DRA-05.4	Dragoon Ck @ DNR campground	47.8862	-117.4406								X			
55DRA-04.3	Dragoon Ck @ North Rd	47.8879	-117.4232		X				X					
55DRA-00.3	Dragoon Ck @ Mouth	47.8751	-117.3728	X	X		X		X			X	X	X
55COLB-LAND	Colbert Landfill outfall	47.8618	-117.3609	X										
55SFLD-03.0	SF Little Deep Ck abv Day-Mt Spokane Rd	47.8870	-117.2070		Q									
55SFLD-01.1	SF Little Deep Ck @ Big Meadows Rd	47.8708	-117.2378		X				X					
55LDP-03.9	Little Deep Ck @ Colbert Rd	47.8267	-117.3448	X										
55LDP-00.1	Little Deep Ck @ Shady Slope Rd	47.7972	-117.3783		X				X					
55LDP-00.0	Little Deep Ck @ Mouth	47.7960	-117.3797	X			X							
55DEA-20.2	Deadman Ck @ Park Bdy	47.8819	-117.1350		X				X					
55DEA-13.8	Deadman Ck @ Holcomb Rd	47.8298	-117.2077		X				X		X			
55DEA-09.2	Deadman Ck @ Heglar Rd	47.7875	-117.2489		**				X					
55DEA-05.9	Deadman Ck @ Bruce Rd	47.7802	-117.3044		X				X					
55DEA-02.6	Deadman Ck blw Market St	47.7793	-117.3540	X	**									
55DEA-00.6	Deadman Ck @ Shady Slope Rd	47.7937	-117.3771		X				X				X	
55SBD-00.5	SB Deadman Ck @ Shady Slope Rd	47.7929	-117.3772		Q									
55DEA-00.2	Deadman Ck blw Little Deep Ck	47.7956	-117.3808	X			X					X		X
55DEA-00.0	Deadman Ck @ mouth	47.7955	-117.3833										X	
55DAR-00.9	Dartford Ck along N Dartford Dr	47.7945	-117.4117	X										
55DAR-00.2	Dartford Ck @ Mouth	47.7847	-117.4173	X	X		X		X			X		
55WAI-00.0	Kalispell (Spokane) Country Club Springs	47.7696	-117.4341	X										
55GRI-00.0	Griffith Springs @ Mouth	47.7682	-117.4616	X										
55CHAI-W	Chain Lake deep location near west end	48.0546	-117.2196			X								
55CHAI-E	Chain Lake deep location near east end	48.0598	-117.1997			h								
55DIAM	Diamond Lake deep location near east end	48.1312	-117.1889			X								
55SACH-E	Sacheen Lake deep location in NE portion	48.1582	-117.3077			X								
55SACH-W	Sacheen Lake deep location nr outlet at W end	48.1478	-117.3346			X								
55HORS-E	Horseshoe Lake deep location in east arm	48.1079	-117.4094			X								
55HORS-W	Horseshoe Lake deep location in west arm	48.1128	-117.4198			X								
55ELOI-N	Eloika Lake location near north end	48.0372	-117.3876			X								
55ELOI-S	Eloika Lake location near south end	48.0227	-117.3757			X								

*We sampled these locations once each during the summer low-flow period.

**We sampled these locations four times each during 2015-2016 during runoff conditions.

Q We only measured flow at these locations, but did not collect samples.

h We took a measurement profile at this lake location but did not collect nutrient samples.

s Spokane Conservation District collected continuous temperature data at these locations.

Data types

The following sections summarize the types of data used to complete the TMDL analyses, and the sources of each type of data used. This includes both Ecology data and data collected by other organizations and agencies.

Nutrients

During 2010, Ecology collected water samples and measurements during two synoptic surveys for the TMDL study: one on July 27-29, and the other on August 24-26. For most parameters, we took two sets of samples at each site during each survey, one in the morning and another in the afternoon. These surveys included a large number of sites along the portion of the Little Spokane River downstream of Chain Lake, as well as one or two sites near the mouth of each direct tributary. These surveys did not include other parts of the watershed.

During 2015-2016, to support the TMDL study, Ecology collected additional water samples and measurements during monthly surveys beginning in February of 2015 and ending in March of 2016. These surveys covered a network of sites distributed widely throughout the watershed. Additional samples were collected twice monthly at the outlets of Chain and Eloika Lakes.

The **NPDES point sources** section below describes hatchery monitoring surveys by Ecology in 2009 and Anchor QEA in 2014-15.

Table 22 lists the sample parameters collected as well as the analytical method used. This table includes parameters from hatchery monitoring surveys as well as the 2010 and 2015-2016 TMDL surveys described above. Manchester Environmental Laboratory analyzed all Ecology samples. IEH Aquatic Research Laboratory in Seattle, WA analyzed Anchor QEA (2015) samples.

Table 24. Sample parameters collected.

Parameter	Method	2010 TMDL frequency	2015-16 TMDL frequency	Hatchery 2009 frequency	Hatchery 2014-15 frequency
Total Persulfate Nitrogen	SM 4500-NB (SM20 4500-NC†)	2x/survey	1x/month	2x/month	6x total
Ammonia	SM 4500-NH_3 -H	2x/survey	1x/month	2x/month	6x total
Nitrate/Nitrite	SM 4500-NO_3 -I	2x/survey	1x/month	2x/month	6x total
Total Phosphorus	SM 4500-P F	2x/survey	1x/month	2x/month	6x total
Orthophosphate (Soluble Reactive Phosphorus)**	SM 4500-P G	2x/survey	1x/month	2x/month	6x total
Total Organic Carbon	EPA 415.1 (SM20 5310B†)	2x/survey	1x/quarter	2x/month*	4x total
Dissolved Organic Carbon	EPA 415.1 (SM20 5310B†)	2x/survey	1x/quarter	2x/month*	4x total
Total Suspended Solids	SM 2130 (SM 20 2540D†)	1x/survey	1x/month	2x/month*	6x total
Settleable Solids	(SM18 2540F†)				6x total
Total Non-Volatile Suspended Solids	SM2540D	1x/survey			
Alkalinity	SM 2320B	2x/survey	Jul-Aug*	2x/month*	
Chloride	EPA 300.0	2x/survey	1x/month	2x/month*	
Chlorophyll a	SM 10200H3M		May-Nov*		
Biochemical Oxygen Demand 5-day	EPA 405.1 (SM20 5120B†)	1x/survey*		1x/month	4x total

SM = Standard Methods for the Examination of Water and Wastewater, 20th Edition (APHA, 2005; ASTM, 1997).

EPA = EPA Method Code.

† Differing method used by IEH Aquatic Research Laboratory.

*Parameter collected only at a subset of sampling locations.

** Manchester Environmental Laboratory refers to this parameter as orthophosphate. It is more commonly referred to as soluble reactive phosphorus (SRP), and that is how we refer to in this report.

Streamflow

Ecology typically measured streamflow during nutrient sampling surveys. We also obtained flow data from other organizations.

The U.S. Geological Survey (USGS) monitors continuous flow at three gaging stations in the Little Spokane watershed:

- Little Spokane River at Elk, WA (ID 12427000)
- Little Spokane River at Dartford, WA (ID 12431000)
- Little Spokane River near Dartford, WA (A.K.A. Painted Rocks; ID 12431500).

During certain years from 1999 through 2014, Spokane Conservation District (SCD) has operated flow gaging stations at several locations:

- Little Spokane River @ Scotia (LS-1, or 55LSR-46.7)
- Little Spokane River at Deer Park-Milan Rd (LS-4, or 55LSR-31.8)
- Otter Creek At Bridges Road (Elk to Highway Rd nr Elk; LS-3, or 55OTT-02.7)
- Moon Creek @ Hwy 211 (U/S of Sacheen Lake; LSRTMDL-17, or 55MOO-02.9)
- Buck Creek @ Mouth (LSRTMDL-06, or 55BUC-00.3)
- West Branch Little Spokane River @ Fan Lk Rd (LSRTMDL-22, or 55WBLS-07.7)
- West Branch Little Spokane River below Eloika Lk (LSRTMDL-23, or 55WBLS-03.1)
- Dragoon Creek at Crescent Rd (mouth; LSRTMDL-13, or 55DRA-00.3)

- Deadman Creek blw Little Deep Creek (nr Mouth, 15628 N. Little Spokane Drive; LSRTMDL-08, or 55DEA-00.2)

To characterize flow balances in the Little Spokane River downstream of Chain Lake, we used flow data from seepage studies. A seepage study, also known as a synoptic flow survey, is a set of flow measurements taken at multiple locations at approximately the same time for the purpose of identifying flow gains from, and losses to, groundwater.

- Ecology's Water Resources Program conducted a seepage study on September 13-14, 2004, during extreme low flow conditions.
- Spokane Conservation District (SCD) conducted two seepage studies, one on October 7, 2009 and the other on September 30, 2010, both during more normal low flow conditions.
- Ecology conducted a seepage study on August 12-14, 2013, concurrent with a time-of-travel dye study, during normal summertime flow conditions.

During 2015-2016, Ecology collected instantaneous stage data alongside streamflow data at most locations listed in Table 21. We collected additional stage data once per month, halfway between sampling runs, at most locations. We then developed stage-discharge rating curves wherever possible, and used the additional stage measurements to estimate streamflow.

During 2015-2016, Ecology took over operation of three gages which the SCD had recently discontinued:

- West Branch Little Spokane River at Eloika Lake Rd. (55WBLS-03.1)
- Dragoon Creek at Mouth (55DRA-00.3)
- Deadman Creek below Little Deep Creek (55DEA-00.2)

NPDES Point Sources

Spokane Hatchery

Ecology collected field data at the Spokane Hatchery, which is run by the Washington Department of Fish and Wildlife (WDFW), during 2009 for the purpose of quantifying nutrient loads from the hatchery to the Little Spokane River (Ross, 2008). These Ecology data are available in the previously mentioned data summary report (Stuart, 2012) as well as in EIM[7].

WDFW contracted for additional monitoring with Anchor QEA, who collected additional water samples and measurements at the hatchery six times during September 2014 – February 2015 (Anchor QEA, 2015). WDFW/Anchor QEA 2014-2015 data are available in Appendix D.

Data for the Spokane Hatchery are also available from their Request for Coverage under the Upland Hatchery and Fish Farm NPDES Permit, submitted January 2015, and from their Discharge Monitoring Reports.

To understand data methods at the Spokane Hatchery, it is important to understand the layout of the hatchery (Figure 15) and how it is managed.

[7] https://fortress.wa.gov/ecy/eimreporting/, Study ID: jros003

- All source water comes from Griffith Springs, which is an outflow from the Spokane Valley-Rathdrum Prairie (SVRP) aquifer. A portion of the spring water is diverted to the hatchery, while the rest continues past the hatchery in a by-pass channel.
- Within the hatchery, the water travels through a complex array of trenches, ponds, tanks, and raceways.
- Eight separate outfalls release wastewater from the hatchery to an oxbow slough, which is an off-channel area in the Little Spokane River floodplain. This report will refer to this area as "Griffith Slough".
- An old structure (apparently an old dam) creates some backwater, although the flow mostly by-passes the structure through a gap. The structure separates an area near the outfalls (which Hatchery staff call a "constructed wetland") from the outlet to the river. Solids from the hatchery appear to have settled in this confined area.
- The Griffith Spring by-pass flow mixes with the outfall flows in Griffith Slough. The combined flows then pass the structure at one end and continue down the slough to the river.

Colbert Landfill

Data for this point source discharge came from the Discharge Monitoring Reports required by their NPDES permit, supplemented from spot measurements by Ecology in July 2010.

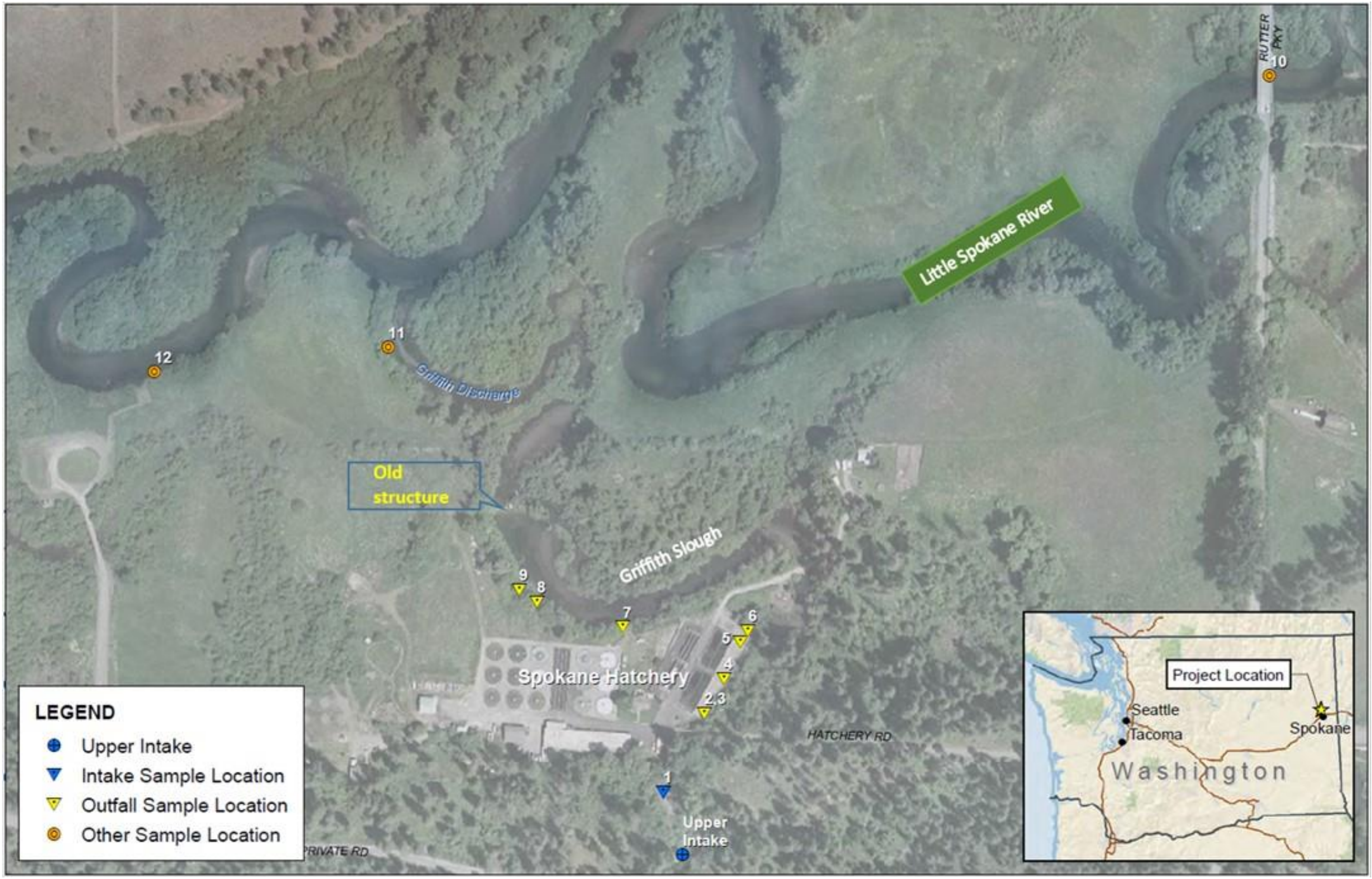


Figure 15. Spokane Hatchery site layout and sampling locations (from Anchor QEA, 2015)

Dissolved oxygen and pH

Ecology and Anchor QEA typically took instantaneous measurements of dissolved oxygen, pH, conductivity, and temperature whenever nutrient samples were collected, during all sample collection efforts, using Hydrolab® multiprobes.

In addition, Ecology deployed Hydrolab® multiprobes to continuously log for periods of time ranging from approximately 1-8 days, in order to capture diel fluctuations in temperature, dissolved oxygen and pH. These probes recorded measurements of these parameters every 10-15 minutes. We deployed multiprobes in this manner on five occasions:

- During summer 2010, we deployed multiprobes twice at selected locations on the Little Spokane River and at the mouths of major tributaries, concurrent with the July and August nutrient sampling synoptic surveys.
- During August 12-15, 2013, we deployed multiprobes at a large number of locations on the Little Spokane River during the time-of-travel dye study. The primary purpose of these deployments was to capture tracer dye concentrations. However, we calibrated and collected all parameters, resulting in a high-resolution diel dissolved oxygen and pH dataset.
- During summer 2015, we deployed multiprobes at selected locations on the Little Spokane River, at most tributary sampling locations throughout the watershed, and at a few additional tributary locations. We did this twice, once on July 21-31 and once on August 18-28.

Hydraulic geometry and time-of-travel

Stream channel width, depth, and velocity have an important influence on the response of DO and pH to instream biological processes and on the downstream transport of nutrients and other substances.

To assess the widths of the Little Spokane River downstream of Chain Lake, we digitized the wetted banks from 2006 18-inch resolution National Agriculture Imagery Program (NAIP) color orthophotos (aerial photographs geometrically corrected to have the same scale as a map). We calculated wetted widths every 321.8 meters (0.2 miles) using the TTools extension for ArcGIS (Ecology, 2015). TTools is a GIS-based tool used for spatial analysis of stream channels and riparian areas, including vegetation and shade.

To assess the water velocities in the Little Spokane River downstream of Chain Lake, Ecology conducted a time-of-travel study on August 12-15, 2013. The time-of-travel study used rhodamine, a fluorescent, non-toxic tracer dye, to estimate travel times by measuring the time it takes for a slug of the dye to reach specific downstream locations. We assessed travel times for 11 separate reaches comprising the entire distance from the outlet of Chain Lake (LSR @ Frideger Rd; 55LSR-39.5) to the mouth (55LSR-01.1). We calculated the average velocity of each reach as the length of the reach divided by the travel time.

To estimate widths, depths, and velocities in tributary streams and in the Little Spokane River upstream of Chain Lake, Ecology conducted channel surveys at 20 locations during 2015. Typically, each channel survey consisted of 10 channel cross-section profiles spaced at 100-ft intervals. We measured cross-section profiles with a laser rangefinder. We chose channel survey locations to be representative of specific reaches and reach types of the streams surveyed.

Periphyton

Periphyton consists of a community of algae, fungi, microbes, and microscopic plants and animals that grow in shallow water habitats attached to submerged surfaces. Periphyton productivity is often one of the most important drivers of DO and pH in shallow streams and rivers.

Ecology collected periphyton biomass samples on July 26 and August 23, 2010 at four locations on the Little Spokane River using a modified version of USGS protocols (Porter et al., 1993). At each site, we collected three representative rocks from the streambed. We scraped periphyton from the rocks into the sample container along with deionized water. Manchester Environmental Laboratory analyzed the samples for Chlorophyll a and Ash-Free Dry Weight. We then calculated areal periphyton biomass as the total quantity of Chlorophyll a or Ash-Free Dry Weight collected, divided by the rock surface area from which the periphyton was scraped. Ash-Free Dry Weight represents total biomass, while Chlorophyll a represents photosynthetic biomass.

We collected periphyton samples for taxonomy September 16-24, 2015 at three locations on the Little Spokane River and one location each on the West Branch Little Spokane River, Dragoon Creek, and Deadman Creek. We collected samples according to Ambient Biological Monitoring protocols (Adams, 2010), which involve scraping rocks from 8 cross sections at each location. Rhithron Associates, Inc. in Missoula, MT analyzed the samples for algal taxonomy.

We generally collected periphyton samples, whether for biomass or taxonomy, from areas with rocky substrate. This is representative of most streams in the Little Spokane River watershed. It may not be representative of some stream reaches that have sandy or silty substrate.

Continuous water temperature

In 2010, Ecology and Spokane Conservation District (SCD) deployed continuous temperature data loggers at selected locations on the Little Spokane River and the mouths of major tributaries. In 2015, Ecology again deployed data loggers, at a similar but pared-down set of locations. In addition, the hydrolabs deployed to collect diel dissolved oxygen and pH data during 2010, 2013, and 2015 also logged diel temperature data. Also, Ecology's ambient monitoring program has deployed continuous temperature data loggers at the mouth of the Little Spokane River during summer months since 2001.

Washington Department of Fish and Wildlife (WDFW) collected additional continuous temperature data in 2002, and Washington State University (WSU) and SCD did so during 2004-2006.

Temperature data loggers installed by Ecology logged temperature at 30-minute intervals. Loggers installed by WDFW, WSU, and SCD logged temperature at either 1 or 2 hour intervals.

Groundwater

To characterize the nutrient concentrations and water quality in groundwater inputs to the Little Spokane River, we used the following data sources:

- Spring data collected by Ecology from Griffith Springs (above Spokane Hatchery intake) and from an unnamed spring located at Kalispell Country Club (formerly Spokane Country Club), near Waikiki Springs.
- Spring data collected by Spokane County from Griffith Springs and Waikiki Springs.
- Well data collected by Spokane County from several wells in the portions of the SVRP aquifer near the Little Spokane River and in the Hillyard trough.
- Well data summarized as part Spokane County's Bi-State Nonpoint Source Phosphorus Study (GeoEngineers, 2010). This data included total phosphorus and soluble reactive phosphorus (SRP; referred to in the report as orthophosphate).
- Drinking water well data collected by Washington State Department of Health from wells near the Little Spokane River. This data generally included nitrate, but did not include forms of phosphorus.
- Well data collected by the U.S. Geological Survey (USGS) over a number of years from a large number of wells located throughout the Little Spokane watershed.

Meteorology

The National Weather Service weather station located at the Deer Park Airport (KDEW) provided most of the weather data used for informative purposes and for model inputs. We obtained snow data from the Natural Resources Conservation Service SNOw TELemetry (SNOTEL) site located at Quartz Peak, near the top of Mt. Spokane, and Ecology recorded additional snow depth data at the eastern edge of Peone Prairie, near the foot of Mt. Spokane.

Lake surveys

On September 1-3, 2015, Ecology conducted surveys at five of the major lakes in the northern portion of the Little Spokane watershed:

- Chain Lake
- Diamond Lake
- Sacheen Lake
- Horseshoe Lake
- Eloika Lake

At 1-2 locations in each lake, we collected epilimnion and hypolimnion composite nutrient samples, along with epilimnion Chlorophyll a. We measured lake clarity using a Secchi disk. We collected profiles of dissolved oxygen, pH, temperature, and conductivity with a Hydrolab® multiprobe by taking measurements every 1-2 meters throughout the water column.

Data quality

We assessed the quality of all data used to develop this TMDL. We found all data to be of adequate quality to their intended use in meeting the objectives of this TMDL, and to meet the standard of "credible data" as required by Water Quality Program Policy 1-11 Chapter 2 and Chapter 90.48 RCW. We have taken data quality and qualifications into account in developing results and recommendations.

The quality of all data collected by Ecology and SCD during 2010, as well as all data collected by Ecology from the Spokane Hatchery during 2009, is detailed in a separately published Data Summary Report (Stuart, 2012). Appendix E provides a detailed quality evaluation of all data collected by Ecology during 2013 and 2015-2016, and data collected from the Spokane Hatchery by Anchor QEA during 2014-2015. Appendix E also describes the quality of data obtained from other organizations and agencies which were used to develop this TMDL, including groundwater data and meteorological data.

Data collected at the Spokane Hatchery by Ecology and Anchor QEA may have some problems with representativeness, due to the complexities of hatchery operation, including:

- Multiple outfalls: Anchor QEA monitored eight separate outfalls. Their location and purpose in the hatchery was confirmed by a site visit on September 28, 2017 (Pickett, 2017). The Ecology 2009 survey did not sample all of the outfalls.
- Temporal variability of effluent: Cleaning practices include direct scrubbing of tanks and raceways with release to Griffith Slough (Pickett, 2017). This suggests that a grab sample from the outfalls may not be representative if they do not capture intermittent bursts of loading. As a result, monitoring data may underestimate total loading over weeks or months.

QC results indicate that collection and analysis of this data was good, but questions remain about whether the number and timing of samples fully captured the range of effluent conditions. This is further discussed in detail in Appendix E.

Watershed Loading TMDL Analysis

Overview

We conducted a watershed loading analysis to assess the phosphorus reductions in the Little Spokane watershed that will be needed to meet the load allocation set for the mouth of the Little Spokane River in the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010).

In order to identify human sources of total phosphorus (TP) in the watershed and estimate potential reductions in human loading, we developed mass balances for flow and TP loading based on the surveys in 2015 and 2016. A mass balance is a running tally based on monitoring data, using changes in observed loads throughout the watershed to infer sources and sinks. We estimated natural background flow and loading, and identified the human component of the TP mass balance as the difference between observed and natural background loading.

In addition to TP, the *Spokane River and Lake Spokane DO TMDL* also set allocations for ammonia and carbonaceous biochemical oxygen demand (CBOD). Ammonia and CBOD are oxygen depleting substances that are mainly associated with municipal and industrial point sources. They are not generally a problem in natural surface waters. Ambient monitoring data from the mouth of the Little Spokane River (Location ID 55B070) show that ammonia levels are very low, with the vast majority of results being non-detects. All BOD samples taken from the lower Little Spokane River during 2010, including at the mouth and at N. Little Spokane Dr., were non-detects. Therefore, our watershed loading analysis focuses solely on TP as the parameter of concern.

Data results for Watershed Loading Analysis

The data used for the watershed loading analysis was primarily from the Ecology 2015-16 surveys. Appendices D and E discuss these data in detail. We also used data from other Ecology and non-Ecology studies, and note this in the discussions of the relevant analyses.

Figures 16-20 present TP concentration data summarized by wet season (November-May), and dry season (June-October). These seasons are based on precipitation patterns and the potential for runoff. Note that for the mass balance analysis, we used different seasonal divisions, based on the load allocation seasons defined in the *Spokane River and Lake Spokane DO TMDL*.

Patterns of data can provide insights into the magnitude and locations of the highest TP concentrations, thus providing insights into potential sources. Some patterns of interest include:

- In most locations, wet season (November-May) concentrations are similar or higher than dry season (June-October) levels.
- Wet season concentrations are relatively low in the mainstem LSR and West Branch LSR, and somewhat higher in Dragoon and Deadman Creeks. The other small tributaries are a mix of lower (Sheets and Bear Creeks) and higher (Dry, Otter, Deer, and Dartford Creeks) wet season levels.
- The Dragoon Creek headwaters and the two lower stations on Deadman Creek had relatively high TP concentrations in the dry season.

- Dry season concentrations tend to be quite low at most other sites.
- Consistent TP levels in the mainstem LSR during the dry season indicate low concentrations in groundwater feeding baseflows. This suggests that the higher levels seen during the wet season are the result of nonpoint surface runoff.

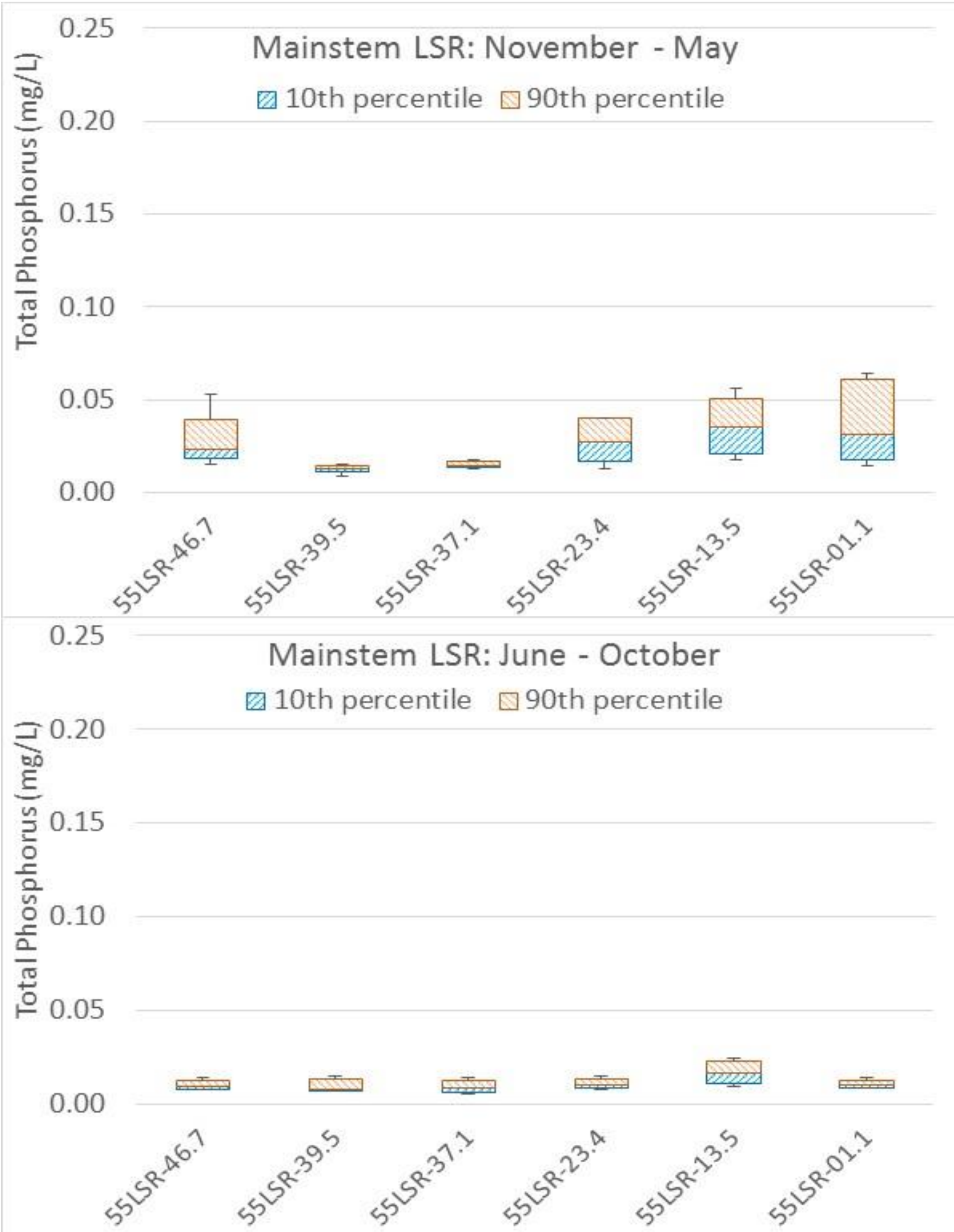


Figure 16. Total Phosphorus in mainstem LSR

The top of the box indicates the 90th percentile. The bottom of the box indicates the 10th percentile. The line in the middle of the box indicates the median.

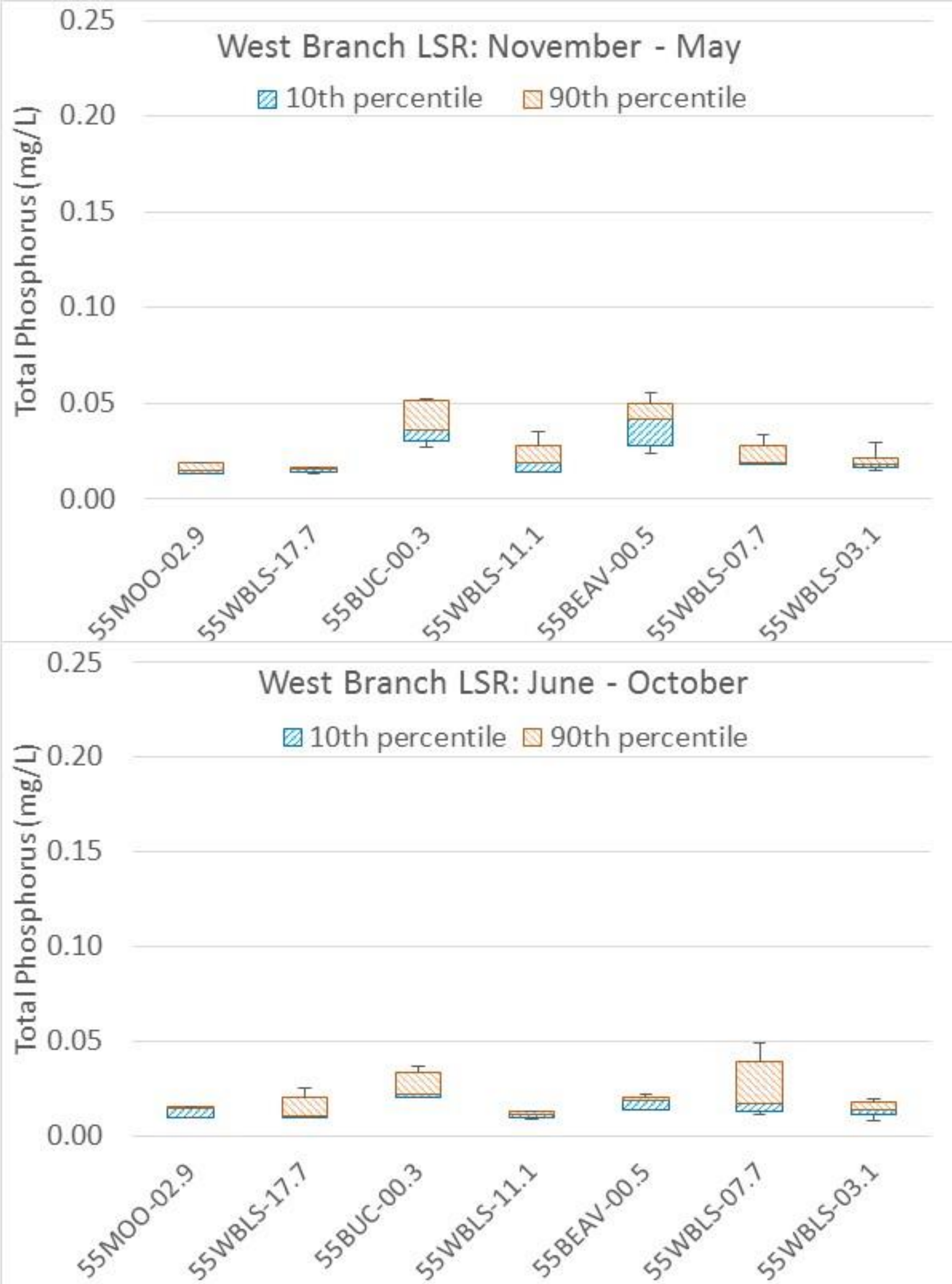


Figure 17. Total Phosphorus in West Branch LSR

The top of the box indicates the 90th percentile. The bottom of the box indicates the 10th percentile. The line in the middle of the box indicates the median.

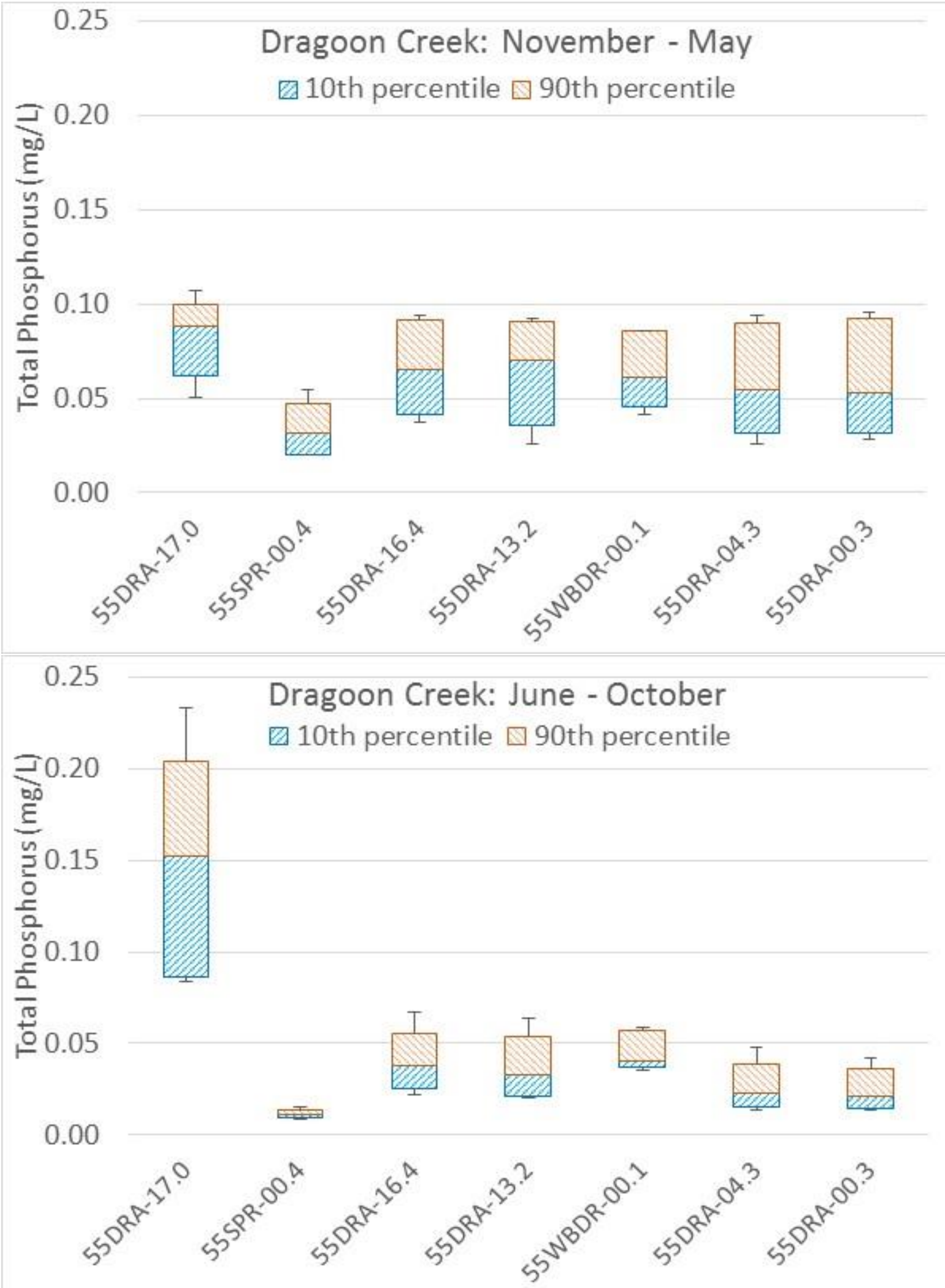


Figure 18. Total Phosphorus in Dragoon Creek

The top of the box indicates the 90th percentile. The bottom of the box indicates the 10th percentile. The line in the middle of the box indicates the median.

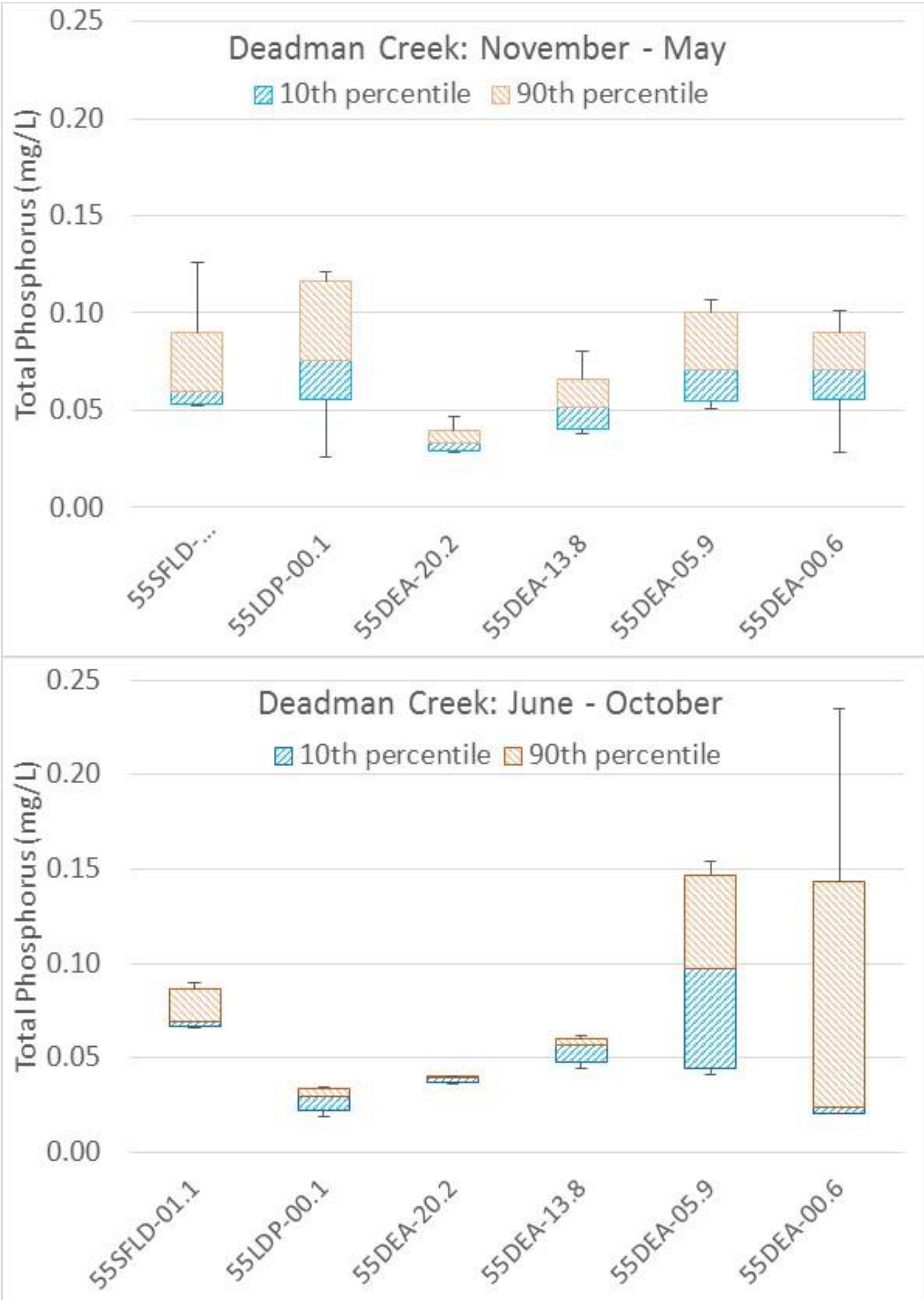


Figure 19. Total Phosphorus in Deadman Creek

The top of the box indicates the 90th percentile. The bottom of the box indicates the 10th percentile. The line in the middle of the box indicates the median.

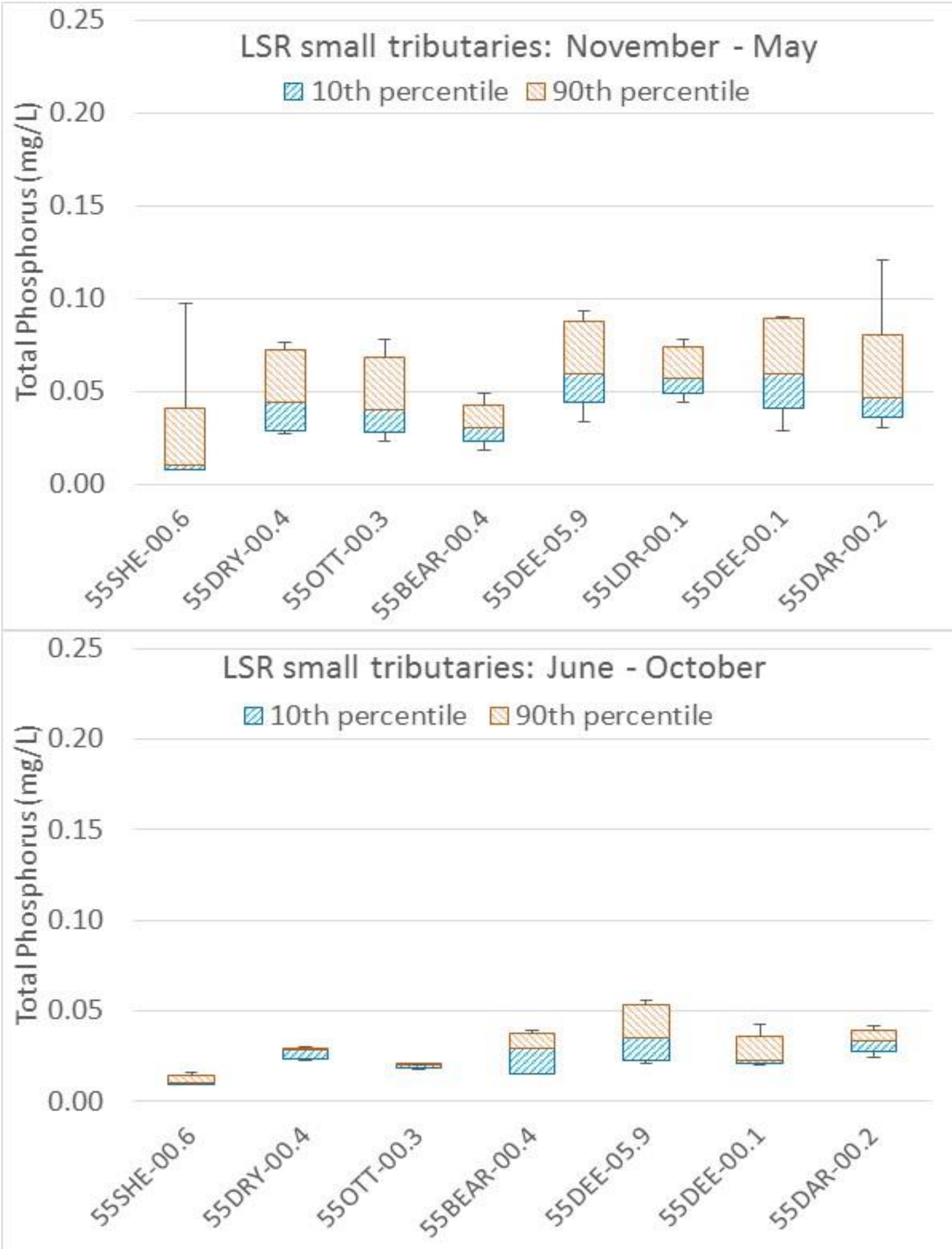


Figure 20. Total Phosphorus in LSR small tributaries

The top of the box indicates the 90th percentile. The bottom of the box indicates the 10th percentile. The line in the middle of the box indicates the median.

Analytical framework

The LSR QAPP 2nd Addendum (Stuart and Pickett, 2015) identified three objectives related to watershed loading analysis:

- *A modeling framework will be selected that meets the project objectives and other criteria such as usability and the ability to capture critical environmental processes. Frameworks to be considered include Watershed Analysis Risk Management Framework (WARMF), Soil and Water Assessment Tool (SWAT), or Hydrologic Simulation Program-Fortran (HSPF).*
- *The watershed model will be built and calibrated to observed flow, sediment, and nutrient data.*
- *The watershed model will be used to evaluate the nutrient reductions that can be expected from implementation of best management practices (BMPs) for various land uses, including agricultural and urban.*

The study evaluated the proposed modeling frameworks, but ultimately we chose a mass balance approach for the analysis. More complex watershed models require a significant investment of time and expertise, but still are limited by their complexity, data availability, and available support. The mass balance approach is sufficient to meet the objectives of the watershed analysis and support TMDL implementation.

The overall approach for the watershed analysis was to:

- Develop mass balances for flow and TP loading for the mainstem LSR and three largest tributaries, for each of the 13 2015-16 surveys. Figure 21 shows the monitoring sites and sub-basins used in the watershed analysis.
- Estimate "natural background" mass balances for flow and TP. Natural background flow and TP concentrations are estimates of conditions absent human water uses or pollutant releases. (Natural background will also be referred to as "background" in this report.) We discuss the methods used to estimate background levels below.
- Estimate human contributions of TP loading by subtracting the background mass balances from the observed conditions mass balances.
- Estimate seasonal average contributions at the mouth by averaging surveys load balance results by the TMDL seasons.
- Estimate TP loading reductions needed to meet load allocations at the mouth of the Little Spokane River.
- Prioritize TP sources to inform TMDL implementation.

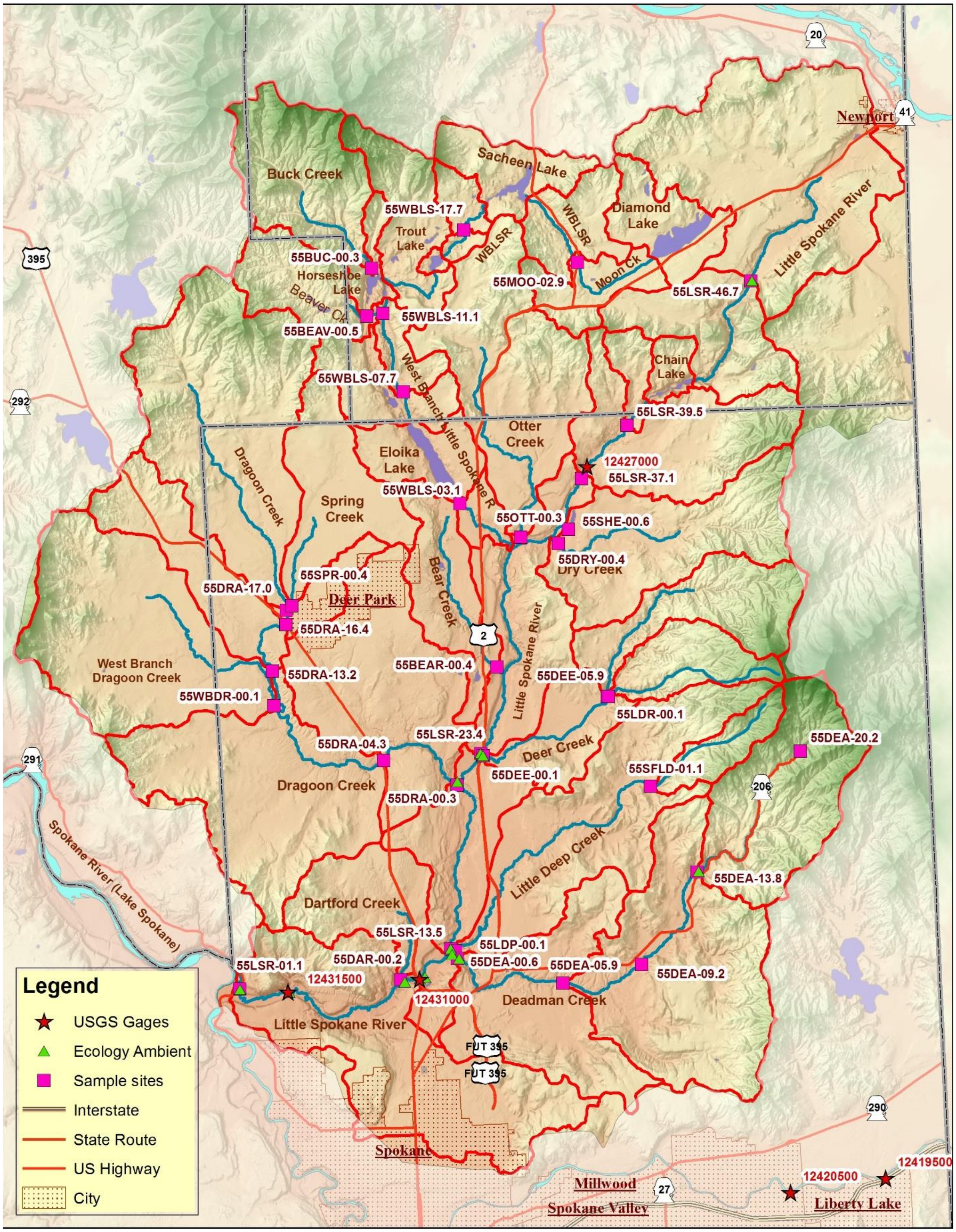


Figure 21. Little Spokane River watershed with sub-watersheds and monitoring stations.

Flow balances

We developed flow balances for observed conditions on each survey date (approximately monthly from February 2015 through March 2016). A flow balance is a running tally based on streamflow data, using changes in observed flow volume throughout the watershed to infer sources and sinks. We divided the mainstem LSR and the three major tributaries – West Branch LSR, Dragoon Creek, and Deadman Creek – into reaches defined by monitoring stations where we measured flows. Each survey balance included calculations of inflows and outflows by individual reach (Figure 22).

Figure 23 shows the network of reaches used for flow balance calculations. This includes: eight mainstem LSR reaches; four reaches on the West Branch LSR; four reaches on Dragoon Creek; and three reaches on Deadman Creek. The mainstem LSR and major tributaries all have headwater stations.

We created a flow budget for each reach which included several types of calculated or estimated inflows and outflows. Appendix F presents details of calculation methods. Tables F-1 through F-4 in Appendix F provide the flow balance values, including the stations used for tributary inflows and the end of flow balance reaches.

Here is a summary of the approach:

- **Upstream flow:** Inflows at the upstream end of each reach were flows measured at a gaging station or during the 2015-16 surveys. Upstream flows could either represent headwaters flow or flow from an upstream reach.
- **Tributaries:** We included the three major tributaries and several other smaller tributaries in the flow balance:
    - 5 tributaries flowing directly to the mainstem LSR (besides the 3 major tributaries).
    - 5 "tributaries of tributaries:" 2 to the West Branch LSR, 2 to Dragoon Creek, and 1 to Deadman Creek.
- **NPDES Point sources:** Colbert Landfill and Spokane Hatchery.
    - Colbert Landfill flows reported on Discharge Monitoring Reports submitted to Ecology
    - Hatchery effluent flows estimated using a regression that predicts flow from fish stocking levels, based on Anchor QEA (2015) measurements and fish stocking levels from WDFW monthly reports to Ecology
- **Evaporation:** We calculated flow lost in each reach to evaporation from standard evaporation pan data measured daily in Spokane by NOAA, using methodology from NOAA (1982).
- **Water withdrawals:** We estimated total potential withdrawals for each reach by applying 20% of the amounts permitted under existing water withdrawal permits, which were prorated by month from typical crop or landscape irrigation demands over the growing season. For discussion and explanation of this number, which we also used for the instream DO and pH analysis, see the **Flow Balances** sections in both Appendices F and G.

- **Groundwater:** We determined groundwater inflows or outflows for each reach from the water balance during the dry season surveys, after accounting for other inflows and outflows. We assumed residual flow (defined as the difference in flow between two adjacent monitoring stations, accounting for any tributary inflows) in the dry season to be groundwater.
  We evaluated the patterns in these calculated flows during the dry season to determine wet season groundwater flows. Depending on the dry season pattern and the flow balance, we set wet season groundwater flows to a seasonal cosine function in some cases, and to a constant in others.
- **Surface runoff:** We assumed surface runoff to be negligible during the dry months and set it to zero. For the wet months, we set runoff rates to the residual remaining in the flow balance after accounting for estimated groundwater flows.
- **Lake volume changes:** We included lake volume changes for Eloika and Sacheen Lakes.
  - A local resident provided Sacheen Lake level data that he collects for the homeowner association (Hood, 2016). We calculated average Sacheen Lake outflows from the lake level change and the surface area.
  - We obtained lake elevation data and flow data from above and below Eloika Lake from Spokane Conservation District (SCD, 2016). We developed a methodology to estimate lake volume changes during the 2015-16 surveys based on lake outflow changes at high flows, and on the residual left after estimating groundwater inflows during low flows.
- **Residual flow:** In each reach, we balanced flows by assigning all residuals to groundwater in the dry season, and to surface runoff in the wet season.

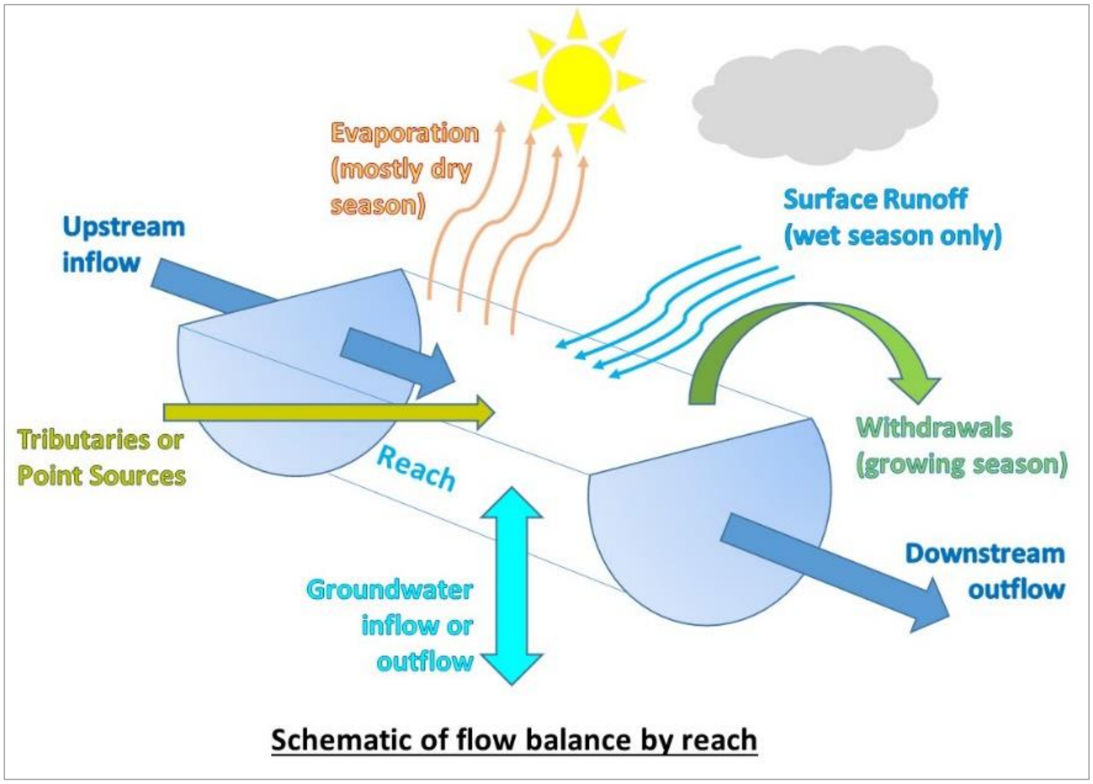


Figure 22. Schematic of mass balance by TMDL reach

Tables F-1 through F-4 in Appendix F present results from the flow balance analysis. Figures 24 and 25 depict inflows to the Little Spokane River by flow volume and percentage of the total, respectively. In the summer months, flows are dominated by direct groundwater inflows and by the headwaters (which are also strongly groundwater influenced). The most significant tributary source of flow in the summer is Dragoon Creek. During the wet season (November through March), the major sources of flow are direct runoff and the tributaries – especially in the West Branch LSR and Deer, Dragoon, and Deadman Creeks.

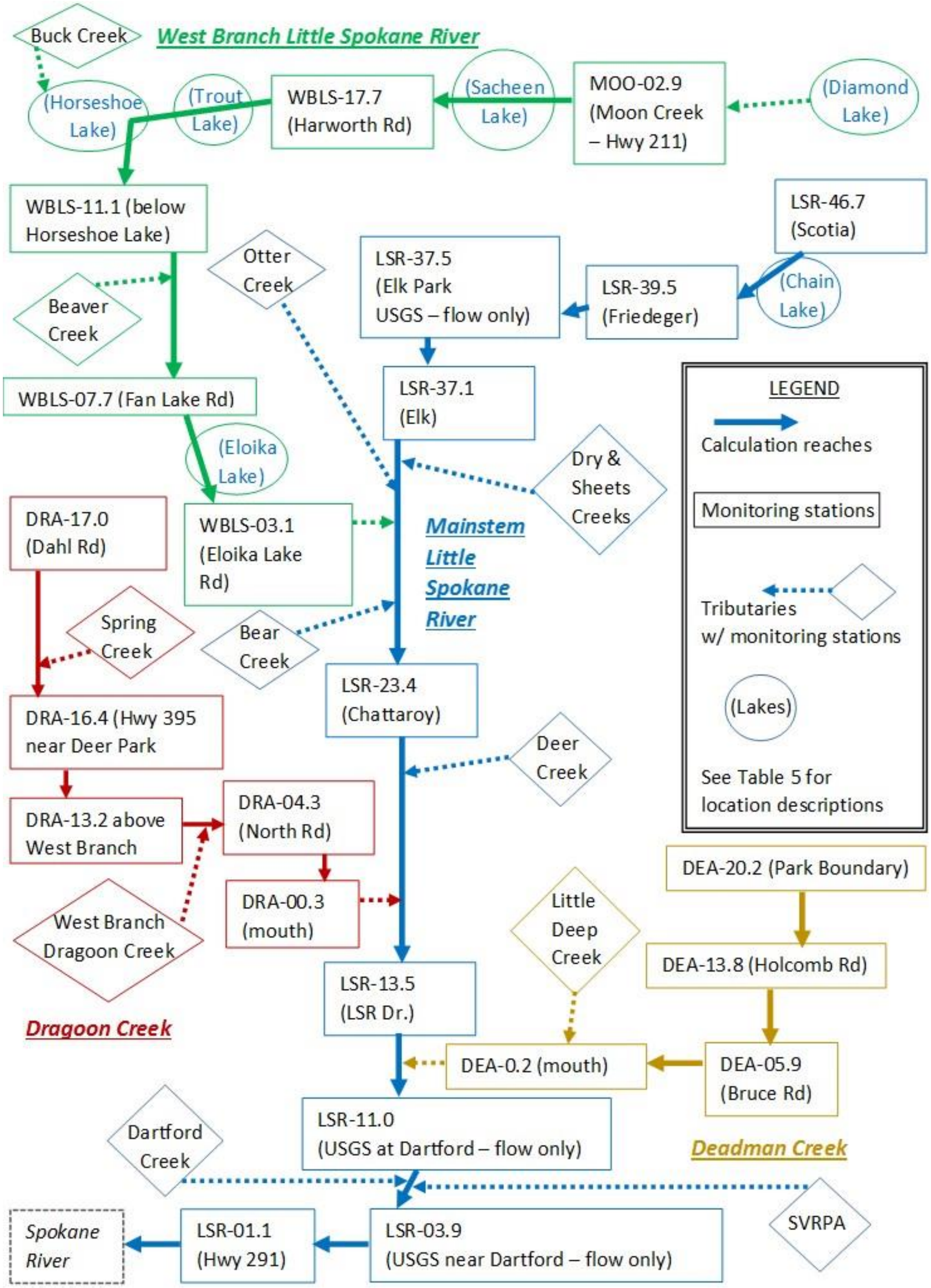


Figure 23. Diagram of flow and load balance network

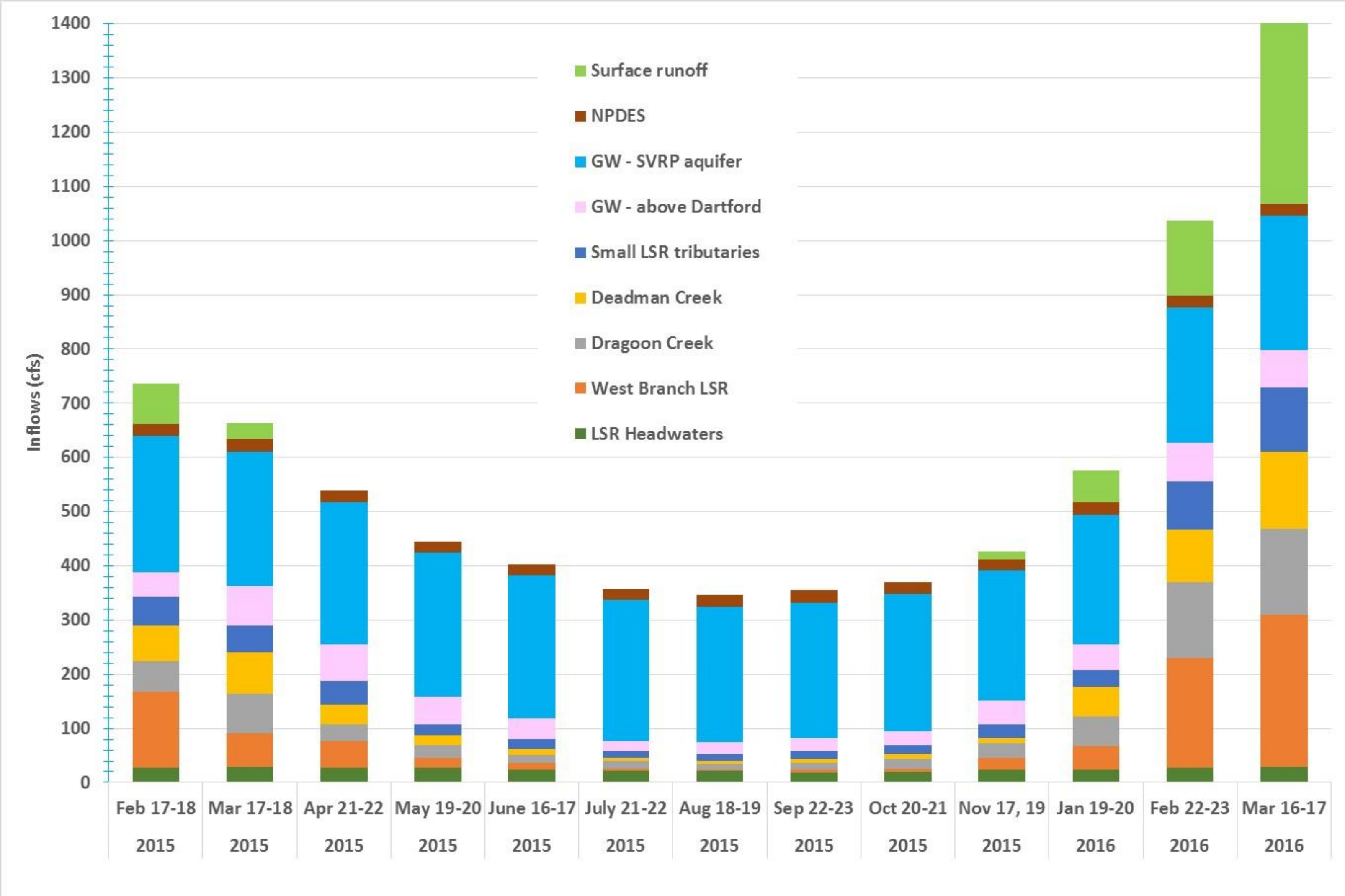


Figure 24. Inflows to Little Spokane River from flow balances.

The total flow for each bar represents the flow at the mouth of the Little Spokane River.

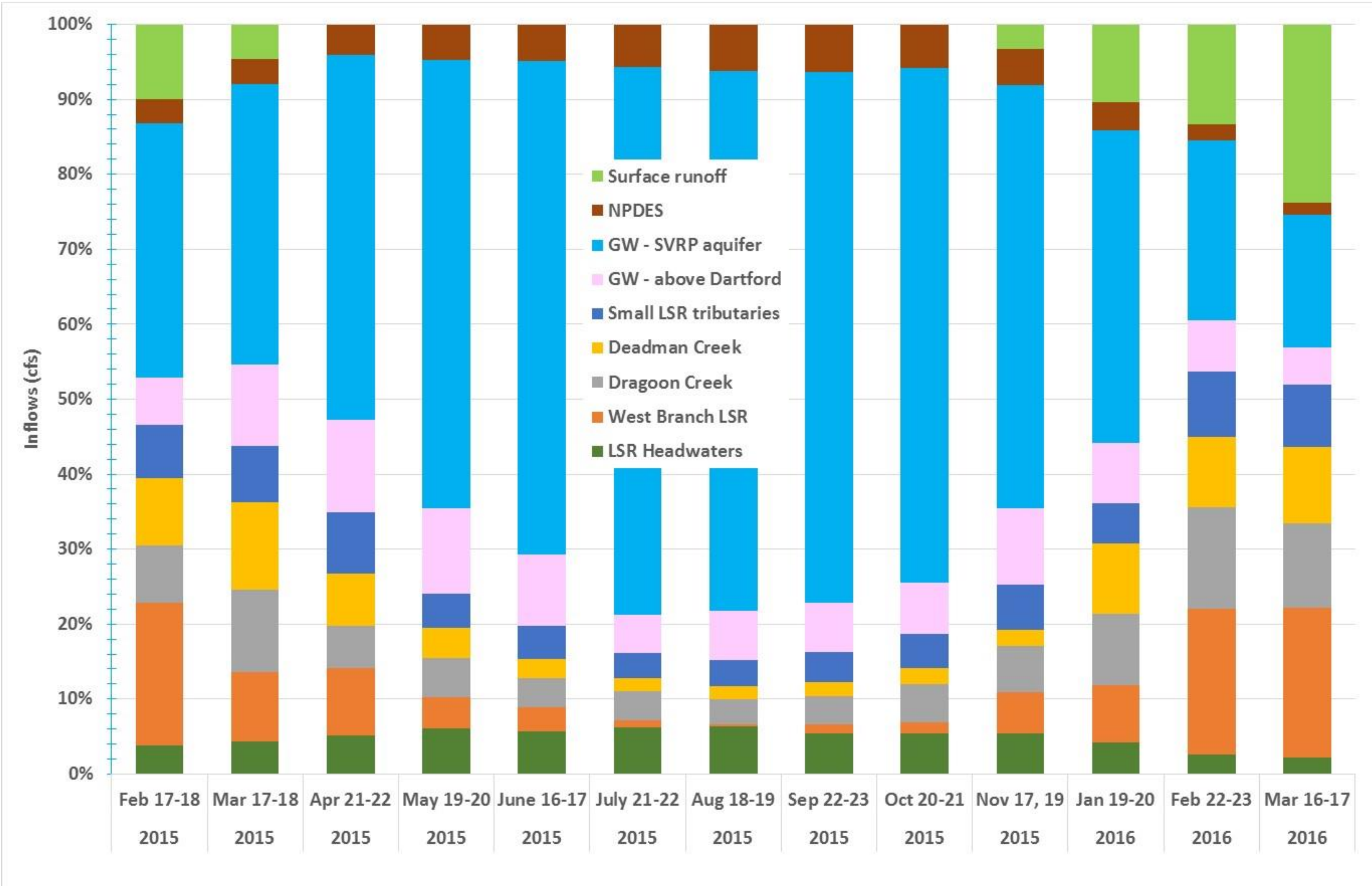


Figure 25. Inflows to Little Spokane River from flow balances, as a percentage of total flow at the mouth.

Phosphorus load balances

We used the flow balances to develop total phosphorus load balances for the Little Spokane River, the West Branch LSR, Dragoon Creek, and Deadman Creek. We calculated a load balance for each survey date and reach by adding up the load inputs and outputs. We compared this sum to the load at the end of each reach, as determined from measured flow and concentrations at monitoring stations. Note that these methods are based mathematically on the mass balance and hydrology – we evaluated local factors such as terrain and land uses to interpret the results, but did not use them in the analysis itself.

We used the two USGS gage sites – 55LSR-11.0 (LSR at Dartford) and 55LSR-3.9 (LSR near Dartford) –only for flow balance, not the TP balance. We calculated the TP load balance for the lowest LSR reach from 55LSR-13.5 (Little Spokane Drive) to the mouth at 55LSR-01.1 (Highway 291 near the mouth).

We assigned TP concentrations for each of the various inflow sources and outflow losses. Appendix F describes the methods in detail. The following is brief summary of methods:

- **Headwaters and tributaries:** We applied observed concentrations.
- **Spokane Hatchery:** We calculated net concentrations (based on net loading above levels in the source spring) for combined outfalls from a regression of observed concentrations from the Anchor QEA monitoring to the monthly fish feed use reported by WDFW.
- **Groundwater:** For each reach, we applied a single groundwater concentration to all surveys.
    - Above Dartford Creek, we determined concentrations by selecting values similar to levels found in reference wells and headwater streams that fulfilled the dry season load balance.
    - For inflows from the SVRP aquifer, we set the concentration to 0.008 mg/L, based on levels in reference wells and springs in the area. The Spokane TMDL used 0.009 mg/L, but 0.008 mg/L provided the least error in this load balance. The DO and pH analysis split out groundwater and spring sources and used different values for each, but overall the values are consistent.
- **Surface Runoff:** For surveys and reaches where the flow balance identified runoff, we defined runoff load as the residual load after accounting for all other sources and sinks. We set runoff concentrations to values which, when combined with the runoff flow from flow balance, equaled the residual load.
- **All outflows (groundwater, direct withdrawals, and source/sink/uncertainty):** We defined the outflow concentration as the instream concentration.

After calculating the load balance, a "source/sink/uncertainty" term remained representing the residual, that is, the difference between the reach-calculated load balance and the observed load at the end of the reach. In most cases, we selected input concentrations (for groundwater in the dry season and surface runoff in the wet seasons) to minimize the source/sink/uncertainty to a value representing a small amount of uncertainty, assumed to represent environmental and data variability. In a few cases, larger values remained that could represent unknown TP sources or sinks that couldn't be accounted for as runoff.

Tables F-5 through F-8 in Appendix F show complete load balance results. Here are some summary observations about the watershed loading analysis results:

- Mainstem LSR, Scotia to Frideger Road (RM 46.7 – 39.5): Background levels for this area constrained both runoff and groundwater concentrations to low levels. The resulting source/sink/uncertainty term is mostly negative, suggesting that Chain Lake may serve as a phosphorus sink. See the **Lakes > Nutrients and Eutrophication in Linked Rivers and Lakes** section later in this report for further discussion.

- Mainstem LSR, Elk to Chattaroy (RM 37.1 – 23.4): Groundwater concentrations were higher here, but negative source/sink/uncertainty terms occur in the growing season, suggesting some TP uptake. This is consistent with the results of the mainstem QUAL2Kw model, which showed a net uptake of nutrients in this reach.

- Mainstem LSR, Little Spokane Drive to Highway 291 (RM 13.5 – 1.1): Large inflows from the SVRP aquifer below Dartford drive the high groundwater TP loads in this reach, even though SVRPA TP concentrations are relatively low.

  Positive source/sink/uncertainty terms of over 2 kg/day remain for this reach during the May and June surveys. The source of this difference is unknown, but could be related to some combination of uncertainty and unidentified sources. We discuss this in more detail in the **Loading Reduction Identification** section below.

- Dragoon Creek headwaters (above RM 17.0): Loads at the upstream boundary of the Dragoon Creek load balance were consistently high, representing about of the total loading in the creek during both the wet and dry seasons.

- Deadman Creek, Holcomb Road to Bruce Road (RM 13.8 – 5.9): This reach has groundwater exchanges which are outflows in the summer and inflows in fall through spring. This suggests that there may be some influence from groundwater pumping near this reach of the creek for irrigation in the summer months.

Separation of human and natural background loading

Natural Background Flow

We estimated natural background flows by adjusting the flow balance for observed conditions as follows:

- Removing surface withdrawals (which restored those instream flows)
- Removing point sources inflows
- Increasing groundwater inflows

In order to increase groundwater inflows, we first had to estimate how groundwater inflows have changed due to pumping in the watershed. We evaluated the human impact on groundwater inflows as follows:

- The WRIA 55-57 Watershed Plan presented a basin-wide estimate of the decline in groundwater inflows into the mainstem LSR (Golder Associates, Inc., 2004; Spokane

County, 2006). The Watershed Plan technical analysis found that the decrease in streamflows due to reductions in groundwater inflows was highest in January at 13 cfs, and reached a minimum of 6 cfs in late June, representing a five-month lag between peak pumping and streamflow effect. We developed a sinusoidal curve that matched the maximum and minimum from the study to represent monthly groundwater flow reductions to the LSR due to human water use.
- We then distributed the estimated depletion of groundwater flow into the LSR due to human use over each reach proportionally to the volume of groundwater production allowed by permits for wells within 500 feet of river for that reach.

Appendix F provides a more detailed description of this approach.

Current surface runoff hydrology has likely been altered from pre-development conditions, particularly for agricultural and urbanized portions of the watershed. However, analyzing changes in storm runoff rates and patterns is difficult since it must take into account land use changes, soil conditions, compaction and impermeable surfaces, channelization and hydraulic interception, and many other factors. Given that we did not develop a full hydrologic model, we deemed that estimating natural background surface runoff volumes was beyond the scope of this study.

Appendix L contains a summary checklist of changes made to reflect natural background conditions for the watershed analysis.

Natural Background TP

We calculated background TP loading values for tributaries, surface runoff, and groundwater from the background flow balances and estimates of background TP concentrations. Below is a brief summary of how we determined background TP concentrations. More details on these methods and the sources for the values can be found in Appendix F, Table F-9.

- For tributaries and surface runoff, we selected natural background concentrations based on several approaches, including using values during runoff conditions from a relatively undeveloped watershed with similar geology and soils, or from breakpoints between relatively low and high concentrations during surveys when runoff was occurring.
- For groundwater above Dartford Creek, we selected reference values from low values in nearby wells, and from the lowest values during surveys under baseflow conditions from locations that represented relatively little development.
- For the SVRP aquifer, we used the background concentrations estimated in the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010).
- As part of evaluating human contributions, we evaluated the source/sink/uncertainty terms to set a background range representing the "noise" in the load balance due to uncertainty, similar to range of values for this term at other nearby locations. To separate the background range of uncertainty from potential unidentified loads, we set it set based on whether:
    - The source/sink/uncertainty load was less than 0.50 kg/day (selected from a break-point in the data), or

- The source/sink/uncertainty load represented less than 10% of the total load at downstream end of the reach where it occurred, or
- A similar negative load was observed upstream or downstream, which would suggest an offsetting imbalance in the calculation.

Appendix F provides more details on the method for determining natural background concentrations.

We applied a single natural background concentration to groundwater for each reach during all surveys, consistent with the approach for groundwater loading in the mass balance for 2015-16 conditions. For tributaries and surface runoff we applied a single natural background value as an upper limit for each tributary or reach, for all surveys. Therefore, observed values less than the background level were not changed. We chose the approach of using background concentrations for tributaries and surface runoff that were constant over all surveys for several reasons:

- There are insufficient data to determine a seasonally varying value, so estimating seasonal values would not reduce uncertainty.
- It's reasonable to assume that concentrations would exhibit lower variability without the impact of human activities in the watershed.
- Sources above background will be prioritized by magnitude, so variability in the natural levels will have little effect on the final recommendations.

Figure 26 illustrates the geographic distribution and magnitude of calculated loads, with background and observed shown by TMDL season (the LA seasons from the Spokane River DO TMDL). Differences in loading between background and observed conditions are most apparent for the March-May season.

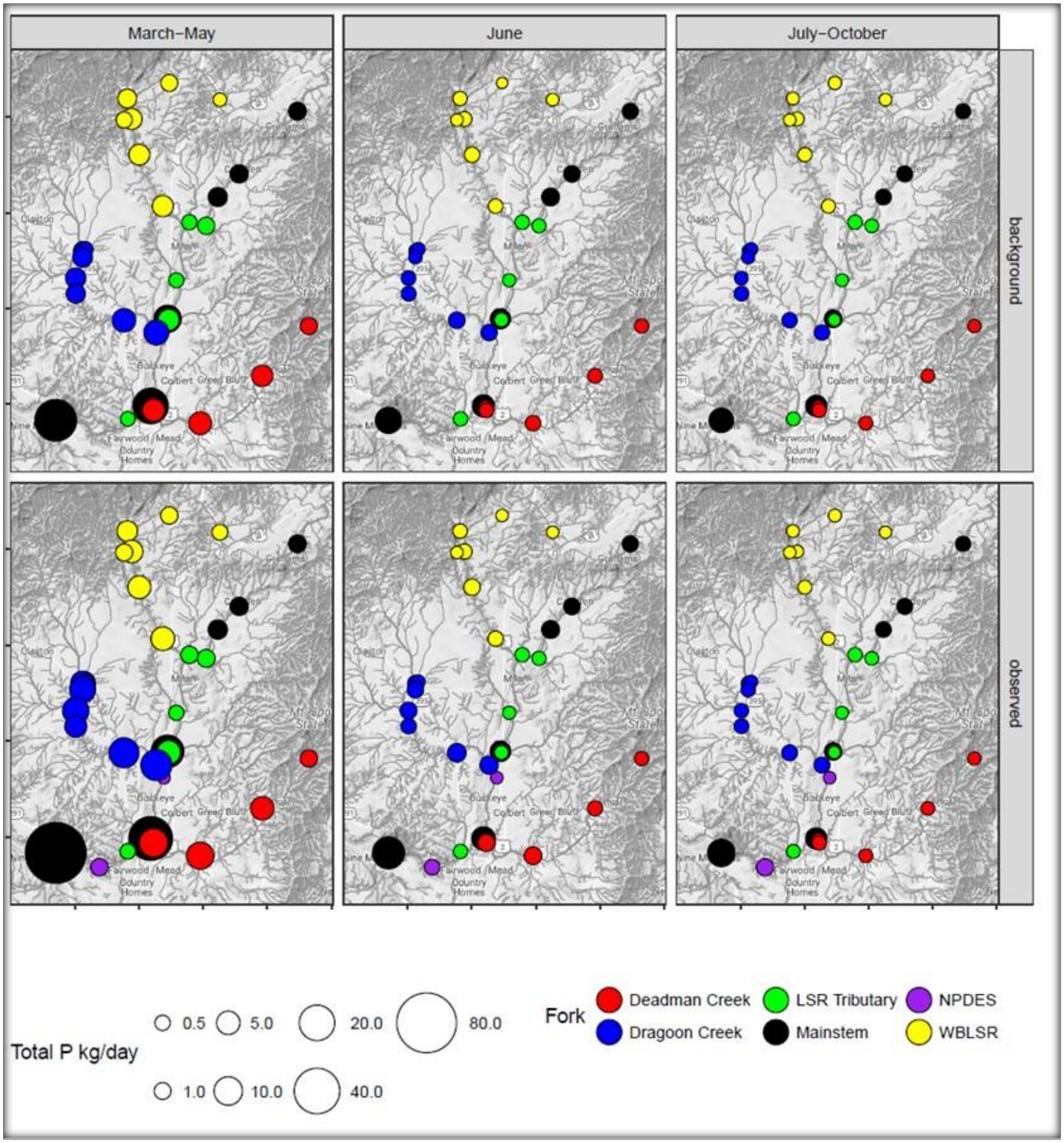


Figure 26. Little Spokane River basin total instream phosphorus loading.

Size of circle indicates the magnitude of loading

Loads above natural background

To estimate the contribution of human activities to TP loading, we subtracted the load balances for natural background conditions from the load balances for observed conditions. We refer to the resulting load above background as "human loading" in this report. We determined this "human loading" mathematically and not by analysis of land uses or identification of sources. Although there is some uncertainty associated with these human loading estimates, they are adequate to identify and prioritize large sources that clearly rise above background levels, and to set targets for load reduction.

Table 23 and Figures 27 through 30 illustrate the results of this analysis. We present loading averaged by TMDL season. Although the November through February season does not have a TMDL Load Allocation, we still present it because it provides information on the sources of wet season TP loading.

Table 25. Human TP load contributions by stream reach and season.

Stream or source	Reach	RM	Mar-May Human TP load (kg/day)	June Human TP load (kg/day)	Jul-Oct Human TP load (kg/day)	Nov-Feb Human TP load (kg/day)
LSR	HW-Scotia	HW - 46.7	-	-	-	0.51
LSR	Scotia-Elk	46.7 - 37.1	0.14	0.079	0.021	0.067
Dry/Sheets			0.25	-	-	0.17
Otter			0.72	-	-	0.51
Moon	HW-Hwy 211	HW - 02.9	0.0016	-	-	-
Moon/WBLSR	Hwy 211-Harworth Rd	02.9 - 17.7	0.16	-	-	0.060
Buck			1.01	0.062	-	0.78
WBLSR	Harworth-BlwHorseshoe	17.7 - 11.1	-	-	-	-
Beaver			0.33	-	-	0.52
WBLSR	BlwHorseshoe-Fan Lk Rd	11.1 - 07.7	0.13	0.21	0.093	0.10
WBLSR	Fan Lk Rd - Eloika Lk Rd	07.7 - 03.1	0.37	-	-	0.48
Bear			0.033	0.0049	-	0.14
LSR	Elk-Chattaroy	37.1 - 23.4	**3.9**	-	-	**2.9**
Deer			1.9	-	-	1.5
Dragoon	HW-Dahl Rd	HW - 17.0	**4.3**	**0.73**	**0.29**	2.6
Spring			0.090	-	-	0.010
Dragoon	Dahl Rd-Hwy395	17.0 - 16.4	0.29	-	-	1.2
Dragoon	Hwy395-abvWBDR	16.4 - 13.2	0.41	-	-	0.61
WB Dragoon			1.8	0.17	0.020	1.3
Dragoon	abvWBDR-North Rd	13.2 - 04.3	-	-	-	1.3
Dragoon	North Rd-Mouth	04.3 - 00.3	0.88	-	-	-
Colbert Landfill			0.075	0.075	0.075	0.075
LSR	Chattaroy-N LSR Dr	23.4 - 13.5	0.32	-	-	**1.9**
Deadman Ck	HW-ParkBdy	HW - 20.2	0.11	-	0.00017	-
Deadman	ParkBdy-Holcomb Rd	20.2 - 13.8	1.5	0.080	0.013	1.5
Deadman	Holcomb Rd-Bruce Rd	13.8 - 05.9	**2.6**	**0.82**	0.0065	1.2
Deadman Ck	Bruce Rd-Shady Slope Rd	05.9 - 00.6	1.5	0.057	0.061	1.2
Little Deep Ck			1.8	-	-	0.97
Dartford Ck			0.23	-	-	0.034
Spok Hatchery			1.2	**0.57**	**1.1**	0.88
LSR	N LSR Dr-Mouth	13.5 - 01.1	**23**	**4.9**	**2.2**	**15**
		Total	*49*	*7.8*	*3.9*	*38*

Loads contributing more than 5% of the total human load for a given season are shown in **bold**.

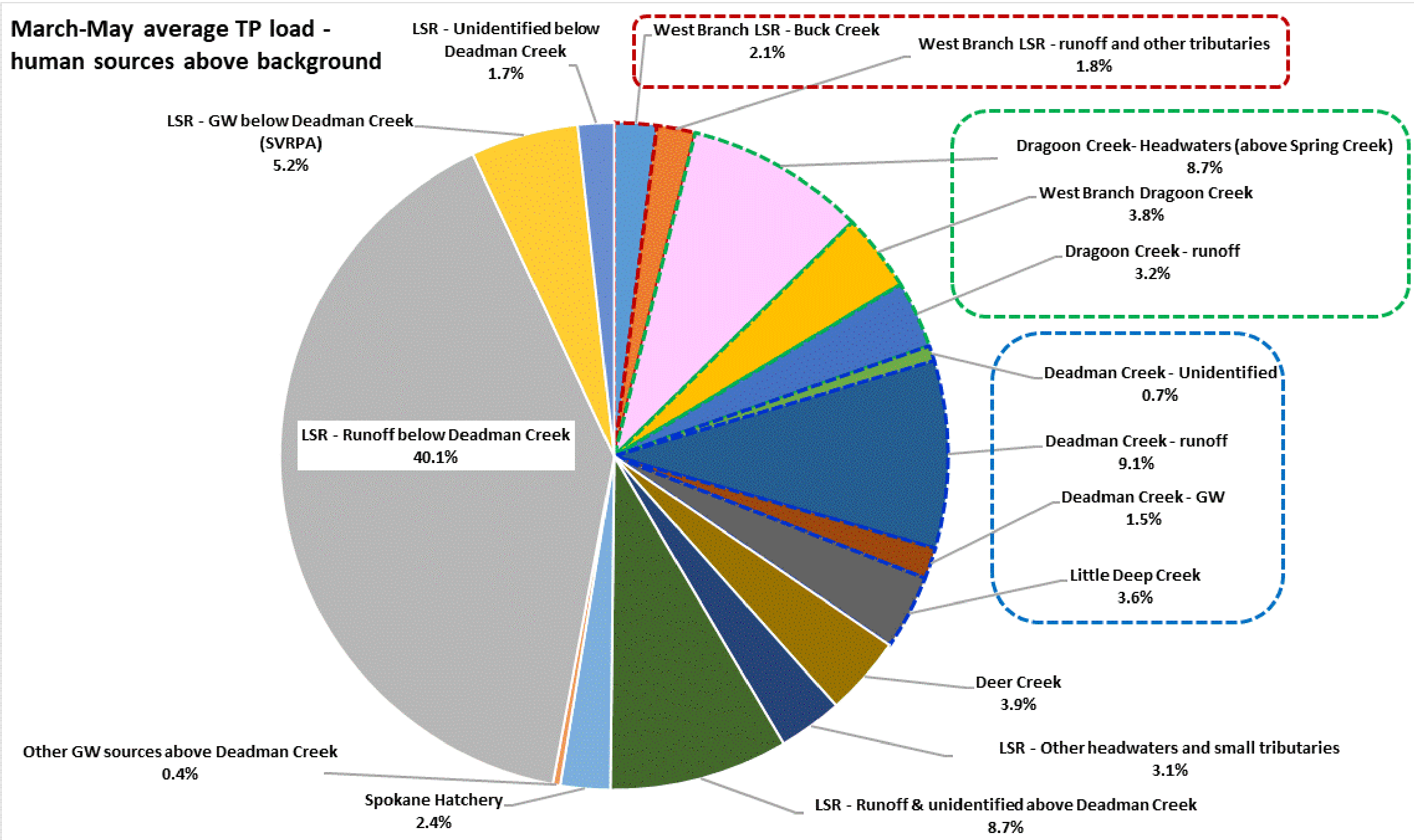


Figure 27. March-May average human total phosphorus loads above background

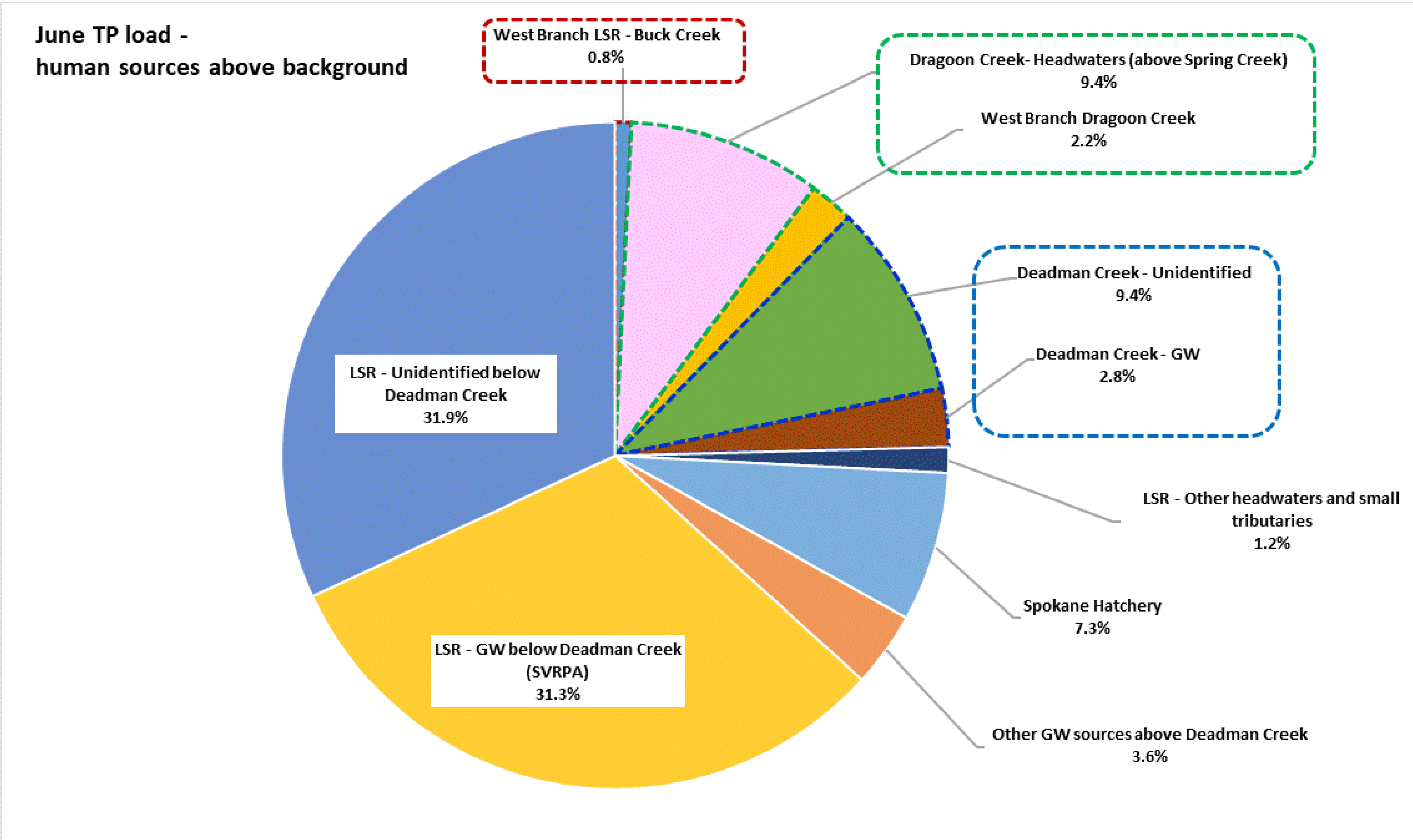


Figure 28. June human total phosphorus loads above background

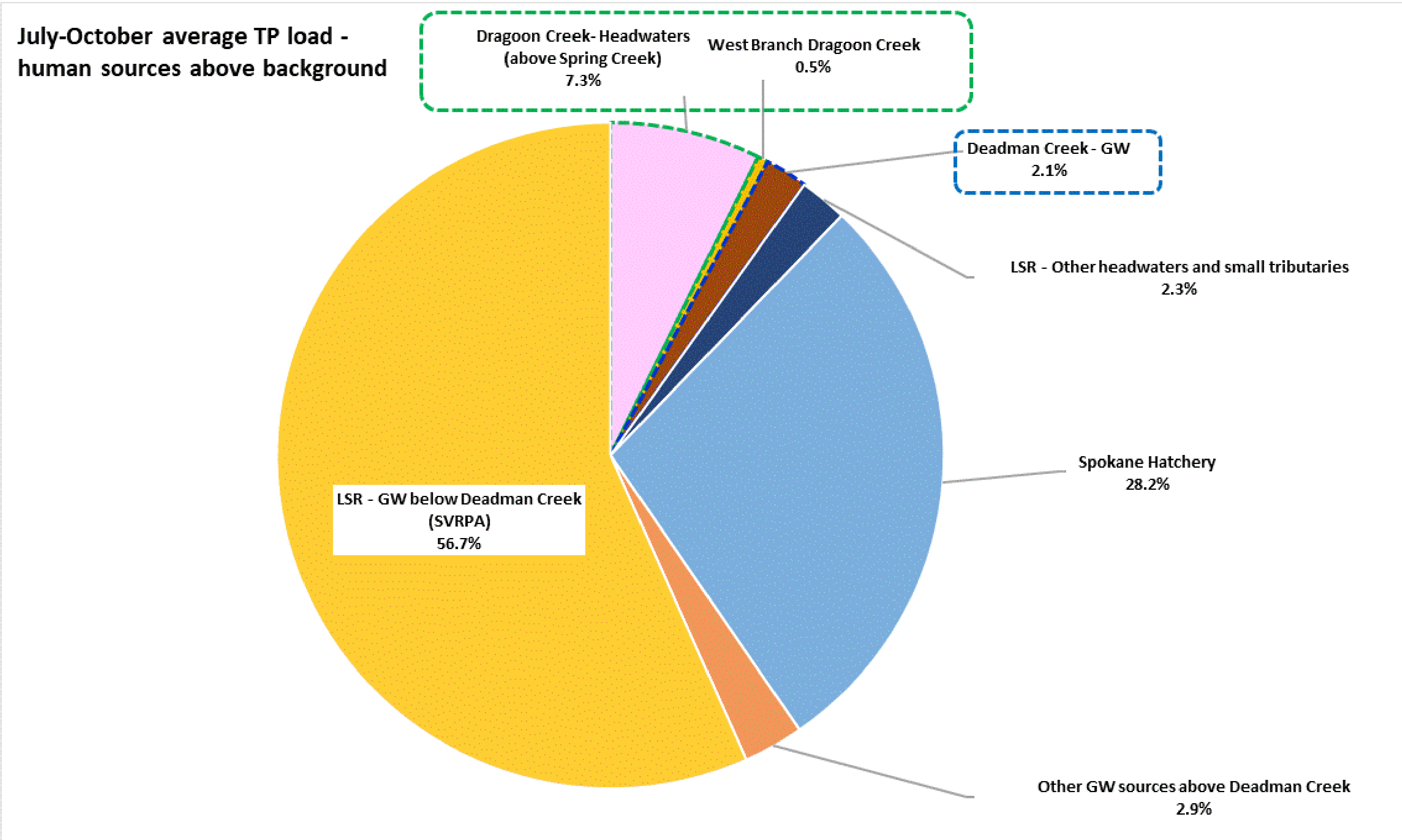


Figure 29. July-October average human total phosphorus loads above background

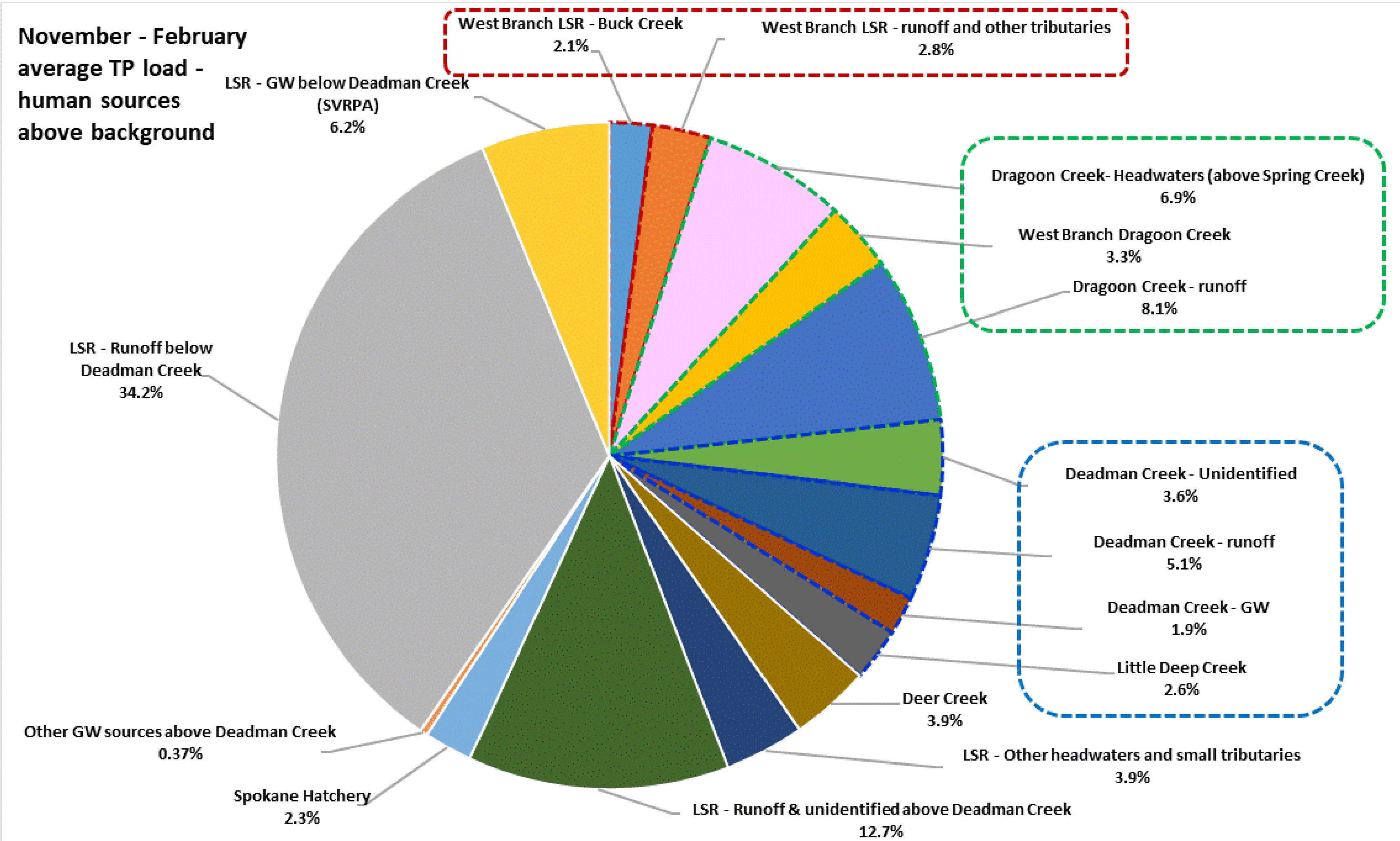


Figure 30. November-February average human total phosphorus loads above background

We discuss these results by TMDL season:

March – May

The load balance for this season shows that runoff sources are the principle human source in multiple reaches. Figure 27 also shows that tributaries and runoff account for the predominant human sources. The sources with the higher percentages of loading in the watershed:

- A relatively large source apparently exists in the headwaters of Dragoon Creek upstream of Spring Creek and Dahl Road near Deer Park.
- Runoff sources in this season are indicated by the flow and load balance in multiple reaches:
    - The mainstem LSR in Spokane metro area (below Deadman Creek, RM 13.5 to RM 1.1 – near the mouth). This is the largest loading source in the basin during this season.
    - The mainstem LSR above Deadman Creek, especially between Elk and Chattaroy (RM 37.1 – 23.4).
    - Deadman Creek through the Peone Prairie area and upstream.
    - Runoff in multiple reaches of Dragoon Creek.
- Small tributaries are also contributing load during the wet season, suggesting the sources are most likely surface runoff. Relatively large loads are coming from Little Deep, Buck, Deer, and Otter Creeks.
- Unidentified loads in Deadman Creek and in the LSR below RM 13.5 (below North Little Spokane Drive and Deadman Creek) represent a significant fraction of the human loading.

Groundwater sources are present, but they are a relatively small proportion of the basin's total TP human load.

June

June 2015 was relatively dry, as part of the extended dry season in 2015. The June survey occurred two weeks after an intense rain event that produced a large spike in sediment and TP on the day that the ambient monitoring sample was taken at the mouth of the Little Spokane River (June 2nd). TP loading was slightly higher than in the summer and early fall surveys, but still reflected mostly groundwater and tributary baseflows. Figure 28 shows the breakdown of human loading sources by basin, and the geographic pattern is similar to the July – October period:

- The unidentified source in the LSR below RM 13.5 is larger in June than in the spring, and represents about one-third of the human loading above background.
- Loading from the SVRP aquifer and Spokane Hatchery represent a larger proportion of the total human load in the basin.
- Loading from Dragoon Creek headwaters in June are lower in magnitude than in the spring, but are a larger proportion of the June total human load.
- Unidentified sources appear to be present along Deadman Creek in the eastern Peone Prairie area, and along the mainstem LSR between Buckeye to Dartford.

July – October

This was the peak dry season of a very dry year, and loading sources reflect those conditions. Figure 29 shows the human loading sources by basin, which were very low compared to the other seasons. Only a few sources appear to be elevating TP above background levels:

- Human TP contributions to the SVRP aquifer represents more than half of the possible human sources. Groundwater in lower Deadman Creek is also influenced by SVRP aquifer inflows.
- Loading from the Spokane Hatchery is also a relatively large fraction of the total human load under these conditions.
- The apparent source in the headwaters of Dragoon Creek represents less loading than earlier that year, but is still a large proportion of the total human load.
- The balance of estimated human loading is made of a possible unidentified load in the West Branch LSR, a small amount of loading from groundwater, and a tiny fraction from other tributaries.

November – February

Loading levels in this season show similar patterns to March through May, again mostly from runoff and tributary sources. The distribution of human sources is shown in Figure 30:

- Over one-third of human loading appears to be coming from runoff to the LSR below RM 13.5 (downstream of Deadman Creek).
- Other sources observed in the spring are present in this season as well, including runoff in the upper mainstem LSR and higher loads in several tributaries.

Loading source identification and prioritization

Sediment-Phosphorus relationships

Phosphorus can exist in several forms: organic vs inorganic, and dissolved vs particulate. Dissolved phosphorus generally is found as soluble reactive phosphorus (SRP) or soluble organic molecules that include phosphorus. Phosphorus can also be associated with particulate matter in an inorganic form (mineral P) or organic (bound in organic molecules). Phosphate and many kinds of other molecules with P can also bind readily to organic and mineral particles. Because of these characteristics, elevated phosphorus is often associated with elevated sediment levels. Strong sediment-phosphorus relationships can indicate soil and streambank erosion or overland flow of animal waste. We evaluated survey data for total suspended solids (TSS) and phosphorus to assess this relationship.

Figure 31 illustrates the relationship between total phosphorus and TSS from data collected during the 2015-16 surveys. Some correlation of higher TSS with higher TP is apparent. It is clear that TP can also reach relatively high levels when TSS is low. This suggests that while some sources of high TP in the LSR basin are linked to high sediment levels, there are also sources that produce high levels of TP despite low levels of sediment.

The specific nature of non-sediment linked TP is uncertain, but a few observations may be useful. Of the 6 highest TP measurements when TSS is below 15 mg/L:

- 3 were measured at Dragoon Creek at Dahl Rd (55DRA-17.0 – Dragoon Creek headwaters)
- 2 were measured at Deadman Ck @ Bruce Rd (55DEA-05.9 – Peone Prairie).

High TP associated with relatively low TSS could result from a source that is mostly dissolved or colloidal, such as manure or fertilizer. These values occurred in March, May, June, August and September – the lack of a consistent seasonal pattern suggests a direct source rather than contributions from stormwater. Sources from agriculture are a possibility, given the amount of agricultural lands in the basin. Also, there are wetlands in these areas, which on the one hand may experience anaerobic conditions and release TP, but may also hold TP in the growing season and then release it in the fall when vegetation dies back and higher flows begin to flush out sediments.

Looking only at TSS levels equal to or greater than 15 mg/L, the relationship is much stronger, as depicted in Figure 32. This suggests that events that produce higher TSS are likely to produce higher TP, although the relationship is driven by a few unusually high TSS values.

We identified several locations as being most prone to high TSS events. Deadman Creek below Market Street (stream mile 2.6) and at Shady Slope Road (stream mile 0.6) had the three highest TSS values, associated with the three highest TP values, all from the June 3, 2015 survey (just after the extreme weather event). These two sites also had three of the nine highest TSS values, one during the February 2015 survey and two during the March 2015 survey. If the site at Heglar Road (stream mile 9.2) in June 2015 is included, nine of the 20 highest TSS values occurred in Deadman Creek. In general, TSS values were much higher from Market Street downstream than they were at Bruce Road (stream mile 5.9), suggesting large TSS sources between these two stations.

Other sites with relatively high TSS levels and strong TSS-TP relationships include:

- Sheets Creek at Reflection Lake outlet (likely algae from the lake)
- Deer Creek above Little Deer Creek
- Deer Creek at Mouth
- Little Deep Creek at Shady Slope Rd

Given that these are all streams draining the east side of the basin, there might be some factor related to soils or geology affecting the TSS-TP relationship.

In evaluating TP sources for reducing loads, these areas may be strong candidates for runoff or erosion control to reduce nutrient loads associated with high TSS levels.

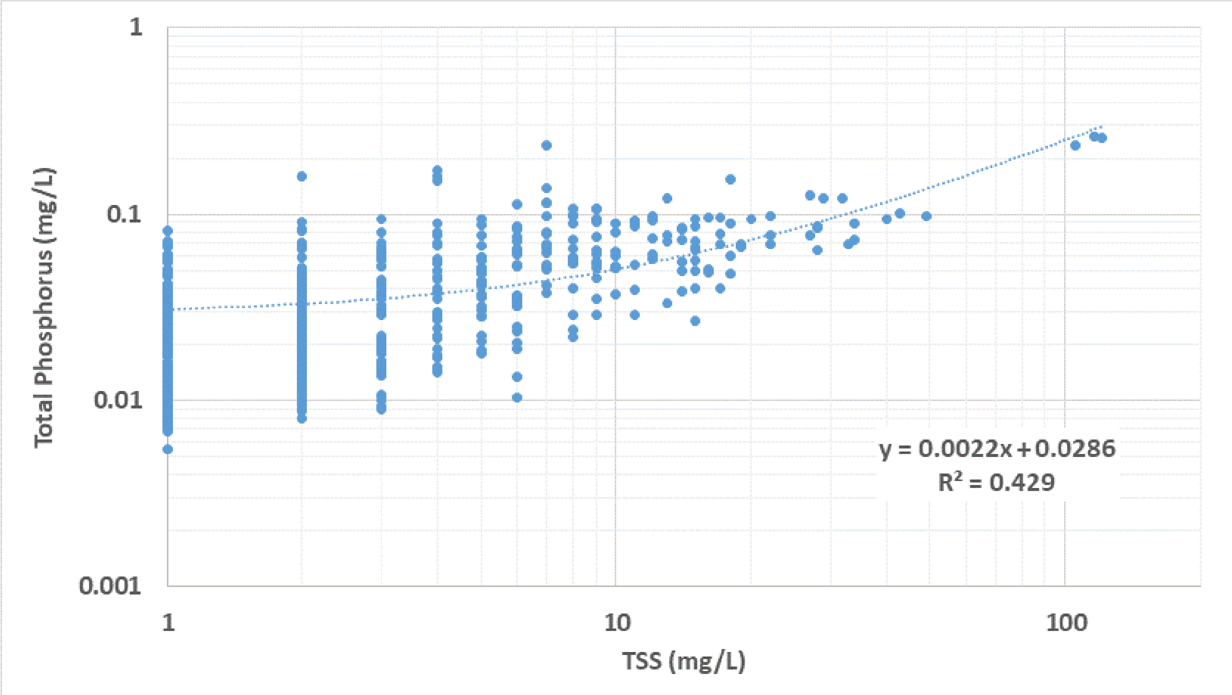


Figure 31. TSS-TP relationship – all 2015-2016 survey data

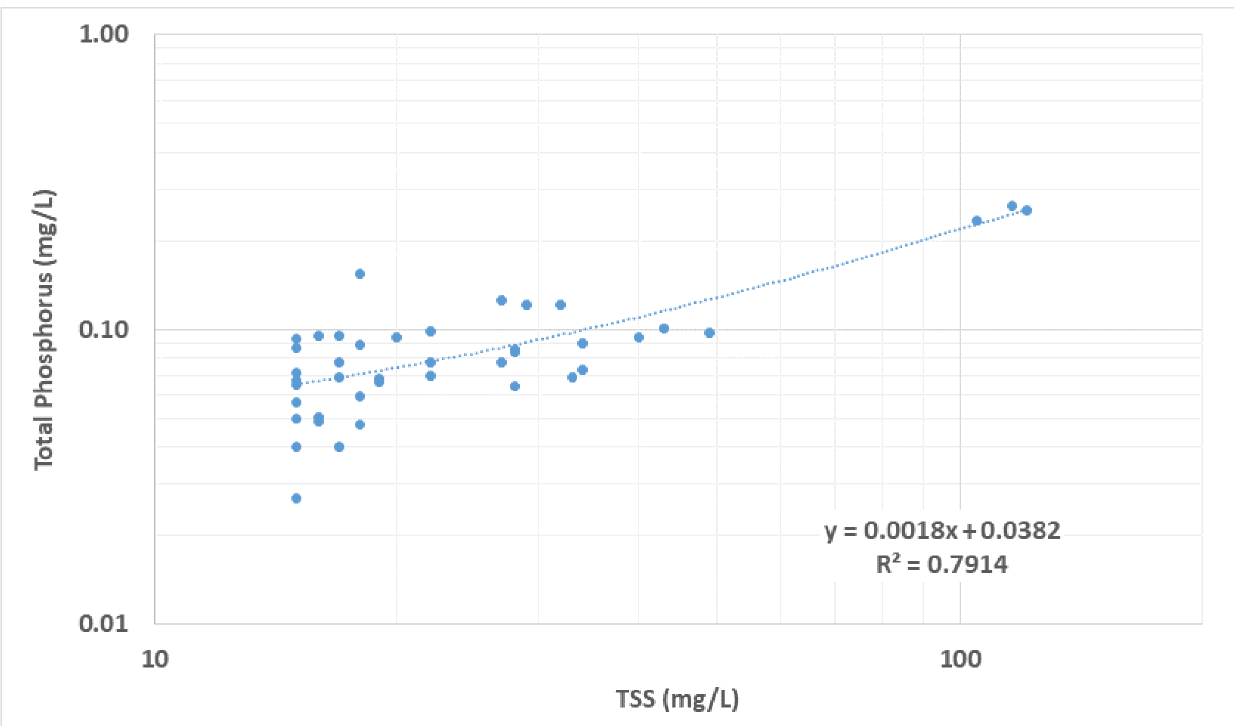


Figure 32. TSS-TP relationship based only on 2015-2016 survey data with TSS levels of 15 mg/L or greater

Spokane Hatchery

Several issues complicate the determination of the contribution of TP from the Spokane Hatchery. We discuss these in more detail in the **Data Quality** section, as well as in Appendix E.

- The number of measurements is limited compared to the complexities of the Hatchery facility and operations. Therefore, the representativeness of existing data is uncertain.
- Net loading in Griffith Slough (based on total loading measured in Griffith Slough minus source water loading at the same flows) is often higher than the net loading from the combined outfalls. Figure 33 illustrates this comparison for the 2014-15 surveys. Possible explanations for this discrepancy include:
  - Combined measured outfall loading may be an underestimate of the actual effluent loading, due to poor representativeness of sampling.
  - The constructed wetland could potentially be storing phosphorus in sediments and releasing additional loading to the water column. This may be occurring if the sediments are anoxic, allowing stored TP to be released in a soluble form. No data is available to analyze this hypothesis, so it would need to be evaluated with a special study.
  - Sources from the Little Spokane River might be influencing Griffith Slough. However, data from the 2014-15 surveys suggest this is unlikely: TP concentrations in the mainstem LSR were always the same or lower upstream of the slough as compared to downstream of the slough, and concentrations in Griffith slough were far higher than in the mainstem LSR.
  - Other unknown sources could be affecting Griffith Slough values.

  In general, more investigation is needed to better understand TP sources and transport from the Hatchery and in Griffith Slough.

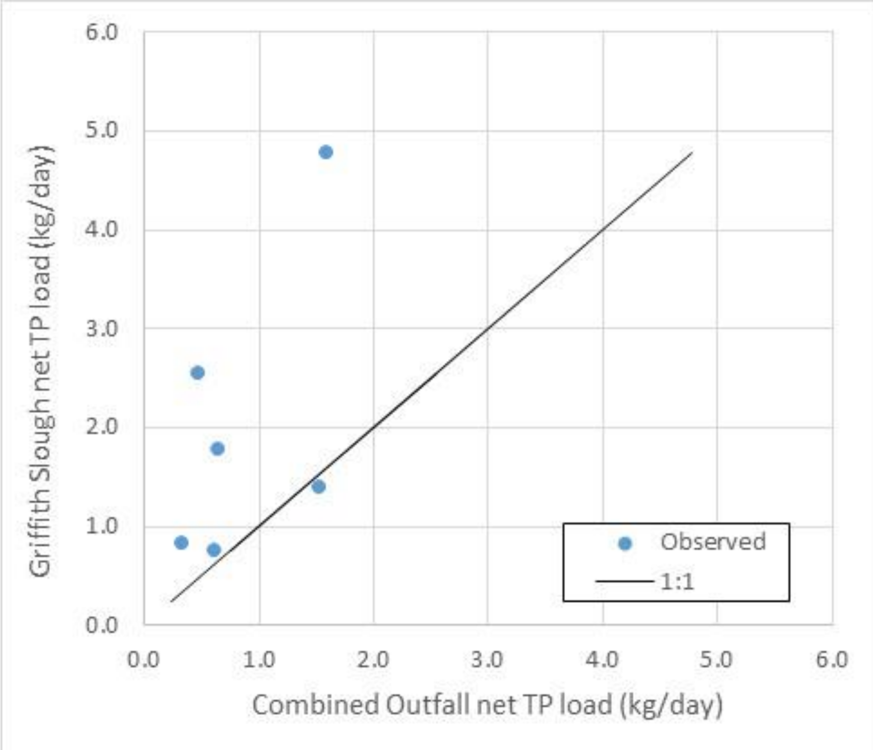


Figure 33. Spokane Hatchery net TP loads from 2014-15 Anchor QEA Analysis.

Possible unidentified loads

The analysis to separate background uncertainty from possible unidentified loads pointed to eight events in particular (Table 24).

Table 26. Possible unidentified TP loads

Location	River/ stream mile	Survey dates	Source load (kg/day)	Percent of seasonal average human load
LSR between Little Spokane Drive and the mouth	13.5 - 1.1	May 2015 June 2015	3.4 2.5	1.7% 32.9%
Deadman Creek from Holcomb Road to Bruce Road	13.8 - 5.9	May 2015 June 2015 January 2016	1.5 0.7 0.9	4.9% 76.9% 4.7%
Deadman Creek from Bruce Road to above Little Deep Creek	5.9 - 0.6	February 2015 February 2016	2.5 2.0	22.9%
LSR between Elk and Chattaroy	37.1 - 23.4	April 2015	2.7	1.4%

These loads occurred when they could not be attributed to surface runoff or groundwater. A number of possible explanations, singly or several combined, could account for these loads:

- A highly concentrated direct source that would not change the flow balance, such as manure or fertilizer

- A source associated with surface runoff, where runoff was occurring but missed by the flow balance analysis
- Spokane Hatchery loading, if it has been underestimated
- A source associated with natural phenomenon, such as release of nutrients from sediments or wetlands
- Numerical error due to lags in timing between stations during dynamic flow

It is not unusual to find unidentified pollutant sources in a TMDL study. These loads should be prioritized for further investigation to confirm if they are continuing and identify possible causes.

The unidentified loads in February are of less concern since they are outside any of the TMDL LA seasons and constitute a small percentage of possible human loading. The April event was a larger percentage of assessed human loading, but was the only event observed in this reach. The primary areas of concern are the May and June loading events which occurred in the Peone Prairie reach of Deadman Creek and in the LSR below Deadman Creek. A future study should focus on February through June.

Prioritization of watershed sources

Addressing uncertainty in the loading analysis

Appendix E discusses sources of uncertainty. In summary, uncertainty in this steady-state mass balance analysis results from:

- Variability in the monitoring and laboratory methods.
- Variability in the natural system which the analysis method captures poorly. This spatial and temporal variability relates to the timing and location of monitoring as compared to changing conditions across the basin over time.

In other words, basin hydrology may be dynamic and nonpoint source pollution may be intermittent and vary widely over time. Therefore, one sample per month for a year is a limited data set to represent conditions across the watershed over time.

A key challenge of the watershed loading analysis is that many of the watershed surveys occurred during a dry summer with extreme low flow conditions (the 3rd lowest summer 7-day low flow at Dartford in 42 years – 1975-2016). One assumption necessary to develop a TMDL based on this dataset is that the sources found during the surveys may be worse in a wetter year. On the other hand, surveys during the wet months (February 2015, and January, February and March 2016) represented conditions that were wetter than average. The relationship of the weather and hydrology during different years is a critical issue that we discuss in more detail below.

To make appropriate use of the information from the surveys, it is necessary to address these sources of uncertainty. In a qualitative sense, small loads and small differences in load may fall within the “noise” of this uncertainty. Therefore, it is most appropriate to consider the results of the load balance analysis at a “coarse” scale. The focus should be on patterns of loading that are large or consistent enough to indicate a significant source that can’t be explained by uncertainty.

Approaching the analysis this way to account for uncertainty, we identified several key areas for nutrient reduction to meet the TMDL allocation at the LSR mouth. Table 25 presents these areas, listed by priority and location. Criteria for prioritization are:

- Percent contribution to March-May human loading (when TMDL LA was not being met).
- Sources that contributed a relatively high magnitude of loading over multiple seasons.
- Sources that are relatively close to the mouth in terms of travel time.

We identified six categories of nonpoint sources as the top priorities for reductions in human TP loading. The Spokane Hatchery, a point source, is also a priority for load reduction. We discuss these categories in detail below.

Table 27. Priority total phosphorus loading source categories as a percentage of the total human load, by season

Priority	Priority source category	% of seasonal average load Jul-Oct	% of seasonal average load June	% of seasonal average load Mar-May	% of seasonal average load Nov-Feb
1	LSR below Deadman Creek: runoff & unidentified	0.0%	32.2%	41.8%	34.7%
2	Deadman Creek sources	2.1%	12.4%	11.3%	10.8%
3	Dragoon Creek headwaters (above RM 17.0)	7.5%	9.5%	8.7%	7.0%
4	LSR above Deadman Creek: Runoff & unidentified	0.0%	0.0%	8.7%	13.2%
5	Small tributaries – Otter, Deer, Little Deep Creeks	0.0%	0.0%	8.9%	7.9%
6	Dragoon Creek runoff & West Branch	0.5%	2.2%	7.2%	10.1%
	subtotal nonpoint	10.1%	56.3%	86.7%	83.7%
WLA	Spokane Hatchery	28.8%	7.3%	2.4%	2.4%
	Total	38.9%	63.6%	89.1%	86.1%

Nonpoint Sources

1. LSR below Deadman Creek (RM 13.5 to RM 1.1), surface runoff and unidentified sources of loading: These sources represented the highest percent contribution to the estimated human loading in these reaches during the March-May season and also during the November-February season.

   This area is a high priority for more investigation, such as detailed sampling and shoreline surveys, to identify possible sources of direct overland flow or unpermitted stormwater discharges. Potential sources to evaluate include:

   - Spokane County MS4: Spokane County's stormwater system may have outfalls that discharge to the Little Spokane River. NPDES permit compliance processes could be used to better quantify phosphorus loading from these outfalls.
   - Unpermitted stormwater discharges: riverside sources not covered by the MS4 permit may be contributing phosphorus loading from fertilizer use, erosion, or other processes.
   - Spokane Hatchery discharges: more representative sampling of loading releases over time.
   - Wetland sources in the natural area along the lower Little Spokane River. If this is the case, then some of the load could be natural rather than human.

2. Deadman Creek sources: Given the variety of human sources identified along Deadman Creek, this tributary should be the subject of follow-up investigation. In the March-May season, we identified human loading for runoff and groundwater in all three reaches, and unidentified sources in the reaches from Holcomb Road to Bruce Road (RM 13.8 – 5.9) and Bruce Road to the mouth. These sources combined represent 11% of human loading in the LSR basin in the March-May season, with most of it coming as runoff. We also found that possible human sources in Deadman Creek contribute 11% of loading in November-February, 12% of loading in June, and 2% in July-October.

   The Holcomb Road to Bruce Road reach was the source of the largest proportion of the human loading in Deadman Creek in March-May and in June. We found high TP concentrations with low TSS at the downstream end of this reach, suggesting a concentrated source associated with a direct discharge rather than erosion. However, lower Deadman Creek experienced four of the five highest TP concentrations associated with elevated TSS – at Market Street (stream mile 2.6) and Shady Slope Road (stream mile 0.6). This suggests that erosional sources are also present in this basin, such as from streambank erosion or devegetated soils.

   Figure 34 shows patterns in TP in Deadman Creek. During three of the regular surveys and during a special survey on June 3, 2015, we monitored two additional stations along Deadman Creek. Concentrations and loads can be seen to climb between Holcomb and Heglar Roads. In two surveys concentrations and loads continued to climb between Heglar and Bruce Roads. Loads increased further downstream to the site below Market Street, then leveled out from there to the mouth. June 3rd is particularly notable, since the survey occurred within two days of an intense rain event, and showed both high TP and TSS.

3. Dragoon Creek headwaters (upstream of Dahl Road, RM 17.0): Human sources that contribute to Dragoon Creek headwaters represent an estimated 7% to over 9% of the watershed human load during every TMDL season. Loading is present in the dry season, but increases in the wet season. This suggests some combination of direct discharge in the summer (such as animal access) and transport by runoff. This also was a site with high phosphorus concentration but low TSS, suggesting a concentrated source rather than erosion. Additional investigation is needed to identify the sources of TP in the sub-basin above this monitoring station.

4. Runoff and unidentified loads to the mainstem LSR above Deadman Creek: About 9% of the human load originates in this reach in the spring season, and represented almost 13% of human load in the winter season. Elevated TSS is associated with some of the runoff events, with levels between 15 and 20 mg/L. However, this is also a reach with higher uncertainty due to the many major tributaries that contribute to flows. Additional investigation during wet weather could help to better understand possible sources in this reach.

5. Small tributary sources: The following tributary creeks each contributed between 1.5% and 4% of estimated human loads in March-May: Otter, Deer, and Little Deep Creeks. Combined, these tributaries represent 11% of possible human loading in the spring and 10% in the winter. Deer Creek and Little Deep Creek were sites where high TP was associated with high TSS levels in the spring and winter seasons, and no contribution in June or the July-October season, which suggests erosion-related sources.

6. Dragoon Creek runoff and West Branch Dragoon Creek: Runoff in the West Branch Dragoon Creek and in the Dragoon Creek watershed from Dahl Road (RM 17.0) to North Rd. (RM 4.3) contributed 7% of human loading in the March-May season and over 11% of the human loading in the November-February season.

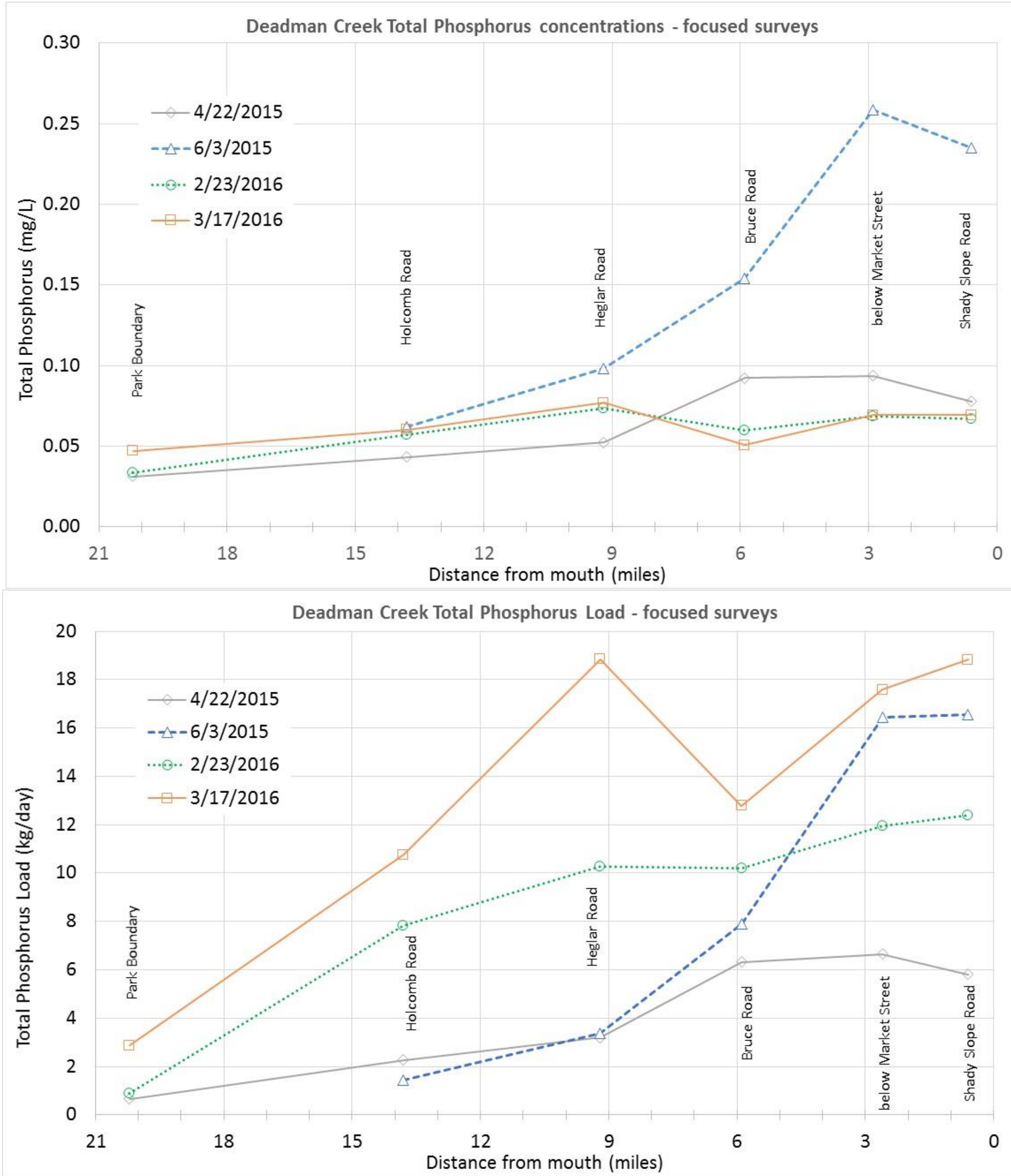


Figure 34. Deadman Creek focused surveys – total phosphorus concentration and load

Point sources

Spokane Hatchery: The fish hatchery is a relatively constant source of TP loading to the lower river. It's a small fraction of watershed human loading in the wet season (a little over 2%) but larger in June (over 7%) and a major source in summer (almost 30%). Although the hatchery did not contribute to an exceedance of the July-October LA in 2015, there have been many years when the summer LA was not met. Therefore, loading reductions are needed. EPA has held NPDES point sources to a higher standard of compliance through its "reasonable assurance" policy. In addition, proposed upgrades to the hatchery represent an opportunity to improve treatment for TP reduction.

Seasonal variation

The watershed loading analysis addresses year-round loading that is averaged by seasons defined in the *Spokane River and Lake Spokane DO TMDL*. These seasons are also sensible for the Little Spokane River watershed. High flows in the Little Spokane River typically occur during April; therefore the March-May season captures the high-flow period well. June represents the early summer transitional period of declining flows. July-October represents the low-flow period. The November-February wintertime period is not part of the Spokane TMDL and does not have load allocations associated with it, but we present data from this season for informational purposes.

Loading capacity for phosphorus from LSR watershed

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA's current regulation defines loading capacity as "the greatest amount of loading that a water body can receive without violating water quality standards" (40 CFR § 130.2(f)).

Because DO and pH in the Little Spokane River and its tributaries are not sensitive to phosphorus (see **Instream DO and pH TMDL Analysis** section), the loading capacity for phosphorus from the Little Spokane watershed is simply the load allocation for the mouth of the Little Spokane River, specified in the *Spokane River and Lake Spokane DO TMDL* (Moore and Ross, 2010).

This section details the loading breakdown for total phosphorus throughout the watershed that will meet the loading capacity at the mouth. The loading capacity for nutrients to meet water quality standards for DO and pH in streams within the Little Spokane watershed will be presented in the **Instream DO and pH TMDL Analysis** section.

Target Reductions

We prioritize loading sources in the watershed into six nonpoint categories plus the Spokane Hatchery. Table 25 lists these sources (discussed above) with the proportion of total loadings from human sources (both nonpoint and point sources) throughout the basin for each season based on the 2015-16 surveys.

To evaluate the effect of reducing human loads, we applied percent load reductions iteratively until the LA targets at the mouth were met, with a small amount of capacity to spare for stormwater WLAs and a margin of safety. We applied the same percent reductions for all surveys, for each reach and source.

To calculate loading that meets the load capacity at the mouth of the Little Spokane River, we set target reductions in human loading for these six prioritized nonpoint sources and for the Spokane Hatchery. We selected targets by category through an iterative process and evaluated reductions with the TP mass balance to ensure the LA loads were met at the mouth. We applied reductions were applied by category with a single value for all seasons.

Based on this approach we simulated the following reductions:

- All unidentified loads and priority 1 human loads reduced by 90%
- All other human nonpoint loads (other than unidentified) reduced by 80%
- Spokane Hatchery reduced by ~50%

The limiting season for meeting the loading capacity was March-May. Table 26 summarizes the load reductions applied to priority sources.

To evaluate the overall reduction in load at the LSR mouth from observed conditions, we applied the target load reductions shown in Table 26 to estimated human loading, and then added the reduced human loads to the natural load. This resulted in an "LA load balance" for the 2015-16 surveys. Comparing the LA load balance to the observed load balance, overall load reductions at the LSR mouth would be:

- March-May: 45%
- June: 27%
- July-October: 19%

Table 28. Human total phosphorus loads: reduction priorities by season and target percent load reductions.

Source	Mar-May [a] priorities	June priorities	Jul-Oct priorities	Target % human load reduction
LSR 13.5-1.1 runoff	1			**90%**
LSR 13.5-1.1 unknown	1	1		**90%**
Deadman Creek 20.2 (headwaters)	2			80%
Deadman Creek 20.2-13.8 runoff	2			80%
Deadman Creek 20.2-13.8 GW	2	2	2	80%
Deadman Creek 13.8-5.9 runoff	2			80%
Deadman Creek 13.8-5.9 GW	2	2	2	80%
Deadman Creek 13.8-5.9 unknown	2	2		**90%**
Deadman Creek 5.9-0.6 runoff	2			80%
Deadman Creek 5.9-0.6 GW	2	2	2	80%
Deadman Creek 5.9-0.6 unknown	2			**90%**
Dragoon Creek 17.0 (headwaters)	3	3	3	80%
LSR 39.5-37.1 runoff	4			80%
LSR 37.1-23.4 runoff	4			80%
LSR 37.1-23.4 unknown	4			80%
LSR 23.4-13.5 runoff	4			80%
Otter Creek	5			80%
Deer Creek	5			80%
Little Deep Creek	5			80%
Dragoon Creek 17.0-16.4 runoff	6			80%
Dragoon Creek 16.4-13.2 runoff	6			80%
West Branch Dragoon Creek	6	6	6	80%
Dragoon Creek 13.2-4.3 runoff	6			80%
Dragoon Creek 4.3-0.3 runoff	6			80%
Spokane Hatchery NPDES	WLA [b]	WLA	WLA	~50% [c]

[a] Also listed if identified for November-January

[b] Will be addressed through a wasteload allocation implemented in an NPDES permit

[c] Approximate net reduction based on WLA

For the 2015-16 survey conditions, the March-May load allocation would just be met (the seasonal load would be 99% of the LA). The loads for June and July-October would be 43% and 50% of the seasonal load allocations, respectively.

We did not include reductions in groundwater loading (other than for the Deadman Creek basin) for several reasons. For the SVRP aquifer:

- The groundwater in this aquifer is regional (originating in Idaho).
- Loads from this aquifer entering the LSR below Dartford are relatively large, but mainly as a result of the high flows combined with low concentrations.

- Changes in aquifer TP levels are most likely the distributed effect of many sources across the region.
- Identification and reduction of phosphorus loading to the SVRP aquifer would be very resource intensive for the small benefit it would provide to the lower LSR.
- However, it should be noted that implementation of the *Spokane River and Lake Spokane DO TMDL* is likely to continue to address reducing phosphorus in the SVRP aquifer.

Outside of the SVRP aquifer and Deadman Creek, we only identified two other human sources to groundwater affecting the river. They appear to be quite small – less than 1% of March-May seasonal loading. The Load Allocation at the mouth of the LSR can be met without reductions in these sources.

Loading capacity breakdown for 2015-16

As described above, we developed an LA load balance based on applying loading reduction targets to the 2015-16 observed load balance. Using this LA load balance, we determined a loading capacity breakdown for 2015-16 conditions at the mouths of major tributaries and for key monitoring locations in the mainstem Little Spokane River. Tables 27-30 summarize the loading capacity breakdown for 2015-16 conditions.

Table 29. Loading capacity breakdown by reach and tributary for 2015-16 conditions, for the Little Spokane River.

Compliance station	2015-2016 TP Loading Capacities (kg/day)								
	March-May			June			July-October		
	NB [a]	Human [b]	Total	NB	Human	Total	NB	Human	Total
LSR RM 46.7 (Scotia)	1.43	0.00	1.43	0.77	0.00	0.77	0.46	0.00	0.46
LSR RM 37.1 (Elk)	2.06	0.09	2.16	1.42	0.05	1.47	0.63	0.00	0.63
Dry/Sheets	1.17	0.25	1.42	0.23	0.00	0.23	0.16	0.00	0.16
Otter	0.32	0.32	0.64	0.31	0.01	0.32	0.51	0.00	0.51
WBLSR	3.20	1.13	4.33	0.31	0.16	0.47	0.04	0.09	0.13
Bear	0.43	0.03	0.46	0.07	0.005	0.08	0.04	0.00	0.04
LSR RM 23.4 (Chattaroy)	8.49	2.35	10.84	2.54	0.19	2.74	1.20	0.06	1.26
Deer	3.35	0.38	3.73	0.23	0.00	0.23	0.01	0.00	0.01
Dragoon	5.46	1.62	7.08	0.81	0.11	0.92	0.52	0.00	0.52
LSR RM 13.5 (LSR Dr.)	18.81	4.75	23.56	3.88	0.35	4.23	2.26	0.02	2.28
Little Deep	1.93	0.35	2.29	0.07	0.00	0.07	0.06	0.00	0.06
Deadman	4.55	1.09	5.64	0.26	0.08	0.34	0.26	0.00	0.26
Dartford	0.34	0.23	0.57	0.29	0.00	0.29	0.18	0.00	0.18
LSR RM 1.1 (Hwy 291)	34.46	11.54	46.00	7.17	3.63	10.79	5.30	1.91	7.22
LA at mouth			46.49			24.45			14.61

[a] NB = Natural background

[b] Human loads in this table that are downstream of Colbert Landfill and Spokane Hatchery account for those point source loads, in accordance with the WLAs established in this TMDL.

Table 30. Loading capacity breakdown by reach and tributary for 2015-16 conditions, for the West Branch Little Spokane River.

Compliance station	2015-2016 TP Loading Capacities (kg/day)								
	March-May			June			July-October		
	NB[1]	Human	Total	NB	Human	Total	NB	Human	Total
Moon Ck	0.14	0.00	0.14	0.04	0.00	0.04	0.02	0.00	0.02
WBLS RM 17.7 (Harworth Rd.)	1.04	0.16	1.20	0.15	0.00	0.15	0.08	0.00	0.08
Buck Creek	1.92	0.20	2.13	0.27	0.01	0.28	0.04	0.00	0.04
WBLS RM 11.1 (blw Horseshoe Lk.)	3.20	0.36	3.56	0.46	0.03	0.49	0.07	0.00	0.07
Beaver Creek	0.78	0.33	1.12	0.02	0.00	0.02	0.01	0.00	0.01
WBLS RM 7.7 (Fan Lk. Rd.)	3.02	0.83	3.85	0.60	0.24	0.84	0.14	0.07	0.22
WBLS RM 3.1 (Eloika Lk. Rd.)	3.20	1.13	4.33	0.31	0.16	0.47	0.04	0.09	0.13

Table 31. Loading capacity breakdown by reach and tributary for 2015-16 conditions, for Dragoon Creek.

Compliance station	2015-2016 TP Loading Capacities (kg/day)								
	March-May			June			July-October		
	NB[1]	Human	Total	NB	Human	Total	NB	Human	Total
Dragoon RM 17.0 (Dahl Rd.)	1.96	0.86	2.82	0.17	0.15	0.32	0.06	0.06	0.12
Spring Creek	0.37	0.09	0.46	0.10	0.00	0.10	0.06	0.00	0.06
Dragoon RM 16.5 (Hwy 395 nr Deer Park)	2.43	1.00	3.43	0.10	0.15	0.25	0.09	0.00	0.09
Dragoon RM 13.2 (Abv WB Dragoon)	2.74	1.08	3.82	0.33	0.14	0.46	0.15	0.00	0.15
WB Dragoon Creek	1.98	0.37	2.35	0.36	0.03	0.40	0.32	0.00	0.33
Dragoon RM 4.3 (North Rd)	4.97	1.45	6.42	0.91	0.12	1.03	0.49	0.00	0.49
Dragoon RM 0.3 (Mouth)	5.46	1.62	7.08	0.81	0.11	0.92	0.52	0.00	0.52

Table 32. Loading capacity breakdown by reach and tributary for 2015-16 conditions, for Deadman Creek.

Compliance station	2015-2016 TP Loading Capacities (kg/day)								
	March-May			June			July-October		
	NB[1]	Human	Total	NB	Human	Total	NB	Human	Total
Deadman RM 20.2 (headwaters)	1.09	0.02	1.11	0.26	0.00	0.26	0.09	0.00	0.09
Deadman RM 13.8 (Holcomb Rd.)	3.36	0.33	3.69	0.35	0.02	0.37	0.13	0.00	0.13
Deadman RM 5.9 (Bruce Rd.)	4.41	0.80	5.21	0.44	0.10	0.54	0.17	0.00	0.17
Deadman RM 0.6 (Shady Slope Rd.)	4.55	1.09	5.64	0.26	0.08	0.34	0.26	0.00	0.26

Loading capacity breakdown for all years

Hydrologic conditions in April through October 2015 were unusually dry. Therefore determining the overall basin-wide loading capacities using the 2015-16 load balance needs to take into account the potential range of future hydrologic and climatic conditions.

We propose loading targets throughout the watershed for the three TMDL seasons to meet the LA at the LSR mouth, based on the target reductions. Tables 31-34 summarize these loading values. We developed these tables were developed by scaling up the target loads from 2015-16 conditions (Tables 27-30) to levels that just meet the LSR LA at the mouth.

These loading capacity targets focus on the mouths of tributaries and at compliance points on the mainstem LSR. They apportion loading to major areas of the basin based on the observed values and anticipated load reductions. These targets are provided to support an adaptive approach to implementation and effectiveness monitoring.

Table 33. Total phosphorus loading capacity breakdown for Little Spokane River.

Compliance station	TP Loading Capacities (kg/day) – scaled up for all years								
	Mar-May			June			Jul-Oct		
	NB[a]	Human[b]	Total	NB	Human	Total	NB	Human	Total
LSR 46.7 (Scotia)	1.43	0.00	1.43	1.68	0.00	1.68	0.86	0.00	0.86
55LSR-37.1 (Elk)	2.06	0.09	2.16	3.12	0.11	3.23	1.21	0.00	1.21
Dry/Sheets	1.17	0.25	1.42	0.51	0.00	0.51	0.31	0.00	0.31
Otter	0.32	0.32	0.64	0.69	0.01	0.70	0.97	0.00	0.97
WBLSR	3.20	1.13	4.33	0.69	0.35	1.03	0.08	0.17	0.25
Bear	0.43	0.03	0.46	0.16	0.01	0.17	0.08	0.00	0.08
55LSR-23.4 (Chattaroy)	8.49	2.35	10.84	5.60	0.43	6.03	2.27	0.12	2.39
Deer	3.35	0.38	3.73	0.50	0.00	0.50	0.01	0.00	0.01
Dragoon	5.46	1.62	7.08	1.78	0.25	2.03	1.00	0.00	1.00
55LSR-13.5 (LSR Dr.)	18.81	4.75	23.56	8.54	0.76	9.30	4.29	0.04	4.33
Little Deep	1.93	0.35	2.29	0.16	0.00	0.16	0.12	0.00	0.12
Deadman	4.55	1.09	5.64	0.58	0.17	0.75	0.50	0.00	0.50
Dartford	0.34	0.23	0.57	0.63	0.00	0.63	0.35	0.00	0.35
55LSR-01.1 (Hwy 291)	34.46	11.54	46.00	15.77	7.98	23.75	10.08	3.64	13.71
Additional capacity[b]			0.49			0.70			0.90
LA at mouth			46.49			24.45			14.61

[a] NB = Natural Background

[b] Human loads in this table that are downstream of Colbert Landfill and Spokane Hatchery already account for those point source loads, in accordance with the WLAs established in this TMDL. The additional capacity shown here is available for other point sources, such as stormwater.

Table 34. Total phosphorus loading capacity breakdown for the West Branch Little Spokane River.

Compliance station	TP Loading Capacities (kg/day) – scaled up for all years								
	March-May			June			July-October		
	NB[1]	Human	Total	NB	Human	Total	NB	Human	Total
Moon Ck	0.14	0.00	0.14	0.09	0.00	0.09	0.04	0.00	0.04
WBLS RM 17.7 (Harworth Rd.)	1.04	0.16	1.20	0.32	0.01	0.32	0.15	0.00	0.15
Buck Creek	1.92	0.20	2.13	0.60	0.03	0.62	0.07	0.00	0.07
WBLS RM 11.1 (blw Horseshoe Lk.)	3.20	0.36	3.56	1.01	0.08	1.08	0.14	0.00	0.14
Beaver Creek	0.78	0.33	1.12	0.05	0.00	0.05	0.01	0.00	0.01
WBLS RM 7.7 (Fan Lk. Rd.)	3.02	0.83	3.85	1.31	0.53	1.84	0.27	0.14	0.41
WBLS RM 3.1 (Eloika Lk. Rd.)	3.20	1.13	4.33	0.69	0.35	1.03	0.08	0.17	0.25

Table 35. Total phosphorus loading capacity breakdown for Dragoon Creek.

Compliance station	TP Loading Capacities (kg/day) – scaled up for all years								
	March-May			June			July-October		
	NB[1]	Human	Total	NB	Human	Total	NB	Human	Total
Dragoon RM 17.0 (Dahl Rd.)	1.96	0.86	2.82	0.37	0.32	0.69	0.12	0.11	0.23
Spring Creek	0.37	0.09	0.46	0.21	0.00	0.21	0.11	0.00	0.11
Dragoon RM 16.5 (Hwy 395 nr Deer Park)	2.43	1.00	3.43	0.23	0.32	0.55	0.16	0.00	0.16
Dragoon RM 13.2 (Abv WB Dragoon)	2.74	1.08	3.82	0.72	0.30	1.02	0.28	0.00	0.28
WB Dragoon Creek	1.98	0.37	2.35	0.80	0.07	0.87	0.61	0.01	0.62
Dragoon RM 4.3 (North Rd)	4.97	1.45	6.42	1.99	0.27	2.27	0.92	0.00	0.92
Dragoon RM 0.3 (Mouth)	5.46	1.62	7.08	1.78	0.25	2.03	1.00	0.00	1.00

Table 36. Total phosphorus loading capacity breakdown for Deadman Creek.

Compliance station	TP Loading Capacities (kg/day) – scaled up for all years								
	March-May			June			July-October		
	NB[1]	Human	Total	NB	Human	Total	NB	Human	Total
Deadman RM 20.2 (headwaters)	1.09	0.02	1.11	0.58	0.00	0.58	0.17	0.00	0.17
Deadman RM 13.8 (Holcomb Rd.)	3.36	0.33	3.69	0.78	0.04	0.81	0.24	0.01	0.25
Deadman RM 5.9 (Bruce Rd.)	4.41	0.80	5.21	0.97	0.21	1.19	0.32	0.00	0.32
Deadman RM 0.6 (Shady Slope Rd.)	4.55	1.09	5.64	0.58	0.17	0.75	0.50	0.00	0.50

Compliance with Load Allocations from Spokane TMDL

The loading capacity breakdowns shown in Tables 31-34, and the load and wasteload allocations in this TMDL, comply with the TP load allocation at the mouth of the Little Spokane River. We explored the potential achievability of meeting these allocations under the variety of hydrologic conditions found during different years.

The load allocations set for the mouth of the Little Spokane River in the *Spokane River and Lake Spokane TMDL* (Moore and Ross, 2010) were established for a critical low-flow condition, represented by the year 2001. Weather patterns that drive yearly hydrologic conditions tend to occur broadly, and affect various river systems similarly throughout the region. Thus, a high-flow year for the Spokane River is also usually a high-flow year for the Little Spokane River; likewise a drought year.

As shown in Figure 35, TP concentrations at the mouth of the Little Spokane River (as with many rivers) are strongly correlated to flow, with higher concentrations occurring at higher flows. Because load is the product of flow times concentration, and because concentrations increase with flow, loads tend to increase exponentially with flow. This means that for load allocations set based on a critical low flow year, meeting these allocation values in terms of load during a high flow year becomes a mathematical impossibility.

For this reason, we are evaluating compliance with the TP load allocations for the mouth of the Little Spokane River in terms of concentration, rather than load. This approach is protective of downstream water quality in Lake Spokane for two reasons:

- Because concentrations increase with flow, meeting concentration targets during higher-flow years will still require reductions above and beyond those needed to meet the target during low-flow years.
- The water quality impacts resulting from phosphorus inputs to Lake Spokane, which involve algae growth and decay, relate more directly to phosphorus concentration, not load.

We evaluated the achievability of meeting the load allocation concentrations, first by regressing TP data collected by Ecology's ambient monitoring program at the mouth of the Little Spokane River (Location ID 55B070) from 2004-2019, with flow data from the USGS gaging station "Little Spokane River near Dartford," located at Painted Rocks (RM 3.9). Figure 35 presents this relationship, along with a statistical evaluation of the quality of the regression. We then used this regression, along with USGS gage flow data, to estimate TP concentration for each day during 2004-2019 (Figure 36).

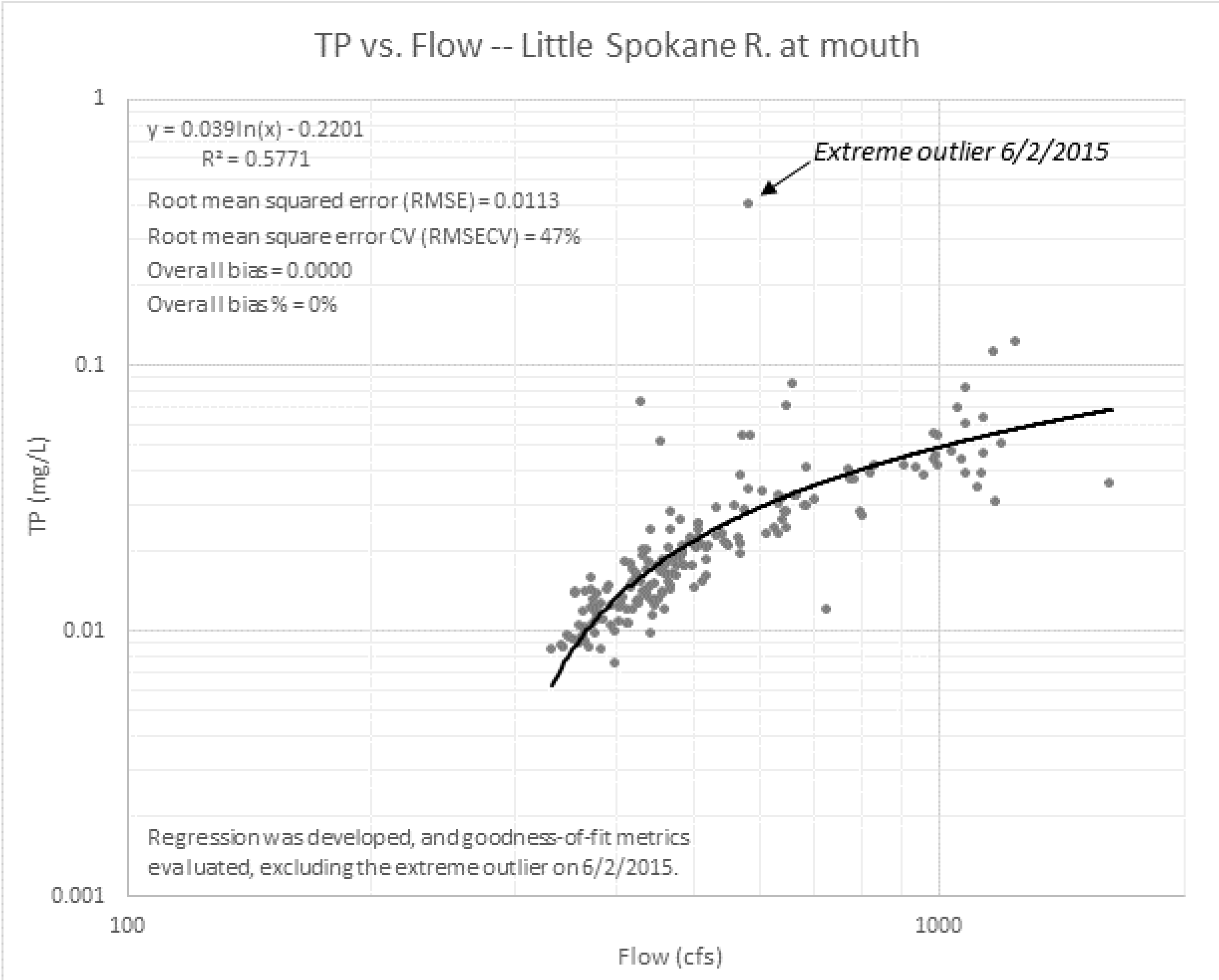


Figure 35. Relationship between flow and total phosphorus (TP) at the mouth of the Little Spokane River, 2004-2019.

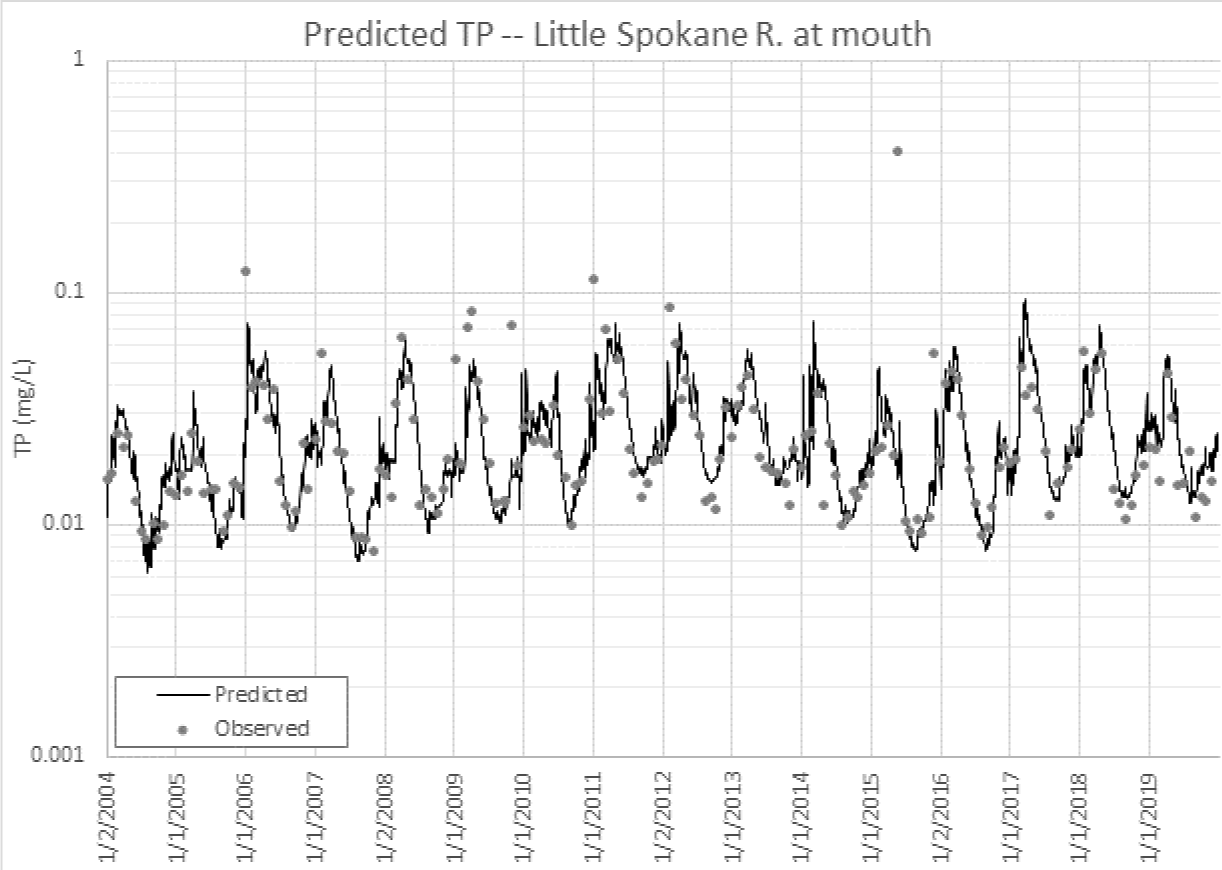


Figure 36. Predicted and observed TP at the mouth of the Little Spokane River, 2004-2019.

We evaluated the number of days that the TP concentration at the mouth of the Little Spokane River was in compliance with the load allocation for each Spokane TMDL season, based on the estimated concentrations shown in Figure 36. Then, to account for the TP reductions prescribed in this Little Spokane TMDL, we reduced these estimated concentrations by the percent total reduction indicated in Table 8 for each TMDL season for Little Spokane River at the mouth (55LSR-01.1). That is, 45% for March-May, 27% for June, and 19% for July-October. We evaluated the number of days in compliance again with the reduced values.

Table 35 presents the results of this analysis. Overall, we expect that the reductions specified in this TMDL will increase compliance with the load allocations at the mouth of the Little Spokane River from about 60% of the time under current conditions, to over 90% of the time with this TMDL fully implemented. In many medium to high flow years, the difference is stark: for example, for July-October 2011 these reductions would have raised compliance from 0% to 70% of days; for June 2018 the increase would have been from 17% to 100% of days.

Table 37. Compliance with Load Allocations for the Little Spokane River mouth, under current conditions and with reductions specified in this TMDL.

	Current Mar-May	Current Jun	Current Jul-Oct	Reduced by 45% Mar-May	Reduced by 27% Jun	Reduced by 19% Jul-Oct
# of days in season	92	30	123	92	30	123
LA conc.	0.034 mg/L	0.023 mg/L	0.016 mg/L	0.034 mg/L	0.023 mg/L	0.016 mg/L
Year	% of days in compliance					
2004	100%	100%	98%	100%	100%	100%
2005	97%	100%	100%	100%	100%	100%
2006	24%	13%	89%	100%	87%	98%
2007	60%	100%	100%	100%	100%	100%
2008	12%	17%	92%	99%	53%	98%
2009	35%	100%	94%	100%	100%	100%
2010	99%	0%	77%	100%	13%	88%
2011	7%	0%	0%	85%	0%	70%
2012	17%	0%	33%	91%	17%	73%
2013	25%	10%	23%	100%	90%	87%
2014	27%	100%	94%	98%	100%	100%
2015	97%	93%	100%	100%	100%	100%
2016	47%	100%	85%	100%	100%	96%
2017	0%	0%	67%	72%	80%	90%
2018	14%	17%	76%	92%	100%	91%
2019	50%	70%	62%	100%	100%	98%
Average %	**44%**	**51%**	**74%**	**96%**	**78%**	**93%**
	Total % of days in compliance for entire 2004-2019 period, all TMDL seasons:					
Total %	**Current (all seasons): 60%**			**Reduced (all seasons): 92%**		

Instream DO and pH TMDL analysis

Overview

We conducted an instream DO and pH analysis to determine the nutrient reductions and other riparian improvements needed to meet water quality standards in the Little Spokane River and its tributaries. This assessment primarily addresses flowing streams, the main focus of this TMDL project. However, because of the important role that lakes play in the Little Spokane watershed, we also undertook a limited assessment of major lakes.

We used numerical water quality models to evaluate the sensitivity of instream dissolved oxygen and pH to temperature, light, nutrients, and other factors. We employed two different model frameworks:

- For the Little Spokane River downstream of Chain Lake, we used the QUAL2Kw model framework.
- For tributary streams and for the portion of the Little Spokane River upstream of Chain Lake, we used the River Metabolism Analyzer (RMA) model.

We describe these model frameworks below in the **Analytical Framework** section. Appendix G provides detailed documentation of inputs, calibration, model quality, and sensitivity for QUAL2Kw, and Appendix H provides these for RMA.

The need for two models was dictated by the characteristics of the models and the layout of streams in the Little Spokane River watershed. QUAL2Kw is Ecology's full-featured river water quality model. For the mainstem Little Spokane River, using QUAL2Kw allowed us to perform a comprehensive analysis of factors relating to instream DO and pH. However, QUAL2Kw is best suited to mainstem river channels, with a limited ability to handle branching stream networks. The streams of the Little Spokane River watershed form a classic dentritic "candelabra" drainage pattern. Using QUAL2Kw throughout the watershed would require building separate models for each tributary stream, including for streams with only one or two sampling locations. This would be neither practical nor a good use of the model. RMA is a simpler modeling framework that analyzes individual stream locations. Using RMA allowed us to analyze the effects of shade, nutrients, and some limited channel characteristics at a variety of tributary locations.

Our analysis found that the vast majority of DO and pH improvement that would occur under system potential conditions results from shade improvements. In contrast, we found that nutrient reductions will produce smaller improvements in most locations, although at certain locations and times nutrient reductions may produce a significant benefit. We discuss these findings further in the **DO and pH Discussion** section below.

Data results for DO and pH analysis

Full summaries of data can be found in a separately published data summary report (Stuart, 2012; Data collected during 2010) and Appendix D (Data collected during 2013 and 2015-2016). The following sections highlight selected data that were key to the instream DO and pH analysis.

DO and pH

The diel surveys conducted during summers of 2010, 2013, and 2015 found DO and pH values frequently out of compliance with the water quality criteria designated for the streams in the Little Spokane watershed. Dissolved oxygen concentrations of less than 9.5 mg/L were observed at every monitoring location where diel data was collected. Values of pH in excess of 8.5 S.U. are common in the Little Spokane River and were also observed in Deer Creek, Dragoon Creek, Little Deep Creek, and Dartford Creek. All pH exceedances in the Little Spokane River were high pH (>8.5 S.U.); we did not observe any low pH exceedances (<6.5 S.U.). Table 36 summarizes where DO and pH exceedances occurred during the diel surveys. Figures 37 through 40 show longitudinal graphs of dissolved oxygen and pH data for the Little Spokane River, West Branch Little Spokane River, Dragoon Creek, and Deadman Creek.

DO and pH patterns in the Little Spokane River reflect algal productivity associated with large diel swings (Figure 37). Overall DO and pH values at Camden (55LSR-39.5; LSR @ Frideger Rd.) are lower than other sites likely reflecting decomposition processes occurring in the wetlands downstream of Chain Lake. Diel swings are less extreme near the mouth of the Little Spokane River likely reflective of the increased streamflow, increased depth, and cooler temperatures associated with the large groundwater inflow from the SVRP aquifer. Diel DO and pH swings at the mouths of most tributaries are much more moderate than in the LSR mainstem. These tributaries generally are influenced by cool groundwater and/or high reaeration.

The West Branch Little Spokane River sub-watershed contains a great diversity of stream types, which are reflected in DO and pH patterns at different sites (Figure 38). Small DO and pH diel swings in Moon Creek and Buck Creek are typical of small tributary streams. Low DO and pH values observed at Harworth Rd. likely reflect decomposition processes occurring in a wetland area. The small DO and pH diel swings at Fan Lake Rd. likely reflect a long deep pool just upstream of the monitoring site, created by a beaver dam. Extreme diel swings and low DO and pH at Eloika Lake Rd. likely reflect shallow, macrophyte-choked conditions in the outlet arm of Eloika Lake.

We observed a variety of DO and pH conditions in Dragoon Creek (Figure 39). Proceeding downstream from Montgomery Rd. to Dahl Rd, DO and pH both drop significantly. This may be due to decomposition processes in Dragoon Lake, an impounded reservoir on Dragoon Creek which appears to function as a wetland at low flows. Downstream of Deer Park, conditions are dominated by the inflow of cool groundwater from Spring Creek, which during summer of 2015 had higher flows than upper Dragoon Ck. We observed eutrophic conditions at the downstream crossing of Hwy 395 (55DRA-04.3; Dragoon Ck @ North Rd) which we attribute to the wide, low gradient, conditions combined with increased distance from the upper-basin groundwater sources. This site also saw the only consistent pH violation in Dragoon Ck. High gradient and reaeration in the bottom reach of Dragoon Ck., result in much moderated DO and pH swings at the mouth.

Figure 40 shows DO and pH conditions in Deadman Creek. Moderate DO and pH diel swings at the two upstream sites reflect the shady, high-gradient, canyon setting of upper Deadman Creek as it proceeds through the foothills of Mt. Spokane. Larger diel swings at Heglar Rd. result from wide, low-gradient conditions across Peone Prairie. Between Heglar Rd. and Bruce Rd., Deadman Creek proceeds through a large area of wetlands. The low DO and pH values observed at Bruce Rd likely result from decomposition processes in these wetlands. Higher DO values and moderate DO and pH diel swings at Shady Slope Rd. reflect an inflow of cool groundwater where lower Deadman Creek cuts across a lobe of the SVRP aquifer. DO and pH patterns at the mouth of Little Deep Creek are very similar to those in Lower Deadman Creek, as the lower reach of Little Deep Creek is also heavily groundwater-influenced.

Table 38. Summary of DO and pH exceedances observed in the Little Spokane watershed.

Exceedances are indicated in ***Bold.***

Location ID	Sampling Location	Monitored during survey?					Exceedances / days measured [a]	
		Jul 2010	Aug 2010	Aug 2013	Jul 2015	Aug 2015	Daily min DO	Daily max pH
55LSR-46.7	LSR @ Scotia				X	X	**4 / 4**	**3 / 4**
55LSR-39.5	LSR @ Frideger Rd	X	X		X	X	**11 / 11**	0 / 12
55LSR-37.1	LSR @ Elk			X	X	X	**13 / 13**	**9 / 14**
55LSR-33.2	LSR @ E Eloika Rd			X			**2 / 2**	0 / 1
55LSR-31.8	LSR @ Deer Park-Milan Rd	X	X	X	X	X	**21 / 21**	**16 / 21**
55LSR-23.4	LSR @ Chattaroy	X	X	X	X	X	**19 / 19**	**18 / 19**
55LSR-19.8	LSR @ Colbert Landfill outfall			X			**1 / 1**	0 / 0
55LSR-16.0	LSR @ E Colbert Rd			X			0 / 0 [b]	0 / 0 [b]
55LSR-13.5	LSR @ N LSR Dr	X	X	X	X	X	**19 / 19**	**15 / 19**
55LSR-11.0	LSR @ Dartford USGS gage	X	X				**4 / 4**	0 / 4
55LSR-03.9	LSR @ Rutter Pkwy (Painted Rocks)			X			0 / 0 [b]	0 / 0 [b]
55LSR-01.1	LSR @ Mouth	X	X	X	X	X	**11 / 11**	0 / 12
55DRY-00.4	Dry Ck @ Mouth	X	X		X	X	**4 / 6**	0 / 6
55OTT-01.4	Otter Ck @ 2nd Valley Rd xing				X	X	**2 / 2**	0 / 2
55OTT-00.3	Otter Ck @ Mouth	X	X		X	X	**2 / 6**	0 / 5
55MOO-02.9	Moon Ck @ Hwy 211				X	X	**2 / 2**	0 / 2
55WBLS-17.7	WBLSR @ Harworth Rd.				X	X	**3 / 3**	0 / 1
55BUC-00.3	Buck Ck @ Mouth				X	X	**2 / 2**	0 / 1
55WBLS-07.7	WBLSR @ Fan Lk Rd				X	X	**3 / 3**	0 / 2
55WBLS-03.1	WBLSR @ Eloika Lk Rd				X	X	**2 / 2**	0 / 2
55BEAR-00.4	Bear Ck @ Mouth				X	X	**2 / 2**	0 / 2
55DEE-05.9	Deer Ck abv Little Deer Ck				X	X	**14 / 14**	0 / 12
55DEE-01.4	Deer Ck @ Elk-Chattaroy Rd				X		**1 / 1**	0 / 1
55DEE-00.1	Deer Ck @ Mouth	X	X		X	X	**4 / 4**	**1 / 4**
55DRA-19.6	Dragoon Ck @ Montgomery Rd					X	**2 / 2**	0 / 2
55DRA-17.0	Dragoon Ck @ Dahl Rd				X	X	**3 / 3**	0 / 2
55SPR-00.4	Spring Ck @ Spring Ck Rd				X	X	**4 / 4**	0 / 4
55DRA-16.4	Dragoon Ck @ Hwy 395 nr Deer Park				X	X	**4 / 4**	0 / 4
55DRA-13.2	Dragoon Ck abv WB Dragoon Ck				X	X	**4 / 4**	0 / 4
55WBDR-00.1	WB Dragoon Ck @ Mouth				X	X	**4 / 4**	0 / 3
55DRA-04.3	Dragoon Ck @ North Rd				X	X	**4 / 4**	**4 / 4**
55DRA-00.3	Dragoon Ck @ Mouth	X	X		X	X	**6 / 6**	0 / 6
55SFLD-01.1	SF Little Deep Ck @ Day-Mt Spokane Rd				X	X	**2 / 2**	0 / 1
55LDP-00.1	Little Deep Ck @ Shady Slope Rd				X	X	**2 / 2**	0 / 2
55LDP-00.0	Little Deep Ck @ Mouth	X	X				**4 / 4**	**1 / 4**
55DEA-20.2	Deadman Ck @ Park Bdy					X	**2 / 2**	0 / 1
55DEA-13.8	Deadman Ck @ Holcomb Rd				X	X	**2 / 2**	0 / 1
55DEA-09.2	Deadman Ck @ Heglar Rd				X	X	**2 / 2**	0 / 1
55DEA-05.9	Deadman Ck @ Bruce Rd				X	X	**2 / 2**	0 / 1
55DEA-00.6	Deadman Ck @ Shady Slope Rd				X	X	**2 / 2**	0 / 2
55DEA-00.2	Deadman Ck blw Little Deep Ck	X	X				**4 / 4**	0 / 4
55DAR-00.2	Dartford Ck @ Mouth	X	X			X	**1 / 3**	**2 / 4**

[a] This counts all days on which daily min DO or daily max pH was measured. If the Hydrolab was deployed for a partial day, then we count that day if the DO minimum (or pH maximum, as appropriate) occurred during that partial day. The fact that some partial days include a DO minimum but not a pH maximum, or vice versa, accounts for the occasional discrepancies between day counts in the DO and pH columns.

[b] We deployed hydrolabs at these sites, but neither daily min DO nor daily max pH occurred during partial day deployments.

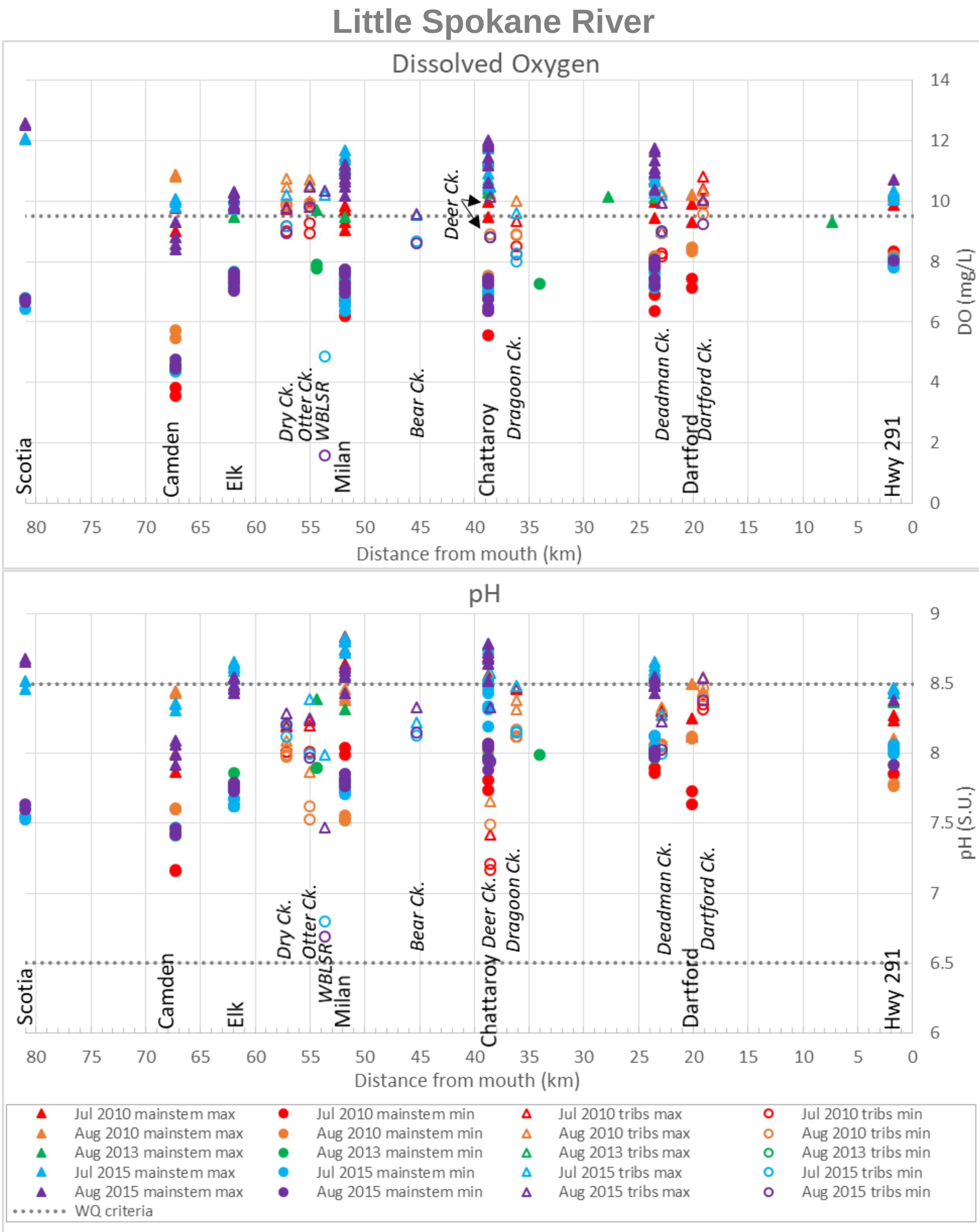


Figure 37. Longitudinal graph of diel dissolved oxygen and pH in the Little Spokane River.

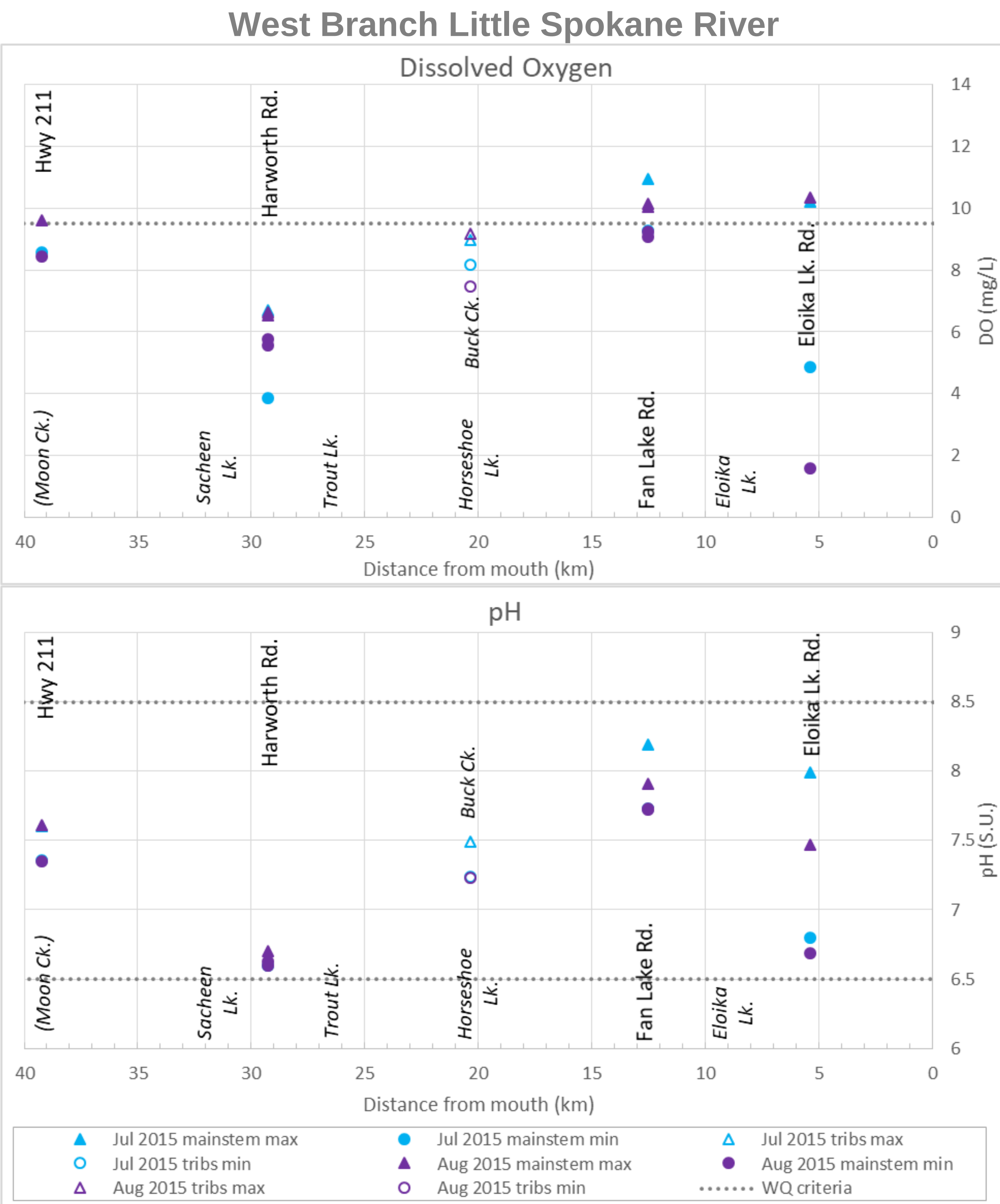


Figure 38. Longitudinal graph of diel dissolved oxygen and pH in the West Branch Little Spokane River.

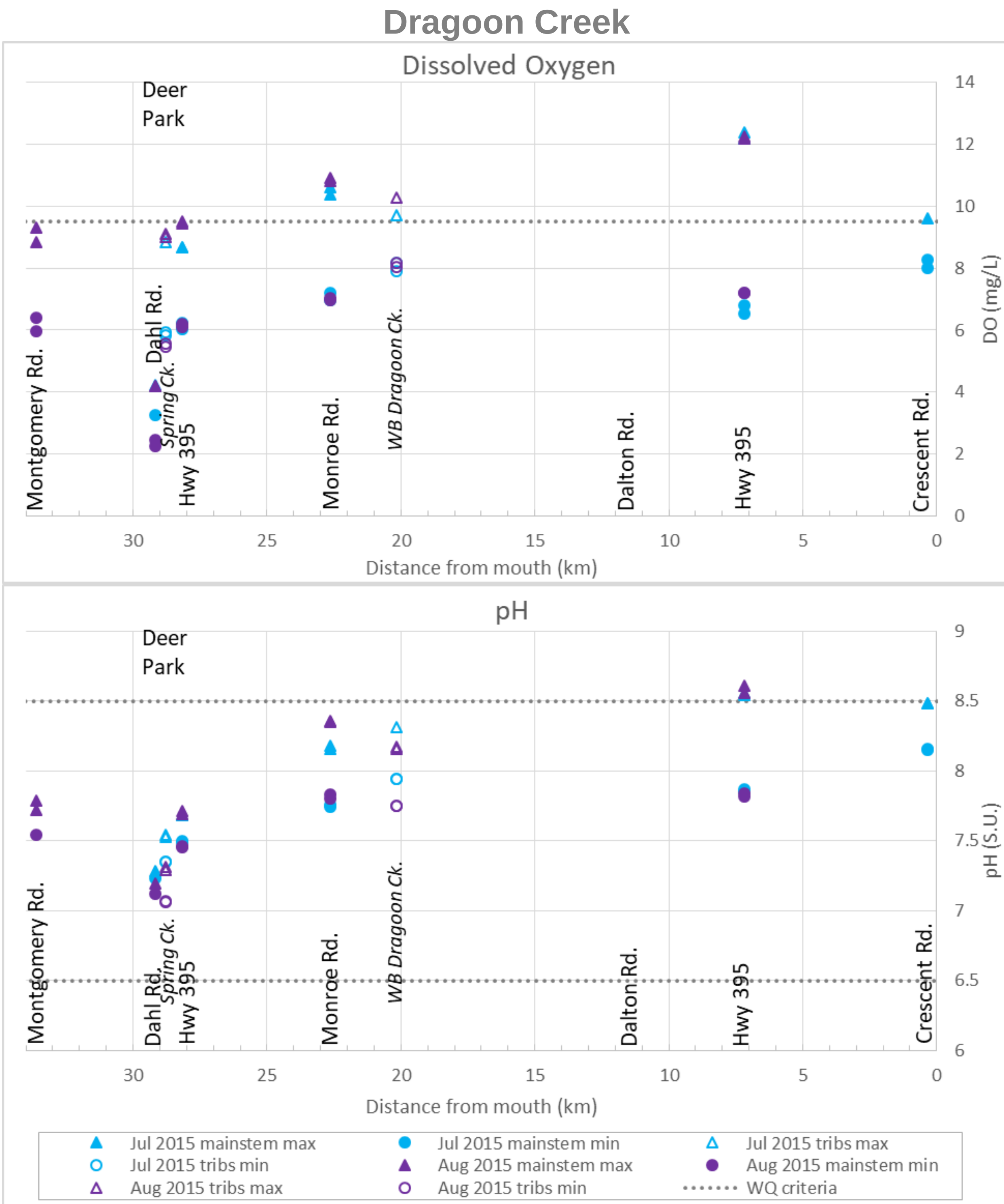


Figure 39. Longitudinal graph of diel dissolved oxygen and pH in Dragoon Creek.

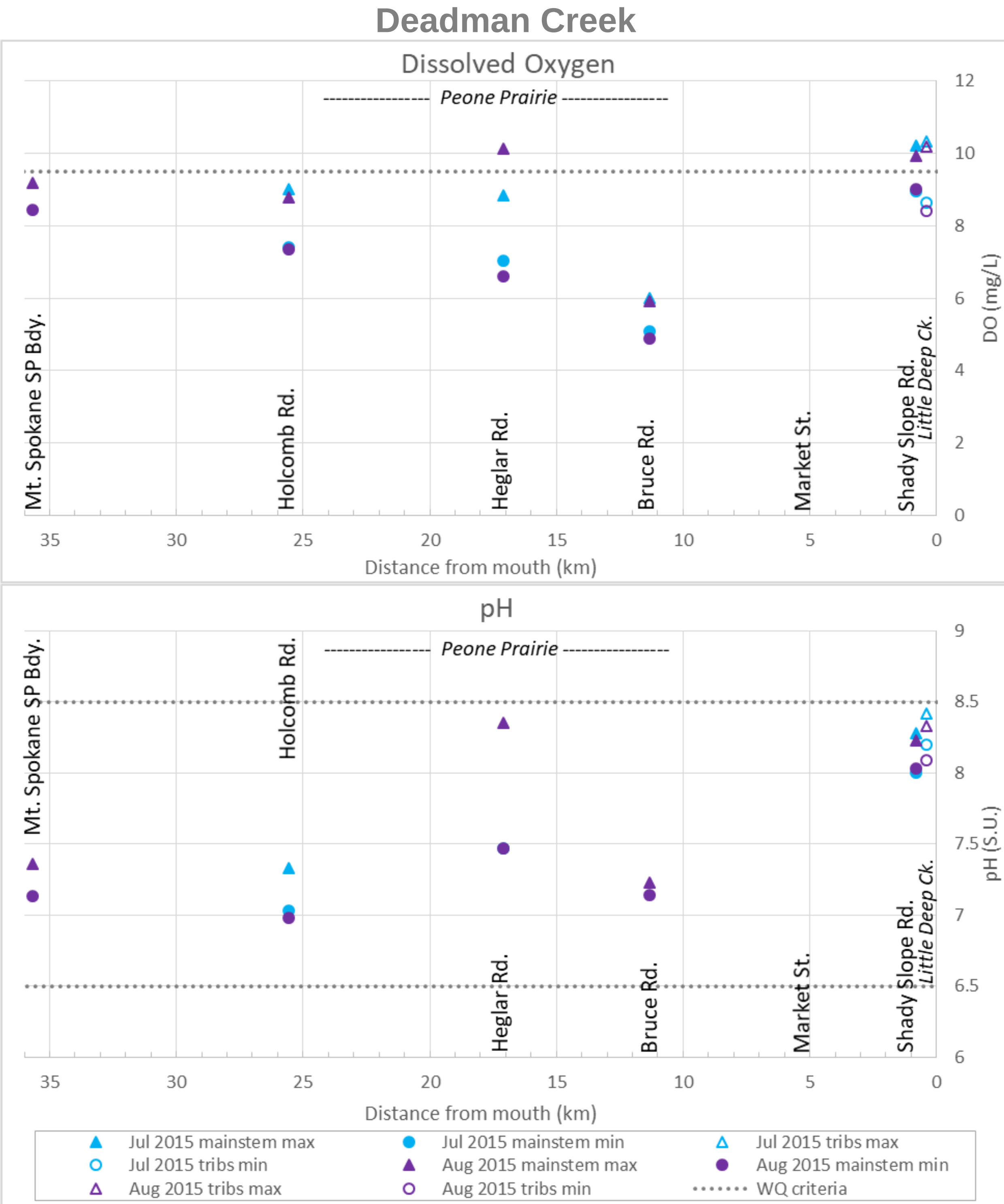


Figure 40. Longitudinal graph of diel dissolved oxygen and pH in Deadman Creek.

Nutrients

Figures 41 through 44 present longitudinal summertime nutrient graphs for the Little Spokane River, West Branch Little Spokane River, Dragoon Creek, and Deadman Creek. We show the following nutrient fractions:

- Dissolved Inorganic Nitrogen (DIN) – Calculated as the sum of Nitrate-Nitrite Nitrogen and Ammonia Nitrogen. This represents the fraction of nitrogen that is available for uptake by algae.
- Total Nitrogen (TN) – Represented by Total Persulfate Nitrogen (TPN). Includes DIN as well as all other forms of particulate and/or organic nitrogen.
- Soluble Reactive Phosphorus (SRP) – This approximates the fraction of phosphorus that is either available for uptake by algae, or is very readily converted to such a state.
- Total Phosphorus – Includes SRP as well as all other forms of particulate and/or organic phosphorus.

Note that the following descriptions and graphs refer only to the summertime low-flow season when in-watershed DO and pH impairments occur. Nutrient conditions during other seasons can be very different (see **Watershed Loading TMDL Analysis** section).

Many lakes and wetlands throughout the Little Spokane River watershed act as nutrient sinks. This appears in the data as lower nutrient concentrations downstream of a lake or wetland than upstream. The **Lakes** section below contains further discussion of this phenomenon.

Figure 41 shows nutrient patterns in the Little Spokane River. Nitrogen and phosphorus concentrations are very low in the upper reaches with concentrations increasing downstream due to higher concentration inputs from tributaries and groundwater. Nitrogen concentrations continue to slowly increase downstream all the way to the mouth. Phosphorus concentrations continue to increase downstream as far as Dartford. After that, dilution by lower-phosphorus groundwater from the SVRP aquifer reduces the phosphorus levels. This figure also shows nutrient concentrations at the mouths of tributaries, many of which are higher than those found in the LSR mainstem.

Nitrogen and phosphorus concentrations are both very low throughout the West Branch Little Spokane River (Figure 42). Non-detects for DIN are common, and TP levels are comparable to the far upper reaches of the Little Spokane River mainstem. This is probably the result of the numerous lakes and wetlands in this sub-basin functioning as nutrient sinks.

Nutrient patterns in Dragoon Creek are complex (Figure 43). Dragoon Creek upstream of Spring Creek has low nitrogen but very high phosphorus. Conversely, Spring Creek has high nitrogen and low phosphorus. Concentrations in Dragoon Creek downstream of Spring Creek are largely a function of the mixing of these two streams. Very elevated nitrogen concentrations (~3-4 mg/L) at the two downstream sites suggest a high-nitrogen source somewhere between Monroe Rd. and the lower Hwy 395 crossing. Given the month-after-month consistency of this pattern, the nitrogen source is probably associated with groundwater inflow.

The bedrock geology of Mt. Spokane appears to produce high phosphorus and low nitrogen in the upper reaches of Deadman Creek (Figure 44). This pattern generally continues through Peone

Prairie, albeit with some variability. SVRP aquifer groundwater inputs, with higher nitrogen and low phosphorus, reverse this pattern in the lower reaches of Deadman Creek.

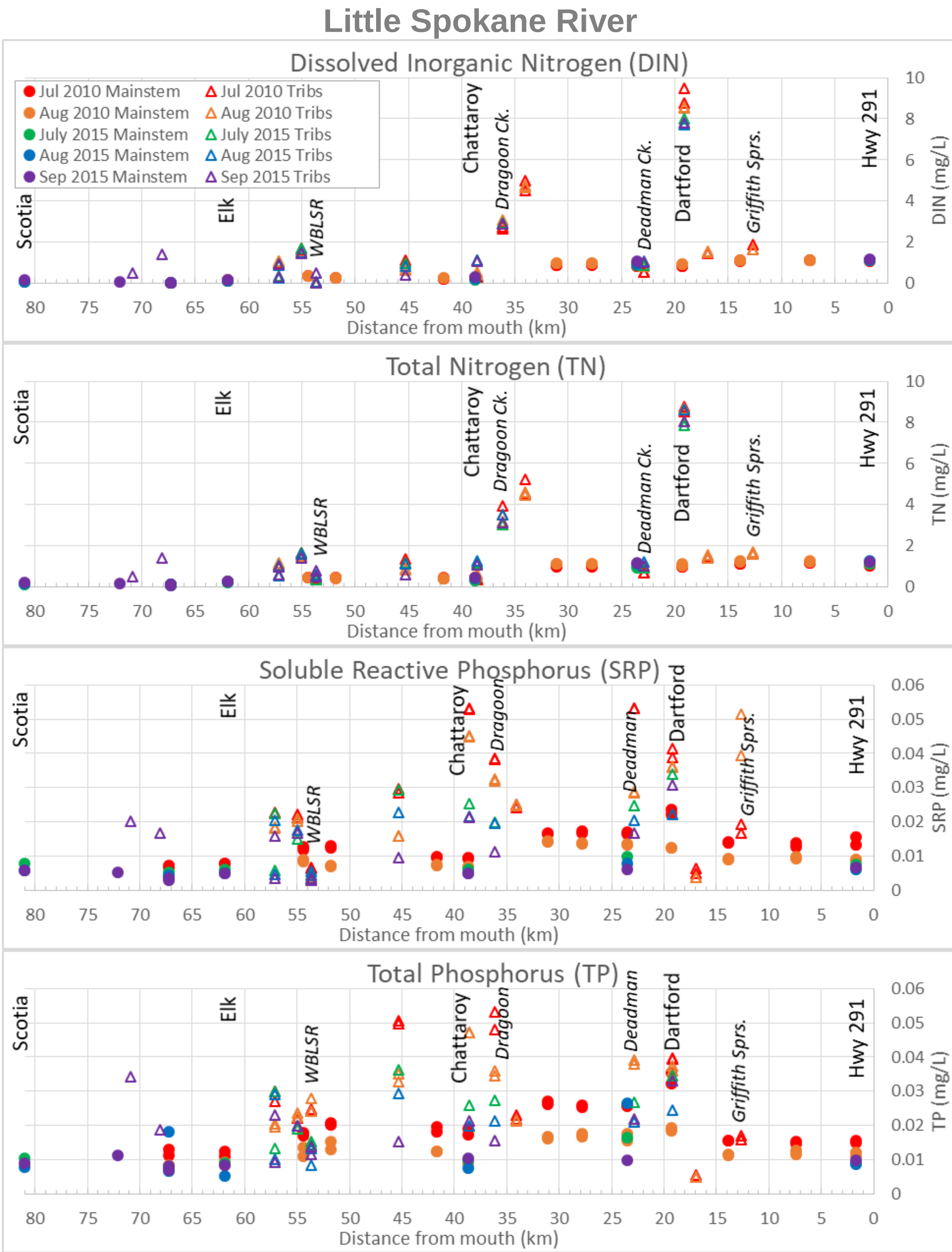


Figure 41. Longitudinal graph of nutrients in the Little Spokane River.

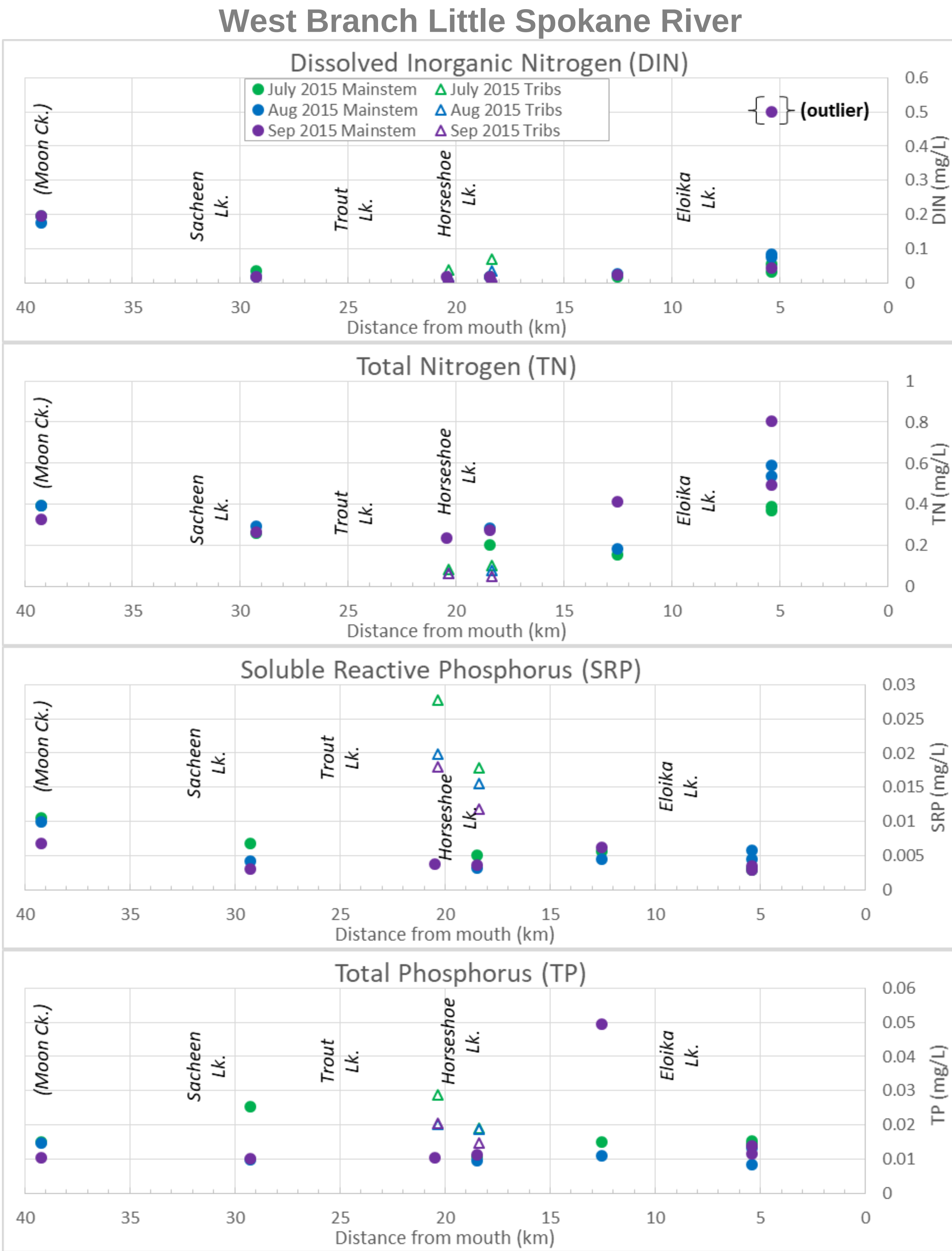


Figure 42. Longitudinal graph of nutrients in the West Branch Little Spokane River.

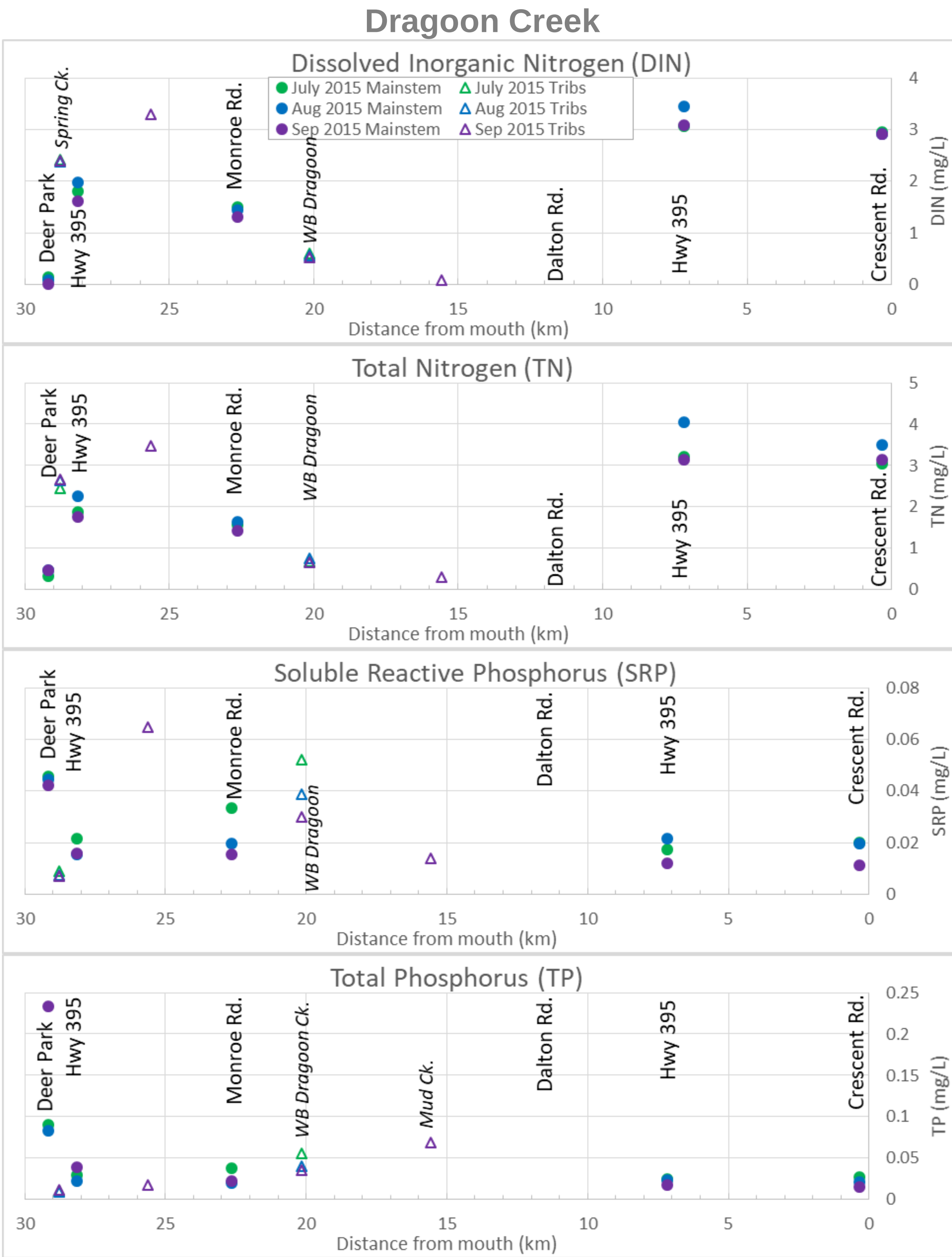


Figure 43. Longitudinal graph of nutrients in Dragoon Creek.

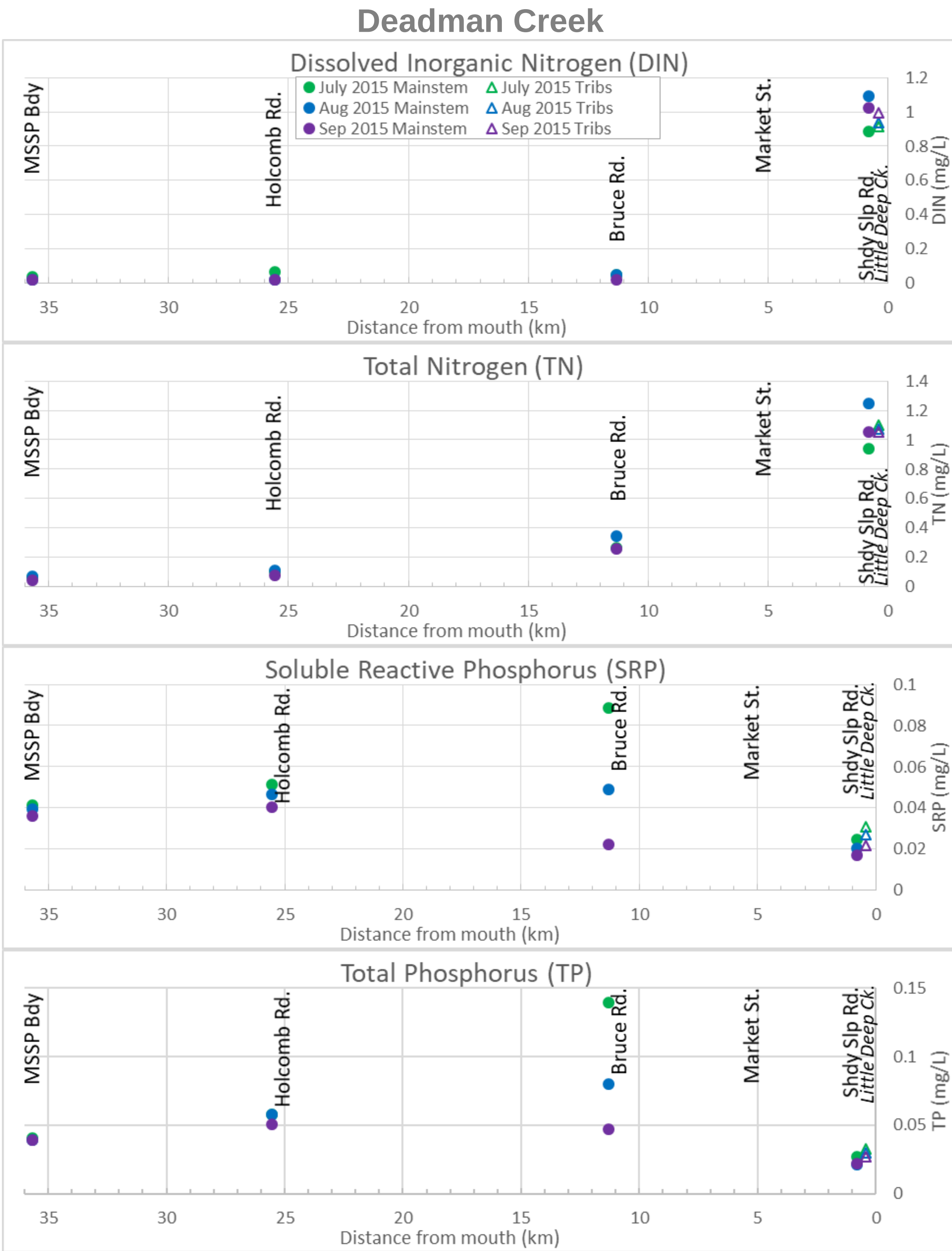


Figure 44. Longitudinal graph of nutrients in Deadman Creek.

Analytical framework

QUAL2Kw

We used the QUAL2Kw water quality model (Pelletier and Chapra, 2008; Chapra 1997) to simulate the effects of nutrients and other factors on DO and pH in the Little Spokane River between the outlet of Chain Lake and the mouth at the Spokane River. QUAL2Kw is a one-dimensional numerical model capable of simulating a variety of conservative and non-conservative water quality parameters.

There are several important concepts for modeling the effect of primary productivity in running waters. Among the most important are:

- Usually, only one nutrient can limit algal growth at a time. The limiting nutrient will be the least available relative to its demand. This principle is known as Liebig's law of the minimum (Chapra, 1997).
- For river modeling, it is important to limit the growth rate to control algal biomass yield. The growth rate is often limited by the concentration of the most limiting nutrient (i.e. the supply rate of the limiting nutrient),[8] and by temperature. In some situations other factors limit growth instead of nutrients, such as space available for attachment, light availability, or the inherent rate that particular species can grow.
- It is appropriate to use the dissolved-fraction concentration of the limiting nutrient, such as soluble reactive phosphorus (SRP) and dissolved inorganic nitrogen (DIN), as the basis for modeling periphyton growth. This is because the nutrient must be in a readily-available form for biological uptake and growth to occur during solute transport (Welch and Jacoby, 2004).
- Total phosphorus and nitrogen are important to model since the particulate and organic fractions can be transformed into the dissolved fractions through various instream and hyporheic processes.

Although QUAL2Kw 6.0 is capable of performing continuous simulation throughout a season, we used the repeating diel version of the model. The repeating diel option provides a quasi-steady state simulation of conditions on one day, while accounting for diel changes that occur throughout the course of the day. (This was the only option in previous versions of QUAL2Kw.) Appendix G provides detailed documentation of the model segmentation, inputs, calibration, and goodness-of-fit. QUAL2Kw requires the following types of data:

- Channel geometry data
- Streamflow data
- Meteorology data and shade estimates
- Nutrient (nitrogen, phosphorus, and carbon) concentration data
- Diel or continuous DO, pH, and temperature data

[8] QUAL2Kw has the ability to limit algal growth based on any of three different principles: 1.) Liebig's law of the minimum, as described above; 2.) multiplicative; and 3.) harmonic mean. The multiplicative and harmonic mean options allow for nutrient co-limitation, but each have particular drawbacks. The Liebig minimum option is most commonly used, and is the option we used in this study.

- Algae/aquatic plant biomass data
- Groundwater nutrient and flow data

QUAL2Kw requires water quality input data to characterize water at all model boundaries, including the upstream end of the model reach, tributaries, point sources, and groundwater inputs. Water quality data at other locations in the model reach serve as a comparison to check model simulations.

Ultimately, we used the calibrated QUAL2Kw model to estimate the assimilative load capacity for nutrients, along with the effect of changes to shade, channel geometry, and flow. These estimates form the basis for load and wasteload allocations that ensure DO and pH levels that protect aquatic life in the Little Spokane River.

RMA

We used the River Metabolism Analyzer (RMA) tool (Pelletier, 2013) to simulate the effects of nutrients as well as other factors on DO and pH in tributary streams, as well as the portion of the Little Spokane River upstream of the outlet of Chain Lake. RMA is an Excel workbook that contains four methods for analyzing stream metabolism, using diel DO, pH, and temperature data. We used two of these methods, inverse modeling and predictive modeling. We did not use the other two methods, the delta method and nighttime regression.

The inverse and predictive modeling tools in RMA predict diel DO and pH patterns using a simple equation with four rate parameters:

- Gross Primary Productivity (GPP)
- Ecosystem Respiration (ER)
- Reaeration (Ka)
- Photosynthetic Quotient (PQ; optional, but used for this project)

The inverse modeling method uses the PIKAIA genetic algorithm (Charbonneau and Knapp, 1995) to find the optimum values for the rate parameters to match observed DO and pH. The predictive modeling method then uses these rate parameter values to predict the effect of nutrient changes on DO and pH. GPP and ER remain in a consistent proportion to one another, attenuated by a specified limiting nutrient concentration. A Monod curve links instream limiting nutrient concentration directly to GPP and ER. RMA is a relatively simple model compared to QUAL2Kw, since it does not include water movement, solute transport, complex algal dynamics, or nutrient cycling.

In order to adequately simulate small tributary streams, which are largely groundwater-fed during the low-flow season, we modified the version of RMA used for this project to include bulk mixing of groundwater, with specified inputs for groundwater inflow rate, DO, and pH. The original version of RMA does not simulate groundwater mixing, and could not adequately simulate DO and pH in streams with large groundwater inflows.

Appendix H provides detailed documentation of the RMA model inputs, calibration, and goodness-of-fit.

RMA does not simulate temperature. Rather, temperature is a user-specified input. RMA also allows the option to specify Photosynthetically active radiation (PAR) as a time-series input. To simulate the effect of shade on temperature and PAR, and of temperature and PAR on DO and pH, we performed a watershed-wide landscape shade analysis. We based this analysis on a set of methods developed by the U.S. Environmental Protection Agency (EPA; Leinenbach, 2016a-e), using Geographic Information System (GIS) software to analyze LANDFIRE data (LANDFIRE, 2016) to provide inputs for Ecology's Shade.xls model (Ecology, 2003). Appendix I provides the details of this landscape shade analysis. We used the rTemp model (Pelletier, 2012a) to predict the effect of shade modifications on temperature at representative high-groundwater and low-groundwater locations. We used the SolRad solar radiation modeling tool (Pelletier, 2012b) to predict the effect of shade modifications on PAR.

Model application and assessment

We provide complete model documentation including inputs, calibration methodology, and detailed quality assessment and sensitivity analyses in Appendix G for QUAL2Kw, and Appendix H for RMA.

Model application

QUAL2Kw

We built a QUAL2Kw model to simulate the Little Spokane River from the outlet of Chain Lake to the mouth. The model contained 41 segments, each 1.609km (1 mile) in length. We ran the model for five different dates (Table 37). All model runs were based on datasets collected during warm summertime weather conditions.

Table 39. QUAL2Kw model run dates and calibration datasets.

Model run date	Dataset type	Flow conditions
7/28/2010	Ecology synoptic survey	Typical summertime flow conditions
8/25/2010	Ecology synoptic survey	Lower than normal summertime flow conditions
8/13/2013	Ecology time-of-travel survey, with high-resolution diel DO and pH data.	Typical summertime flow conditions
7/22/2015	Ecology synoptic survey	Approximately 20-year (7Q20) low flow conditions
8/19/2015	Ecology synoptic survey	Approximately 20-year (7Q20) low flow conditions

We calibrated the model rate parameters primarily using the July 2010, August 2010, and August 2013 datasets. We further adjusted two rate parameters (bottom algae growth rate and photosynthetic quotient) after adding the July 2015 and August 2015 datasets. Ultimately we used the same rate parameters for all five model dates, as well as for all scenario simulations.

RMA

We built RMA models to simulate 27 stream locations, including the upper Little Spokane River (at Scotia) and tributary locations throughout the watershed. For each location, we built between 1 and 4 models, depending on the number of available diel DO and pH datasets. The datasets we used were those collected during July 27-29, 2010; August 24-26, 2010; July 21-31, 2015; and August 18-28, 2015. The exact model run dates depend on the dates when the diel data was collected, which varies by site. We calibrated the rate parameters for each model separately, using the "approximate Bayesian computation" feature of RMA.

Model quality assessment

We assessed the quality of both the QUAL2Kw and RMA model calibrations in two principal ways. First, we compared model predictions to observed values. Second, we carefully assessed the model sensitivity of algal growth to instream nutrient concentrations and compared this to literature and available data. We took particular care to insure that the sensitivity of algal growth to nutrient concentrations was essentially the same between the QUAL2Kw and RMA models.

Both models provide an excellent simulation of DO and pH, and have realistic sensitivity to inputs which should provide reasonable predictions for various scenarios. The results shown here are a very brief synopsis.

QUAL2Kw

We compared model predictions to observed data for all modeled parameters. Figure G-2 and Table G-13 in Appendix G provide complete calibration plots and model goodness-of-fit statistics for all model variables. The results presented here are a very brief summary. We used two metrics to assess model fit, root mean squared error (RMSE), and overall bias. We also expressed each of these metrics in relative terms as RMSE CV (RMSE coefficient of variation) and Bias %. We calculated the metrics as follows:

$$RMSE = \sqrt{\frac{\Sigma(T_{modeled} - T_{observed})^2}{n}} \qquad Bias = \frac{\sum(T_{modeled} - T_{observed})}{n}$$

$$RMSE\ CV = \frac{RMSE}{Avg\ obs\ value} \qquad Bias\,\% = \frac{Bias}{Avg\ obs\ value}$$

Daily minimum DO predictions for all model runs had a root mean square error (RMSE) of 0.40 mg/L (RMSE CV = 5.5%) and an overall bias of +0.09 mg/L (Bias% = +1.3%). Daily maximum pH predictions for all model runs had a RMSE of 0.25 S.U. and an overall bias of +0.18 [9].

These compare well to model results from other Ecology TMDL studies. Previous Ecology TMDL models had a mean RMSE for DO of 0.60 mg/L, with a range from 0.001 – 2.2 mg/L. Previous models had RMSE for pH ranging from 0.2 to 0.58 S.U. (Sanderson and Pickett, 2014).

Figure 45 presents calibration plots for DO and pH for the August 19, 2015 model run.

[9] The RMSE CV and Bias% statistics are not used for pH. See Appendix G, **Model Goodness-of-fit** section, for discussion.

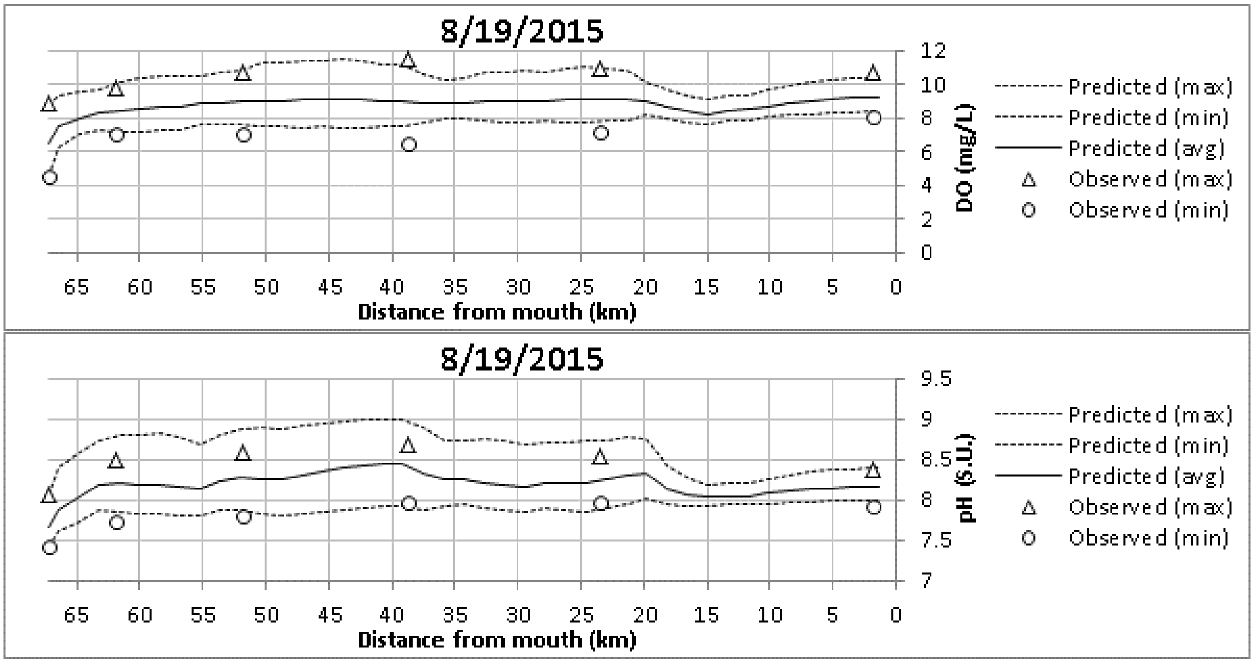


Figure 45. QUAL2Kw calibration plots for DO and pH for the August 19th, 2015 model run.

We performed an assessment of model sensitivity to nutrients. The model calibration produces a relationship between algal productivity and instream nutrient concentrations that is consistent with the experimental literature (Bothwell, 1985; Rier and Stevenson 2006). The **Assessment of Model Sensitivity to Nitrogen and Phosphorus** section of Appendix G provides complete details.

RMA

Figure 46 presents selected calibration plots for DO and pH for RMA model calibrations. As compared with observed data, DO predictions for all models had a RMSE ranging from 0.03 – 0.36 mg/L, with a median value of 0.12 mg/L. RMSEs for pH range from 0.02 – 0.19 S.U. with a median value of 0.05 S.U. Median model bias was negligible; 0.00 for DO and +0.01 for pH. Table G-4 in Appendix H provides complete model goodness of fit statistics.

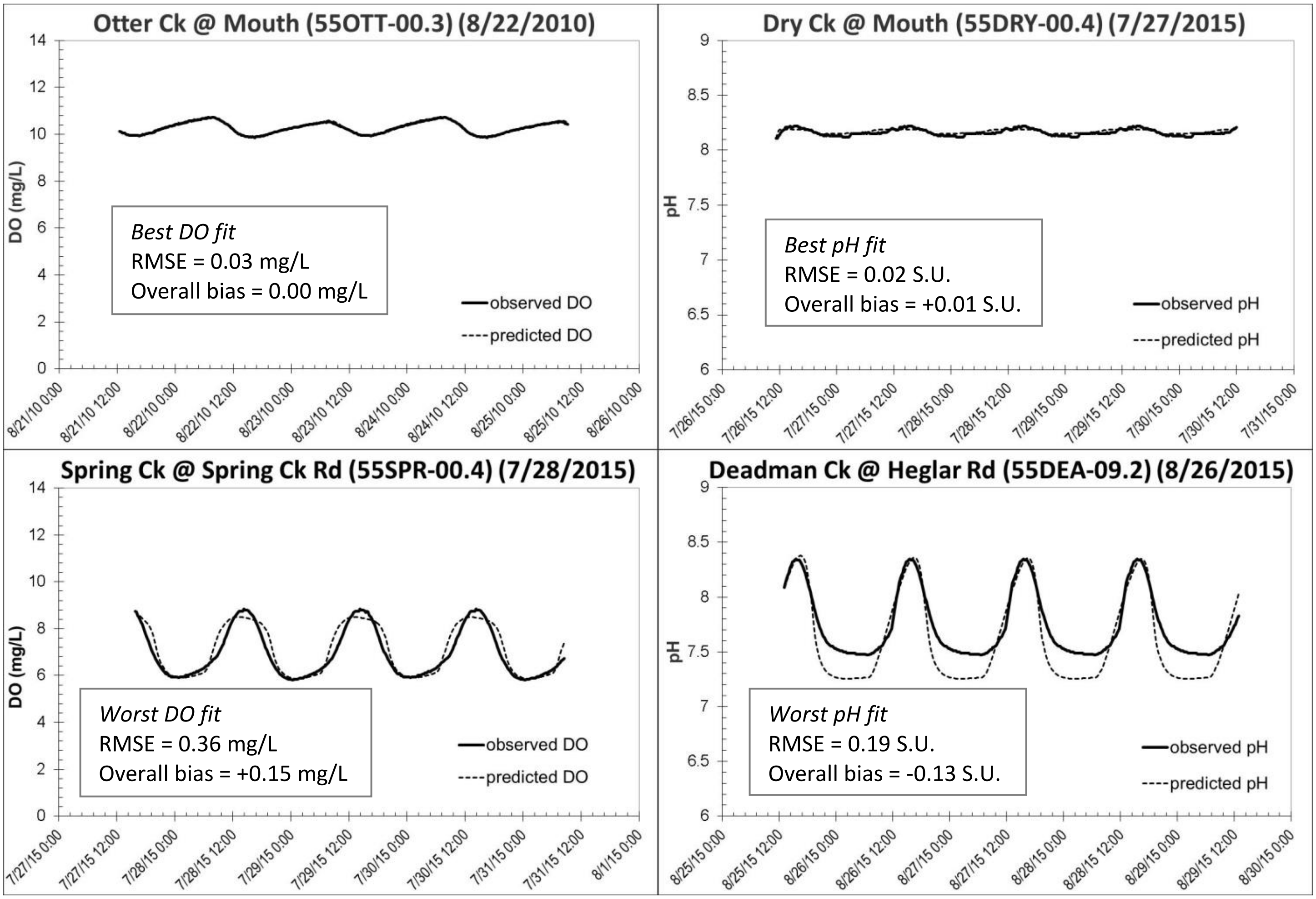


Figure 46. Selected calibration plots for RMA models, showing the best and worst model fits for DO and pH.

Unlike QUAL2Kw, RMA allows the user to explicitly specify model sensitivity to nutrients as a calibration parameter. For the RMA models, we set this parameter to closely mimic the assessed QUAL2Kw model sensitivity. See Figure G-4 in Appendix G for a comparison of the way that we handled nutrient sensitivity in the two model frameworks.

Critical conditions

Total Maximum Daily Load studies typically use a "critical" or reasonable worst-case meteorological assumption to assess loading capacities and allocations. Choosing a severe set of meteorological conditions helps to insure that load and wasteload allocations are adequately protective under a wide range of conditions.

We used the calibrated QUAL2Kw model to simulate critical climactic conditions. We simulated two sets of critical conditions, moderate critical conditions with 7-day average, 2 year low flow (7Q2) and 50th percentile air temperatures, and extreme critical conditions with 7-day average, 10 year low flow (7Q10) and 90th percentile air temperatures. Appendix G, **Critical Conditions**

Scenarios section, provides additional information about the model inputs chosen to reflect these conditions.

We used calibrated RMA models to simulate one set of critical climatic conditions, with 90th percentile air temperatures. Thus, we normalized all models (based on different dataset dates) to a uniform climate condition, regardless of the conditions when the data was collected. The RMA model framework does not include streamflow. Appendix H, **Critical Conditions Scenarios** section, and Appendix I provide additional information about how we implemented critical air temperatures in RMA.

System potential conditions

As discussed earlier, conditions absent the pollution impacts of human settlement and development are termed "natural conditions" in the Water Quality Standards. An estimate of conditions absent human impacts is also termed "system potential," which is the term we use in the following discussion.

We used the calibrated QUAL2Kw model to simulate system potential conditions in the Little Spokane River from the outlet of Chain Lake to the mouth. We used the calibrated RMA models to simulate system potential conditions in tributaries and in the upper reaches of the Little Spokane River. To simulate system potential conditions, we adjusted model inputs to reflect a best estimate of natural background conditions that did not include human modifications. Table 38 summarizes the inputs which we adjusted in each model framework.

QUAL2Kw is a more comprehensive model framework than RMA so it was possible to simulate system potential simulations in greater detail in QUAL2Kw than it was in RMA. Appendices G, H, and I provide specifics of how we adjusted each of the model inputs. Appendix L contains a summary checklist that provides an overview of how we modified model inputs to reflect system potential/natural conditions.

We aligned the system potential conditions used in this instream DO and pH analysis to be consistent with those used in the watershed loading analysis. For example, we set groundwater and tributary nutrient concentrations, as well as streamflow increases due to removal of surface and groundwater withdrawals, to the same values used in (or determined by) the watershed loading analysis.

Table 40. Model inputs that were adjusted to reflect system potential conditions.

Model input	QUAL2Kw	RMA
Nutrients	X	X
Shade/Temperature/PAR	X	X
Channel Geometry: Depth	X	X
Channel Geometry: Width	X	
Streamflow	X	
Riparian microclimate	X	

Model scenario results

Little Spokane River (QUAL2Kw) model scenarios

Figures 47 and 48 present QUAL2Kw model predictions for daily minimum dissolved oxygen and daily maximum pH under current and system potential conditions. In addition, we present several scenarios which demonstrate the impact of changing some, but not all, model inputs to estimated system potential conditions. We ran all scenarios under moderate and extreme critical conditions. The scenarios are as follows:

- **Current conditions** – all modern day human impacts included that existed during the five surveys used for calibration. This is the baseline scenario from which we derived all the following scenarios.
- **Full natural** – all inputs listed in Table 38 adjusted to estimated system potential conditions
- **Nutrients only** – nutrient inputs adjusted to estimated system potential conditions
- **Shade only** – shade inputs adjusted to estimated system potential conditions
- **Shade + microclimate** – shade, air temperature, and dew point inputs adjusted to estimated system potential conditions, accounting for expected improvements in the riparian microclimate due to increased vegetation.
- **Shade + microclimate + channel** – shade, air temperature, dew point, and channel geometry inputs adjusted to estimated system potential conditions
- **Shade + microclimate + channel + flow** – shade, air temperature, dew point, channel geometry, and streamflow inputs adjusted to estimated system potential conditions
- **TMDL –** shade inputs adjusted to estimated system potential conditions, and nutrients reduced to reflect load and wasteload allocations specified later in this TMDL document.

Figures 49 and 50 present these predictions in a relative fashion, expressed as difference from the "full natural" condition (dissolved oxygen deficit from full natural or pH increase over full natural). Visualizing the model predictions this way allows the quantification of the total human impact for a given scenario. (Note that the "dissolved oxygen deficit from natural" expresses the difference in daily minimum dissolved oxygen between a given scenario and the "full natural" scenario. For example, under the "current" scenario, daily minimum DO is predicted to be up to 0.6 mg/L lower (worse) than under the "full natural" scenario.)

The QUAL2Kw model predicts that even under the full natural conditions scenario, DO will not meet numeric criteria in any part of the Little Spokane River, and pH will not meet numeric criteria in much of it. We predict this to be the case for both extreme and moderate critical weather conditions. This means that the incremental increases of 0.2 mg/L DO and 0.1 S.U. pH allowed for human impacts by the Water Quality Standards (see the **Natural Background Levels** section above) will be the applicable factors that drive load and wasteload allocations to meet the water quality standards.

We predict that restoration of full natural conditions on the Little Spokane River would result in up to 0.66 mg/L improvement of DO under extreme critical conditions, and up to 0.59 mg/L improvement under moderate critical conditions (Figure 49). For pH, predicted improvements are 0.23 S.U. under extreme critical conditions, and 0.26 S.U. under moderate critical conditions (Figure 50). The largest predicted DO and pH improvements occur upstream of Dartford. Downstream of Dartford, the groundwater inflow from the SVRP aquifer dominates water quality characteristics, and predicted improvements are small.

A key model result is that the vast majority of improvement in DO, and the majority of improvement in pH, are the result of restored shade and resulting reduction in water temperatures and light availability. In contrast, restoring nutrient concentrations to system potential conditions has a smaller predicted impact on DO (up to 0.15 mg/L improvement) and pH (up to 0.05 S.U. improvement). The reason for this is that estimated natural background concentrations of phosphorus are too high to effectively limit periphyton growth. Thus, we predicted that reducing phosphorus to natural background levels will have a relatively small impact on primary productivity, DO, and pH.

Impacts from the other model inputs were small. Restoration of natural microclimate has a very small predicted impact to both DO (up to 0.03 mg/L improvement) and pH (up to 0.01 S.U. improvement). Restoring channel geometry and streamflows has a small predicted impact, perhaps totaling 0.1 mg/L DO and 0.1 S.U. pH.

For DO, we predict that restoring shade alone to system potential conditions will reduce the total human impact to less than 0.2 mg/L (Figure 49). For pH, we predict that restoring shade or restoring shade plus microclimate will reduce total human impact to less than 0.1 S.U. in most locations, with the exception of the Elk area. Restoring shade as well as channel geometry reduces the total predicted human impact to less than 0.1 S.U. in all locations (Figure 50). We found that it is also possible to reduce the predicted human impact to less than 0.1 S.U. by restoring shade in all locations and reducing nutrients, specifically dissolved inorganic nitrogen (DIN), in the Elk area. This is the option (restoring shade plus reducing DIN) that we chose for the allocations in this TMDL.

The TMDL scenario represents all of the load and wasteload allocations specified by this TMDL. This includes restoration of shade, the phosphorus reductions specified by the watershed analysis, and nitrogen (DIN[10]) reductions in the Elk area. This scenario limits human DO impacts to less than 0.2 mg/L, and pH impacts to less than 0.1 S.U. in all locations, as required by the water quality standards.

[10] The reason for reducing nitrogen rather than phosphorus in this reach is that essentially all phosphorus in this reach appears to be natural. Most of the nitrogen, on the other hand, appears to result from human activity. DIN:SRP ratios in this reach are near the Redfield ratio, and therefore it is uncertain which nutrient is more limiting.

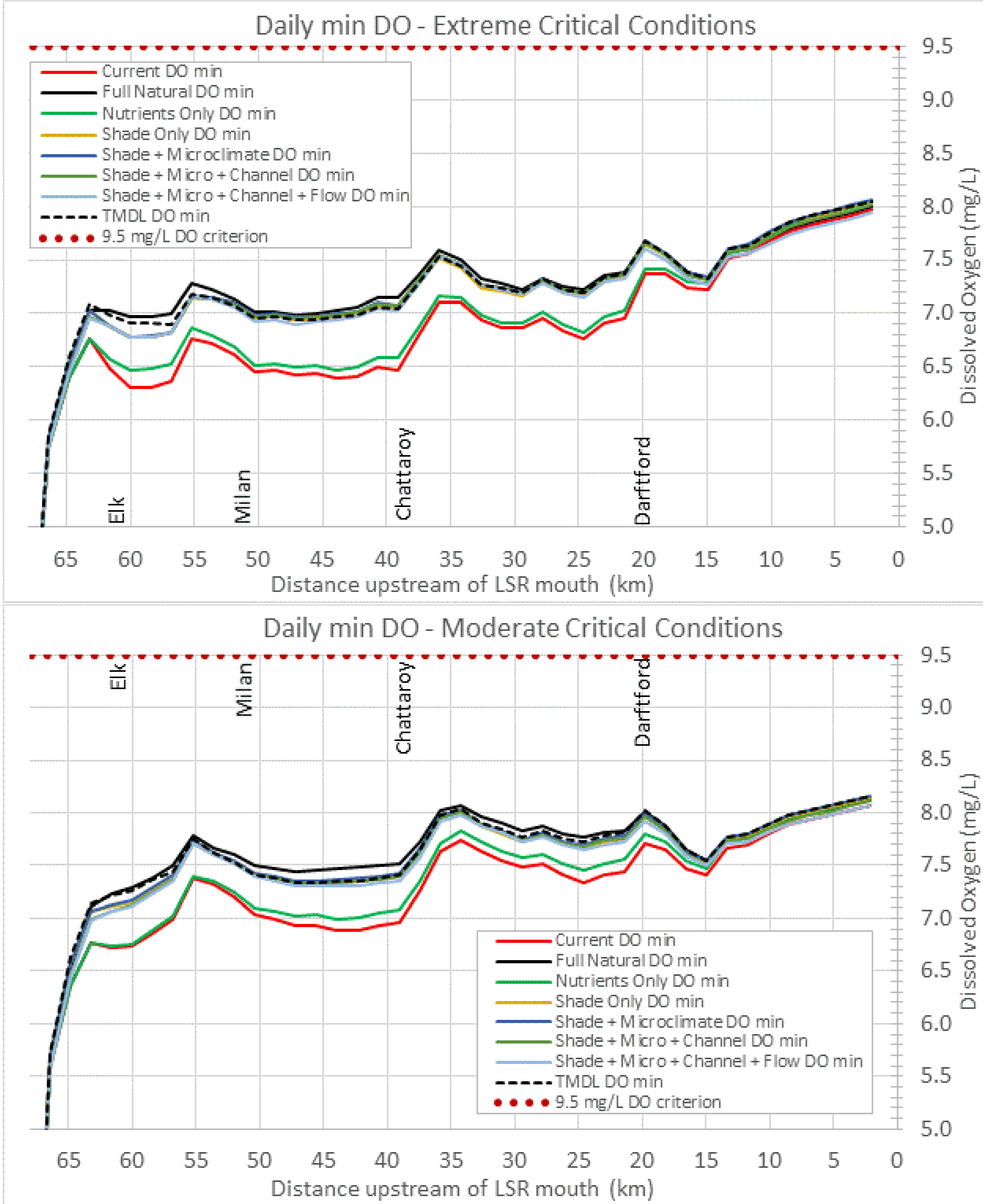


Figure 47. QUAL2Kw model predictions of daily minimum dissolved oxygen under various scenarios.

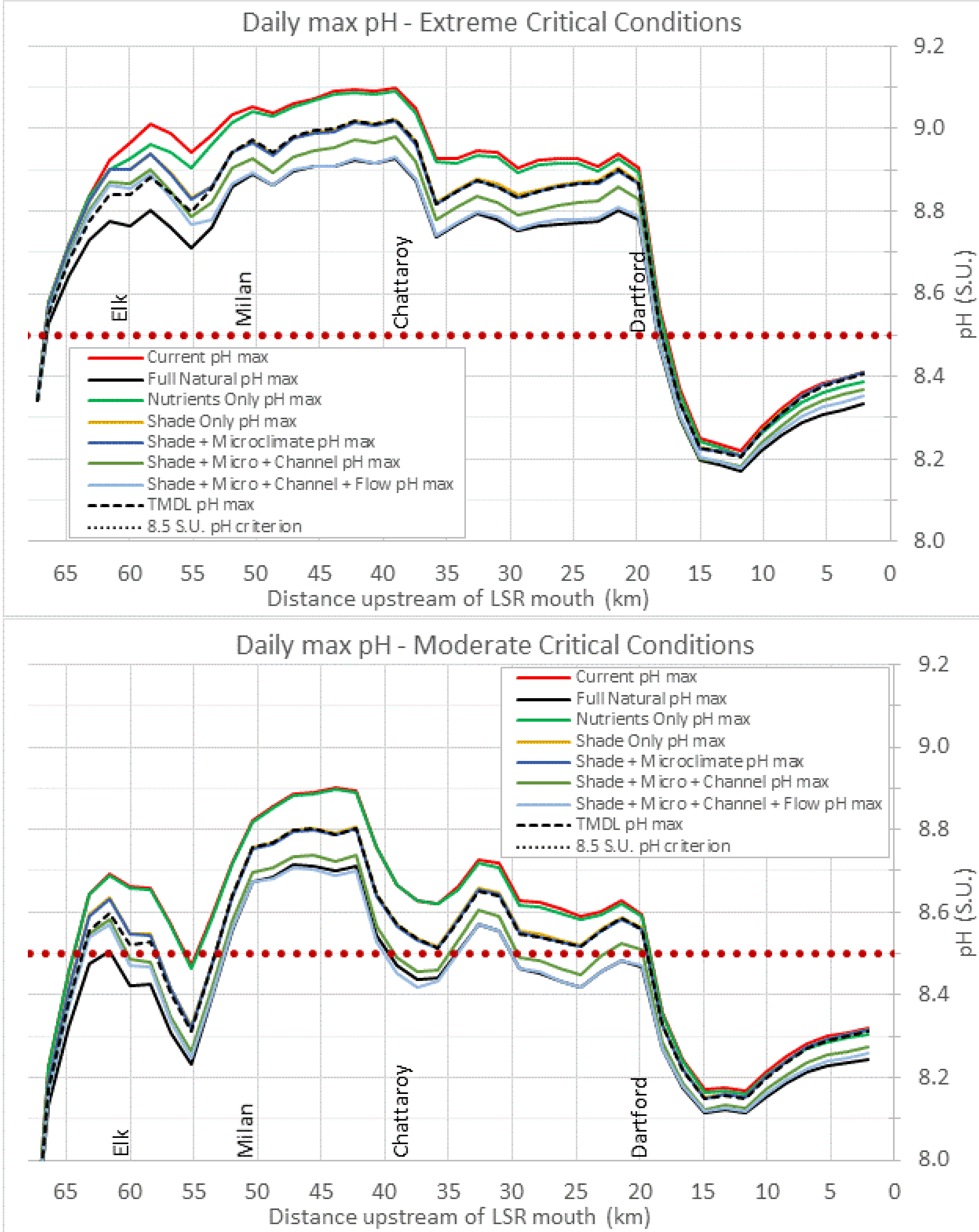


Figure 48. QUAL2Kw model predictions of daily maximum pH under various scenarios.

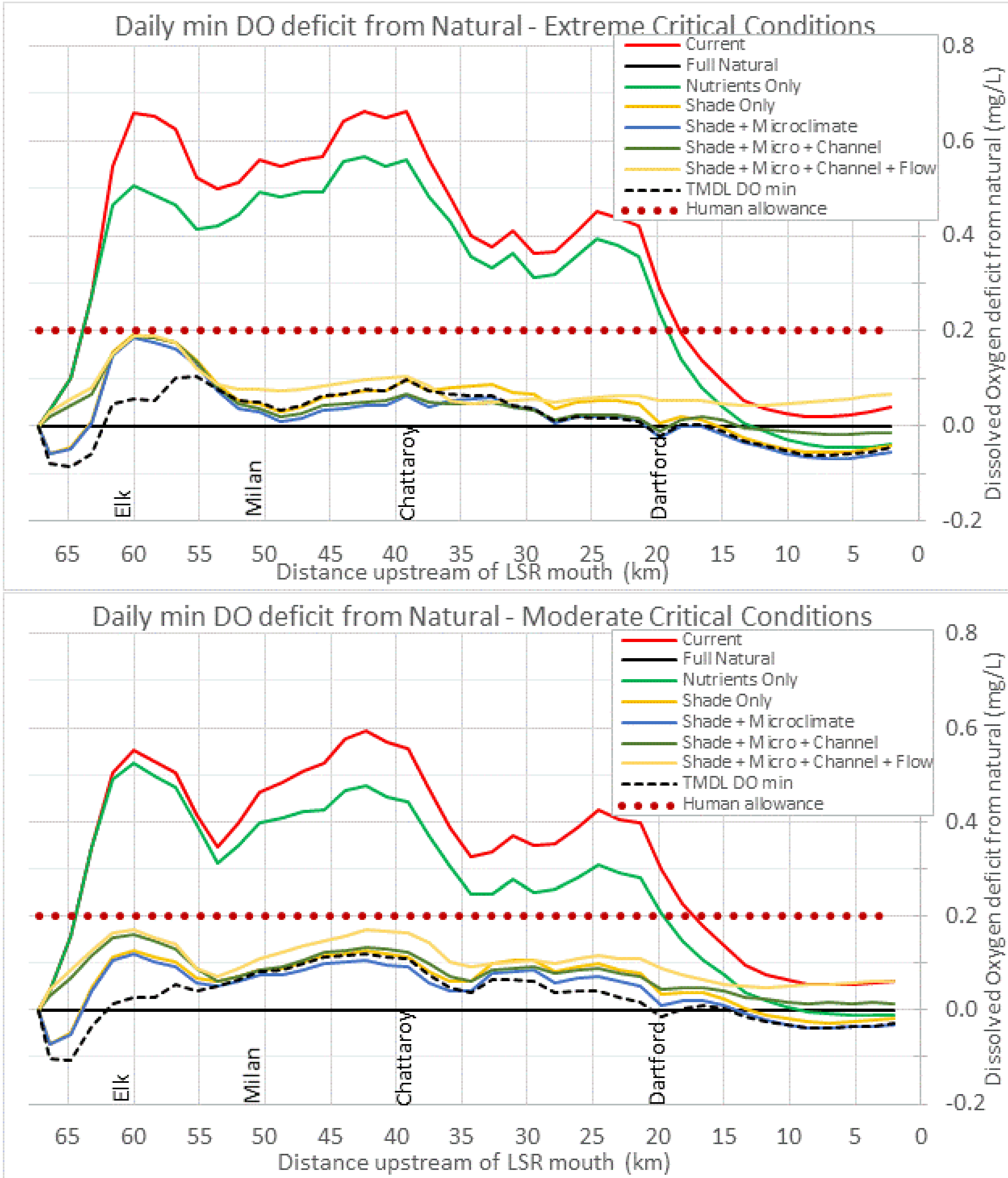


Figure 49. Comparison of various scenarios to "full natural" scenario, as daily minimum dissolved oxygen deficit.

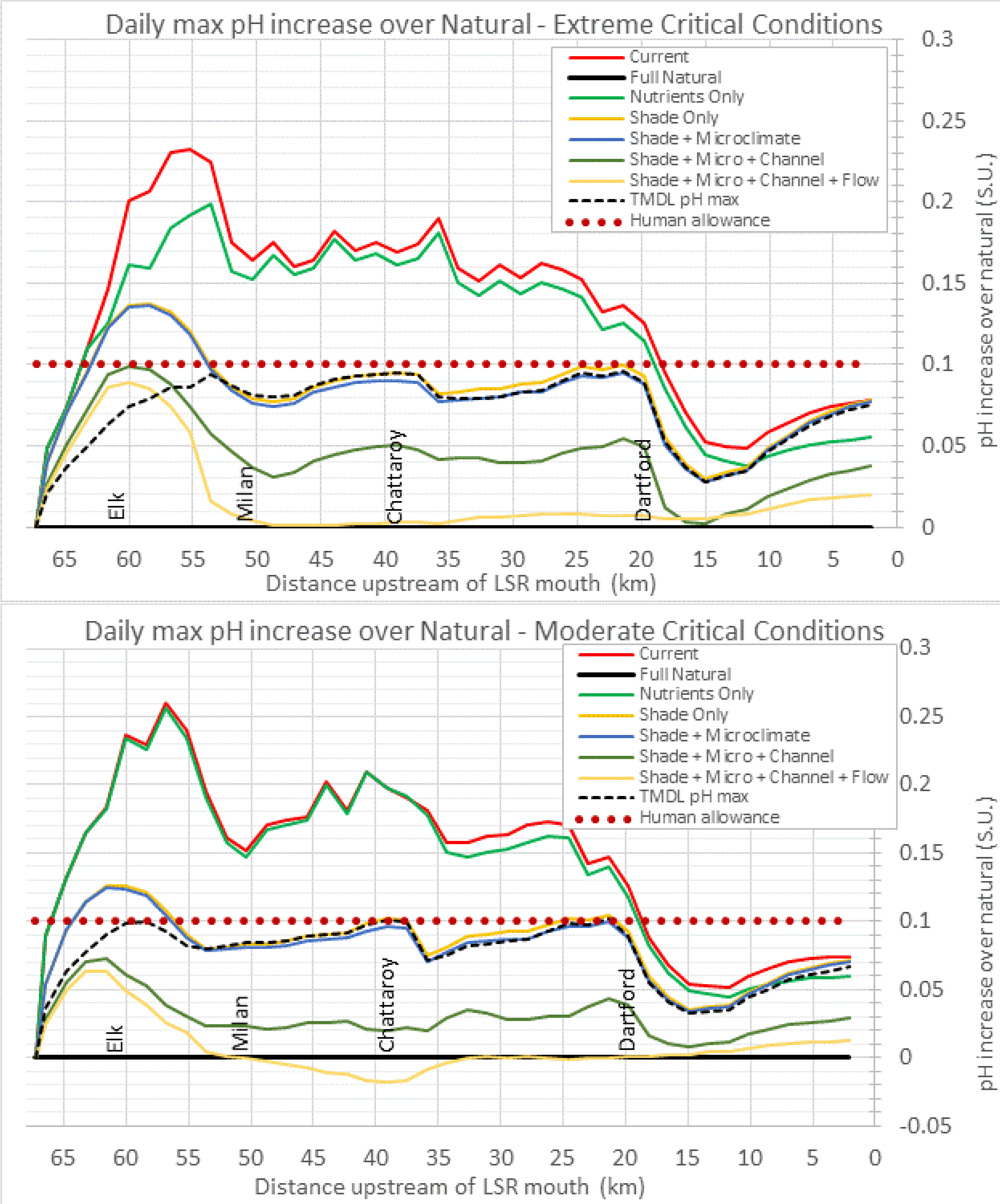


Figure 50. Comparison of various scenarios to "full natural" scenario, as daily maximum pH increase.

Tributaries and upper Little Spokane River (RMA) model scenarios

Figures 51 and 52 present RMA model predictions for daily minimum dissolved oxygen and daily maximum pH under current and system potential conditions. We ran the following scenarios:

- **Current conditions** – all modern day human impacts included.
- **Natural temperature** – temperature and PAR inputs adjusted to reflect system potential conditions improvements in shade. This scenario also includes improvements in channel depth.
- **Full natural** – temperature, PAR, channel depth, and nutrient inputs adjusted to reflect system potential conditions.

The RMA model framework does not include streamflow, transport, or channel width. Also, there was no way to account for riparian microclimate improvements. However, the QUAL2Kw simulations of the Little Spokane River did include these elements, and the resulting analyses indicate these inputs are unlikely to make a large difference in system potential conditions DO and pH estimates. By capturing temperature, PAR, nutrients, and channel depth, we expect that the RMA model provides a reasonable simulation of system potential conditions.

We ran all scenarios under critical weather conditions, represented by 90th percentile air temperatures.

The RMA models predict that even under system potential conditions (represented by the “full natural” scenario), DO will not meet numeric criteria in the upper Little Spokane River or in most tributary locations (Figure 51). Possible exceptions to this include Dry Creek (55DRY-00.4), where four out of four models predict system potential conditions meeting criteria, Otter Creek (55OTT-00.3), where three out of four models predict system potential conditions meeting criteria, and Dartford Creek (55DAR-00.2), where both of the two models predict system potential conditions meeting criteria. All three of these creeks are cool, spring-fed streams with high levels of reaeration.

Model predictions indicate that pH will meet numeric criteria even under current conditions in most tributary locations, but not in the upper Little Spokane River (Figure 52). The models do not predict that any sites which currently exceed pH criteria will meet them under system potential conditions, with one possible exception on the Little Spokane River. For the upper Little Spokane River (Little Spokane River at Scotia; 55LSR-46.7), one of two models predicts pH improving from barely exceeding the criteria to barely meeting it.

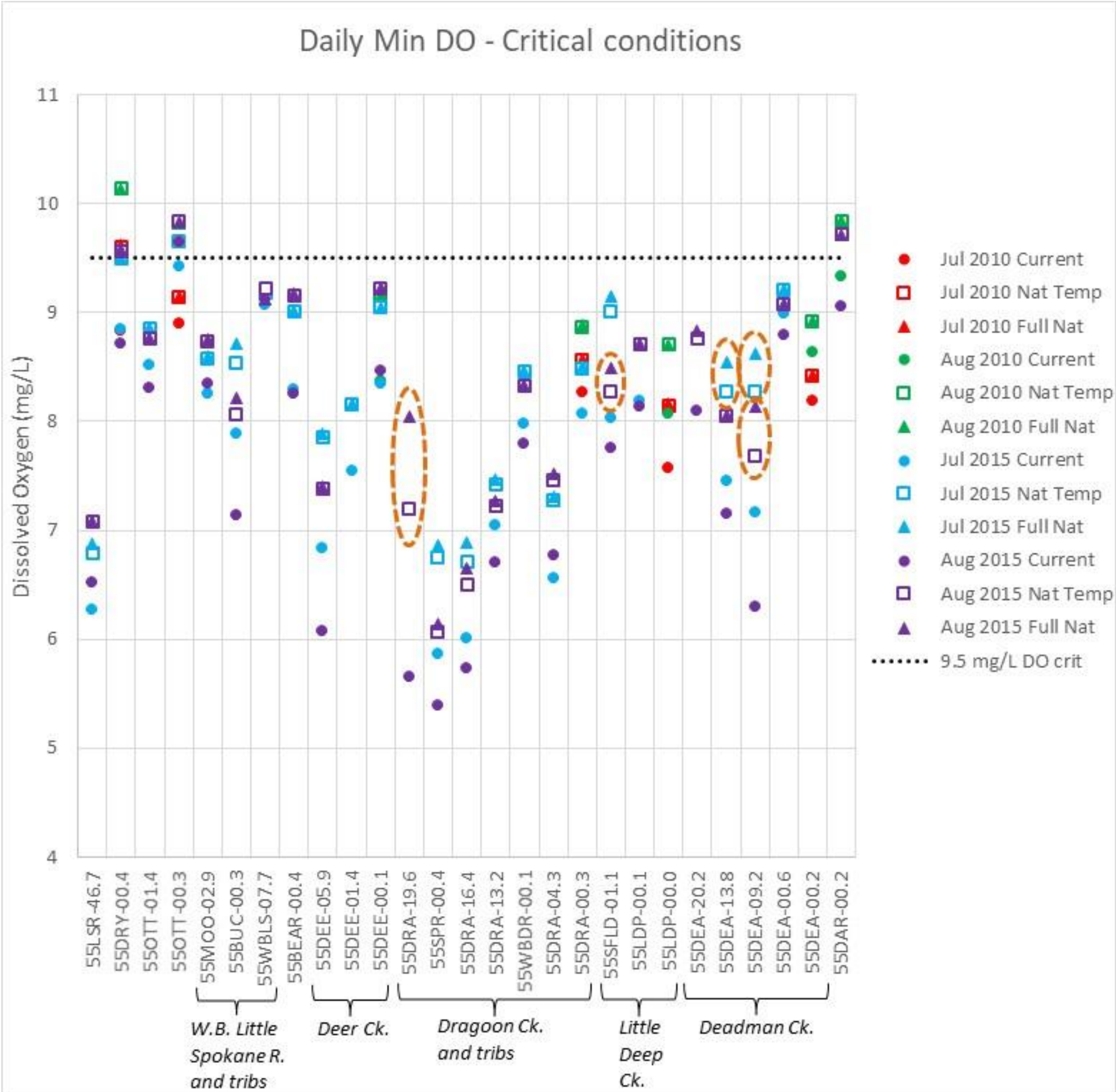


Figure 51. RMA model predictions of daily minimum dissolved oxygen under system potential and current conditions scenarios.[11]

[11] Orange dashed circles indicate instances where the difference between the "natural temperature" and "full natural" scenarios (that is, the difference that is attributable to nutrients/productivity) is greater than 0.2 mg/L.

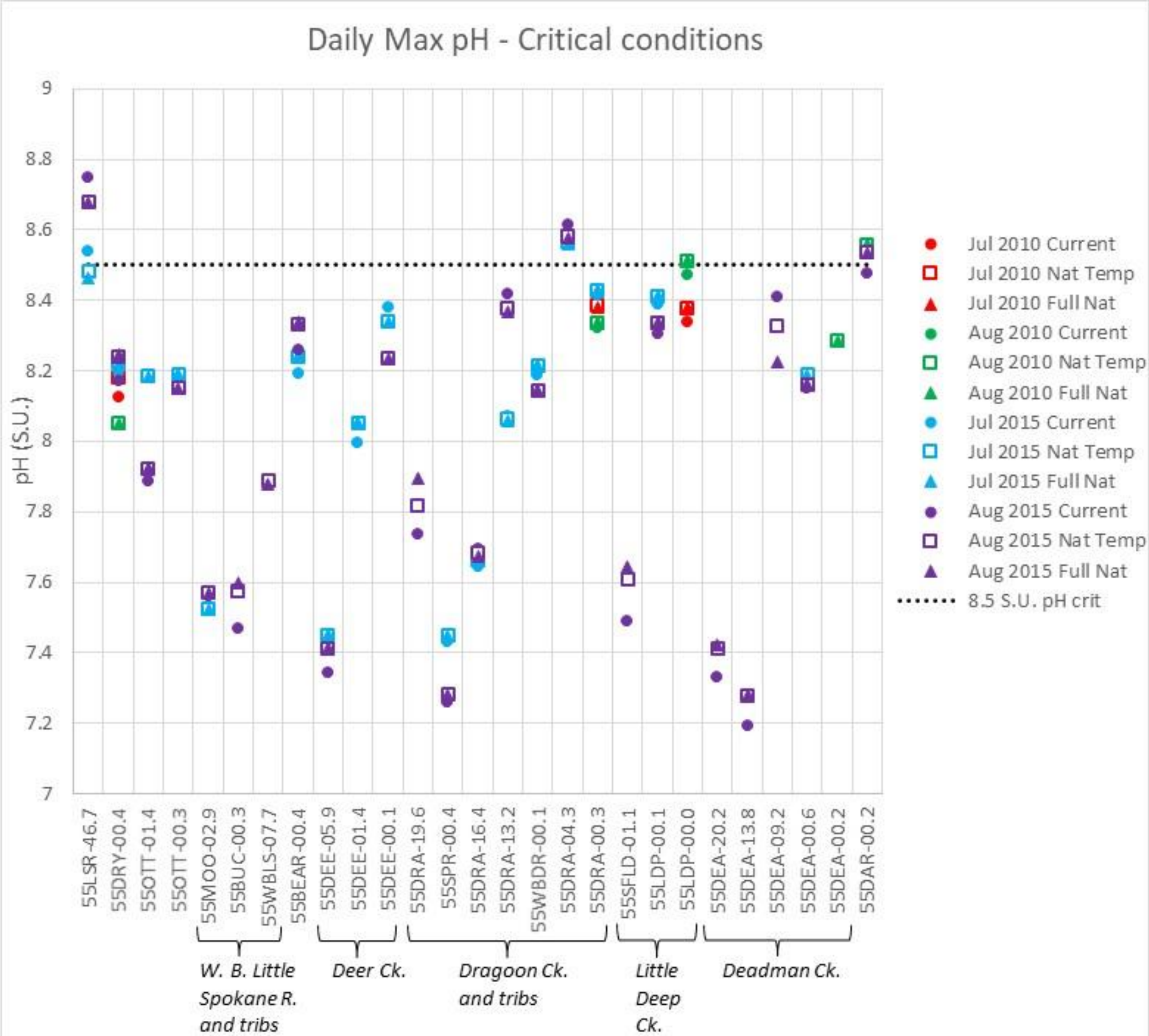


Figure 52. RMA model predictions of daily maximum pH under system potential and current conditions scenarios.

The full natural conditions scenarios predict up to 2.4 mg/L of DO improvement, depending on the location. The largest predicted improvements are for Dragoon Creek at Montgomery Rd. (2.4 mg/L change) and Deadman Creek at Heglar Rd. (1.5-1.8 mg/L change). The model does not predict any improvements for the West Branch Little Spokane River at Fan Lake Rd., which is downstream of a largely unimpacted, natural reach. We predict intermediate levels of improvement (0.2-1.3 mg/L change) for most other tributary sites. For pH, there is little or no predicted change (<0.1 S.U. improvement) for most locations. The only location with predicted pH improvement greater than 0.1 S.U. is Deadman Creek at Heglar Rd. (0.2 S.U. change); however, we note that pH met numeric criteria at this site during the four surveys.

Similar to the QUAL2Kw model findings for the Little Spokane River, the RMA models predict that for most tributaries, most or all DO improvement would be the result of restored shade and resulting cooler water temperatures and reduced PAR. Figure 51 represents the predicted DO improvement due only to restored shade, temperature, and PAR as the distance between the circle (current conditions scenario) and the same-colored square (natural temperature scenario). The predicted DO improvement due to reduction of nutrients and algae growth is the distance between the square (natural temperature scenario) and the triangle (full natural scenario).

At most locations, the predicted DO improvement due only to reduction of nutrients is negligible. However, there are a few exceptions. These include the following sites:

- Dragoon Creek at Montgomery Rd. (55DRA-19.6; 0.8 mg/L change)
- S.F. Little Deep Creek at Big Meadows Rd. (55SFLD-01.1; 0.2 mg/L change)
- Deadman Creek at Holcomb Rd. (55DEA-13.8; 0.3 mg/L change)
- Deadman Creek at Heglar Rd. (55DEA-09.2; 0.5 mg/L change)

These four sites will need nutrient reductions to meet the water quality standards. All four of these sites are in nitrogen-limited stream reaches, so the reductions will be to dissolved inorganic nitrogen (DIN). We discuss nutrient limitation patterns further in the **DO and pH Discussion** section below.

For the few RMA-modeled sites where pH is currently in violation of criteria (Little Spokane River at Scotia, Dragoon Creek at North Rd., and Dartford Creek at mouth), the very small improvements predicted under system potential conditions result almost entirely from restoration of shade and reduced temperature. We do not expect nutrient reductions to provide significant pH improvement at these sites.

For locations that already meet pH criteria, the water quality standards also require any human influence to be less than 0.2 S.U. This is already the case at most locations, with the possible exception of Deadman Creek at Heglar Rd (55DEA-09.2; 0.2 S.U. total human impact). We predict that restoration of temperature alone would restrict human influence on pH to less than 0.2 S.U. at all locations.

DO and pH Discussion

The most important finding from the QUAL2Kw and RMA modeling exercise is that the vast majority of DO and pH improvement that would occur under system potential conditions results from shade improvements. In contrast, we predict that nutrient reductions will produce smaller improvements in most locations, although at certain locations and times nutrient reductions may produce a significant benefit. There are only four locations, all in tributaries, where the estimated anthropogenic nutrient impact to DO exceeds 0.2 mg/L.

This is an unusual finding for a DO and pH TMDL study. In many systems where such analyses have been performed, we have found DO and pH to be very sensitive to nutrients (e.g., Carroll and Anderson, 2009; Snouwaert and Stuart, 2015). The following sections provide some discussion of the relationships between DO, pH, nutrients, algal productivity, channel characteristics, shade, and other factors. This discussion will provide context to understand why streams in the Little Spokane River watershed are mainly sensitive to shade rather than nutrients.

Processes that determine dissolved oxygen and pH

Shade, temperature, and light

Shade, temperature, and light are some of the most important factors that affect dissolved oxygen and pH in flowing streams in the Little Spokane River watershed. Shade affects DO and pH in two important ways. First, well-shaded streams tend to be cooler than poorly-shaded ones. Lower water temperatures mean higher saturation points for dissolved gasses, leading to higher DO and lower pH. Also, most biological and metabolic processes occur more slowly at lower temperatures. Second, shade blocks light from reaching the stream. Aquatic algae and plants, like all photosynthetic organisms, depend on light for photosynthesis. Less light reaching the stream usually results in less biological productivity.

Algal productivity and reaeration

Two key biological and physical processes that affect dissolved oxygen and pH are 1) photosynthesis and respiration of aquatic algae and plants; and 2) gas exchange with the atmosphere, or reaeration. These processes function within the context of water temperature, which determines the amount of dissolved gasses that water can hold.

During daylight hours, aquatic algae (in shallow streams usually mostly attached algae, or periphyton, as opposed to phytoplankton, or floating algae) and aquatic plant (macrophyte) photosynthesis outpaces respiration. When this happens, DO increases in the water column. At the same time, the photosynthesis depletes dissolved carbon dioxide, raising the pH of the water. At night, the opposite happens – photosynthesis ceases and respiration dominates, depleting DO and at the same time increasing dissolved carbon dioxide, which reduces pH. Thus, these biological processes tend to result in dissolved oxygen and pH “swings” with high DO and pH during late afternoon and low DO and pH during early morning.

Gas exchange between the water and the atmosphere tends to push dissolved gas levels toward their saturation point. Thus, under supersaturated conditions degassing will reduce dissolved oxygen and carbon dioxide, and under subsaturated conditions reaeration will increase dissolved gas levels. The saturation point varies with temperature, with colder water able to hold more oxygen than warm water. Therefore, for dissolved oxygen, the combination of temperature and gas exchange works counter to the effect of biological productivity, tending to raise DO early in the morning when water is cold, and lower DO later in the afternoon when water is warmer. For pH this is not the case, since late afternoon warm temperatures (and therefore lower CO_2 and higher pH) happen to coincide with time of day when biological productivity also lowers CO_2 and therefore raises pH.

Biological productivity tends to dominate in low-gradient streams with long pools, stretches of quiescent water, few and gentle riffles, and wide or poorly shaded channels that allow sunshine to reach the stream. Such streams experience high DO in the afternoon and low DO in the morning, and the magnitude of both the DO and the pH "swings" tends to be large.

In higher-gradient streams with more riffles, "white water," and narrow or well-shaded channels where riparian vegetation prevents sunlight from reaching the stream, reaeration tends to dominate. Such streams experience high DO in the morning and low DO in the afternoon, and the magnitude of both the DO and pH "swings" tends to be smaller.

Figures 53 and 54 present photographs of representative productivity-dominated and reaeration dominated streams in the LSR basin, respectively. Figure 55 presents typical diel DO and pH profiles from productivity-dominated and reaeration-dominated streams.

Bulk groundwater mixing
In areas with large groundwater inflows, the DO and pH of the groundwater can directly influence instream DO and pH, through bulk mixing. In the LSR watershed, it is common for groundwater to have lower DO concentrations and pH values than surface water. Thus, in the inflow reach, groundwater can lower DO and pH. However, groundwater inflows tend to be cooler than surface water (during the summer months), and they contribute to streamflow. These attributes of groundwater tend to benefit DO, and probably more than offset the bulk mixing effect over medium- to far-field distances.

Organic decomposition
The decay of carbonaceous organic material requires oxygen and produces carbon dioxide, lowering DO and pH. This is referred to as carbonaceous biochemical oxygen demand (CBOD). Where these processes occur in the streambed sediments, it is referred to as sediment oxygen demand (SOD). These processes are common in wetlands, but can also occur in flowing streams. CBOD and SOD can be either human or natural in origin.

In the LSR watershed, strongly subsaturated DO conditions and low pH are most commonly found immediately downstream of wetland areas. This is likely the result of CBOD/SOD processes occurring in the wetland. Some tributary streams display a lesser degree of subsaturation (usually in conjunction with more dominant productivity and/or reaeration driven diel cycles), suggesting that CBOD/SOD processes may come into play to a small degree there as well.

In the Little Spokane River mainstem, the QUAL2Kw model provides a way to account for carbonaceous material and potential CBOD/SOD effects. We found organic carbon to be extremely conservative in the Little Spokane River, with an insufficient supply to produce any appreciable oxygen demand. This finding is consistent with BOD5 sample results from the Little Spokane River, which were nearly always non-detects. Appendix G, Tables G-5 through G-9, footnotes for CBODfast; and Table G-12, notes for Slow CBOD, Fast CBOD, and Detritus, provide more detail. Appendix G, Figure G-1, symbols m_o, c_s, and c_f, illustrate the relationship between these model variables.

Figure 53. Two examples of productivity-dominated streams.

Top: Little Spokane River @ Elk (55LSR-37.1)
Bottom: Dragoon Creek @ North Rd. (55DRA-04.3)

Figure 54. Two examples of reaeration-dominated streams.

Top: Dragoon Creek @ Mouth (55DRA-00.3); taken from Crescent Rd. bridge
Bottom: Otter Creek @ Mouth (55OTT-00.3)

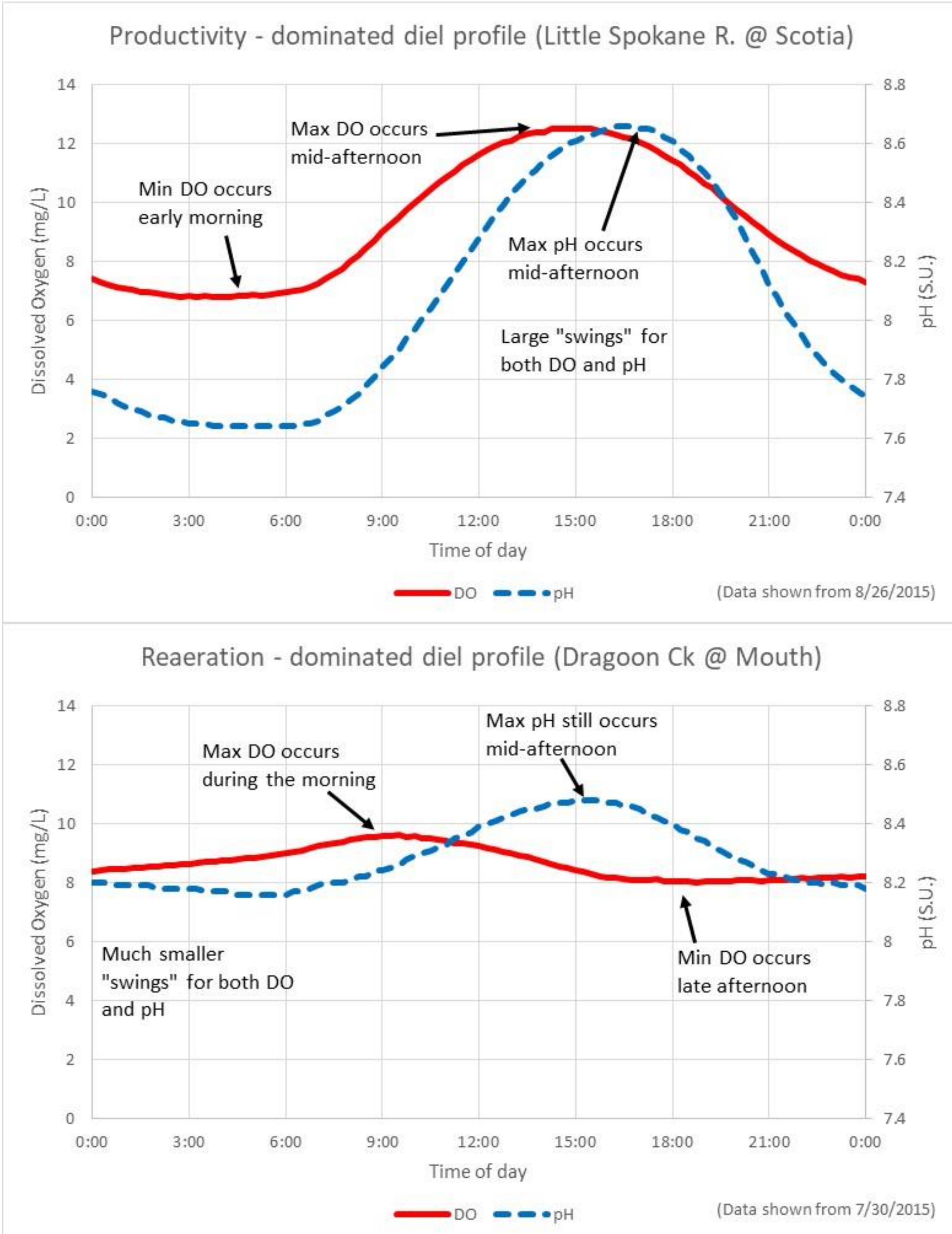


Figure 55. Typical diel DO and pH profiles from productivity and reaeration-dominated streams.

DO and pH dominant processes in the Little Spokane River watershed

The Little Spokane watershed contains a wide variety of stream types, ranging from high-elevation forest headwater streams to wide valley-bottom rivers. Groundwater inputs, lakes, ponds, wetlands, and even beaver activity can have various effects on streams.

Figure 56 shows where different processes dominate DO patterns, overlaid on a map of stream gradients throughout the watershed. The four categories shown on this map are:

- Productivity: DO and pH patterns defined by algal productivity, similar to top graph in Figure 55. Estimated as occurring where DO max occurred later than 13:00 (approx. solar noon). Reaeration can still be important, but this means that productivity is a more significant force relative to reaeration.
- Balanced: Estimated as occurring where DO max typically occurred between 12:00 and 13:00. Productivity and reaeration are likely both in effect, approximately in balance or on the "tipping point."
- Reaeration: DO and pH patterns defined by reaeration, similar to bottom graph in Figure 55. Estimated as occurring where DO max occurred before 12:00.
- Low-DO Processes: DO and pH patterns defined by bulk mixing with low-DO groundwater and/or organic decomposition processes (CBOD or SOD). Estimated as occurring where average DO saturation throughout a 24-hour period was less than 80%.

Figure 56 illustrates several patterns:

- Productivity-dominated DO and pH patterns prevail in the Little Spokane River, as well as in low-gradient reaches of the larger tributaries, including parts of the West Branch Little Spokane River, Dragoon Creek, and Deadman Creek.
- Reaeration-dominated DO and pH patterns are found in the smaller tributary streams, as well as in locations where a larger stream travels through a higher-gradient reach, such as lower Deadman and lower Dragoon Creeks.
- Bulk mixing of low-DO groundwater and organic decomposition processes (CBOD/SOD) are likely responsible for the low-DO patterns found in the upper portion of the Dragoon sub-watershed.
- Low-DO (and/or low-pH) patterns also occur in the Little Spokane River at Frideger Rd., the West Branch Little Spokane River at Harworth Rd., and Deadman Creek at Bruce Rd. Each of these locations is directly downstream of extensive swamp/wetlands, and organic decomposition processes (CBOD/SOD) in the wetlands are probably responsible.

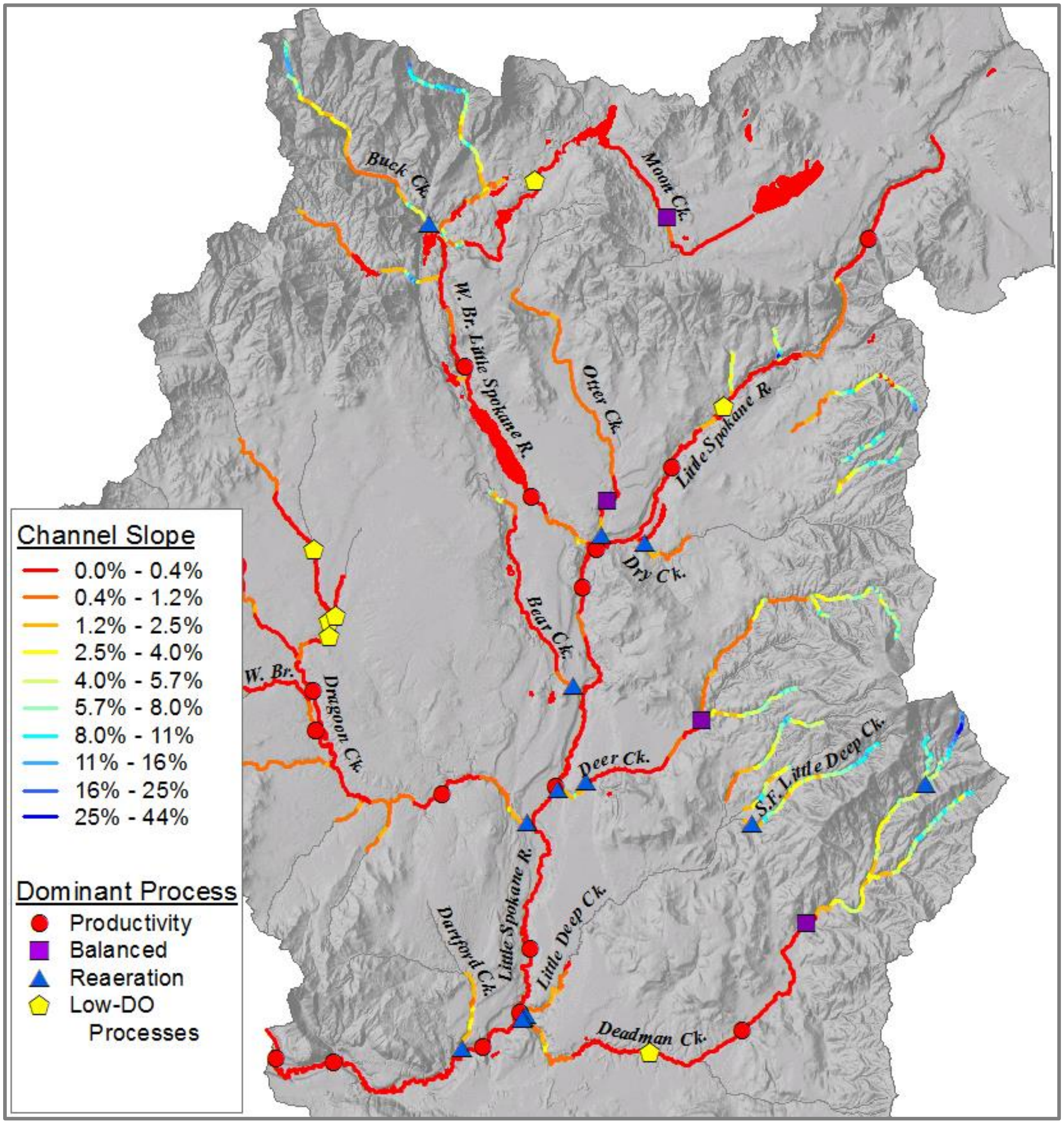


Figure 56. Dominant processes that define DO and pH throughout the Little Spokane watershed, shown as they relate to channel slope.

Sensitivity of algae to nutrients

Biological productivity in shallow streams with rocky or gravelly substrates is mainly driven by attached bottom algae, or periphyton. Periphyton-driven productivity likely holds for most streams in the Little Spokane watershed. Periphyton depend on nutrients derived from the water column for their sustenance and growth, so they can be very sensitive to changes in nutrient concentrations.

Nitrogen vs. Phosphorus

The nutrients most likely to limit algae growth are nitrogen and phosphorus. Whichever nutrient is in shorter supply relative to algal demand, will be potentially limiting. Scientists often use the ratio of dissolved inorganic nitrogen (DIN; defined as ammonia plus nitrate plus nitrite) to soluble reactive phosphorus (SRP) as an indicator of the limiting nutrient. Ratios of DIN to SRP of less than 4.5:1 indicate nitrogen limitation, ratios over 9:1 indicate phosphorus limitation, while ratios between 4.5:1 and 9:1 are uncertain (Borchardt, 1996).[12]

Summertime nutrient data indicate that the Little Spokane watershed contains a variety of phosphorus-limited and nitrogen-limited streams (Figure 57). Nutrient limitation appears to vary across the watershed according to landscape characteristics. Streams originating in low-elevation valley areas, including the Little Spokane River, Dragoon Creek, and many small tributaries, tend to be phosphorus-limited. These areas often have strong summertime baseflows from groundwater, and may reflect human impacts to groundwater nitrogen. These streams display excess nitrogen but low background SRP levels (Average July-September value = 0.019 mg/L). In contrast, streams originating in the mountainous areas surrounding Mt. Spokane and Boyer Mtn. tend to be nitrogen-limited. These streams have little or no DIN during the summer, but relatively high SRP concentrations (Average July-September value = 0.032 mg/L). These high SRP concentrations appear to be a natural occurrence, given that they occur in some areas with little or no human impacts upstream. They may be the result of bedrock geology in these headwater areas.

Factors other than nutrients can also limit periphyton growth. These include as streambed space, light, temperature, and the inherent growth rate of a given algae species. Therefore, it is important to remember that regardless of the DIN:SRP ratio, productivity in streams may be limited by something other than nitrogen or phosphorus.

[12] We express ratios here as mass (mgN/L:mgP/L). These ratios are often expressed as molar ratios, including in the reference literature. Molar N:P ratios of 10:1 or less indicate nitrogen limitation, ratios over 20:1 indicate phosphorus limitation, and ratios between 10:1 and 20:1 are uncertain.

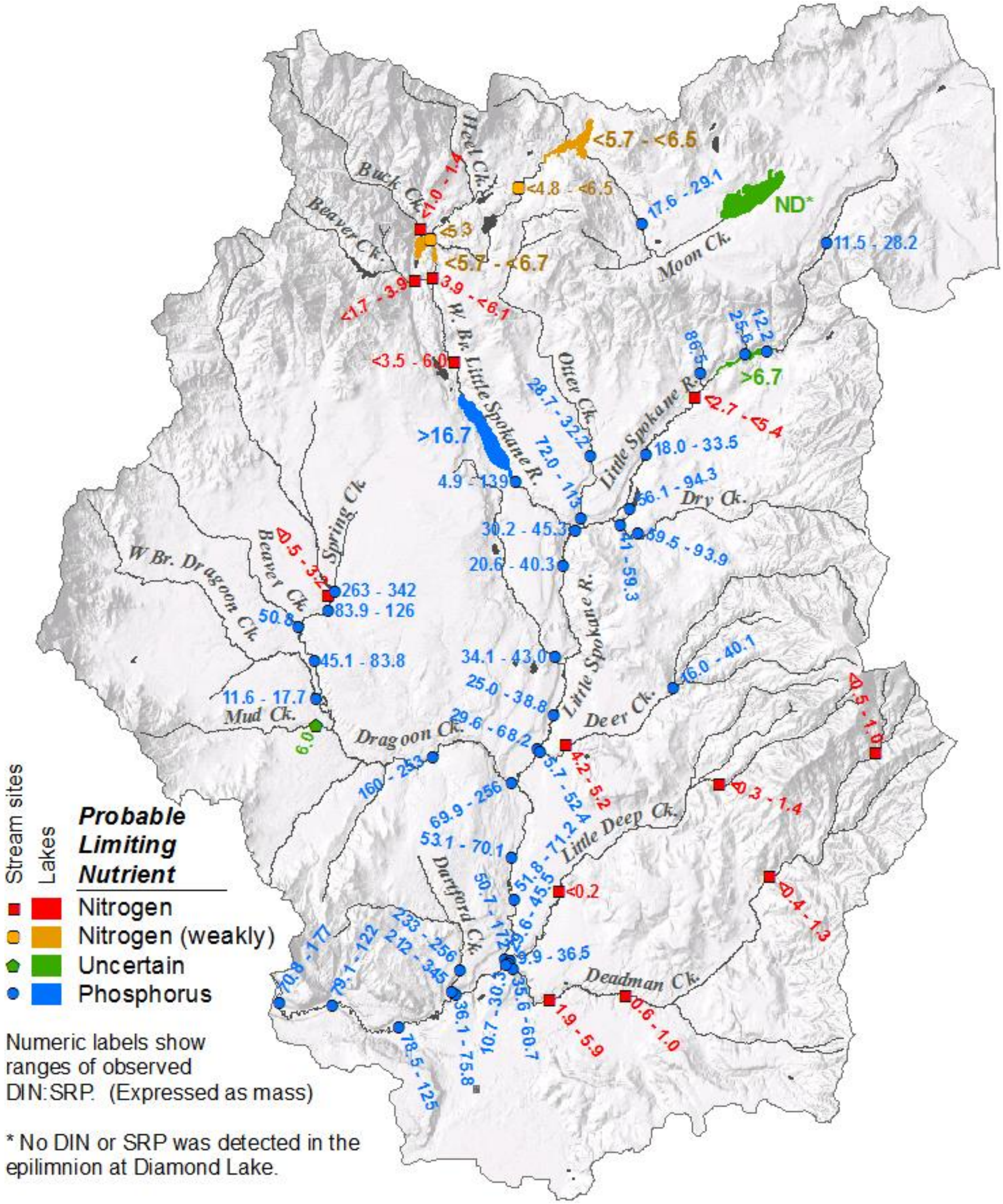


Figure 57. Observed inorganic nitrogen:phosphorus ratios and probable limiting nutrient during July-September.

Algae growth saturation by nutrients

The relationship between nutrient concentrations and periphyton growth is not linear. At low concentrations of the limiting nutrient, a small increase in limiting nutrient concentration will have a large impact on productivity. At higher concentrations, additional increases in concentration will have a smaller impact on productivity (Figure 58). The **Assessment of Model Sensitivity to Nitrogen and Phosphorus** section of Appendix G provides an in-depth discussion of this relationship as it relates to model calibration.

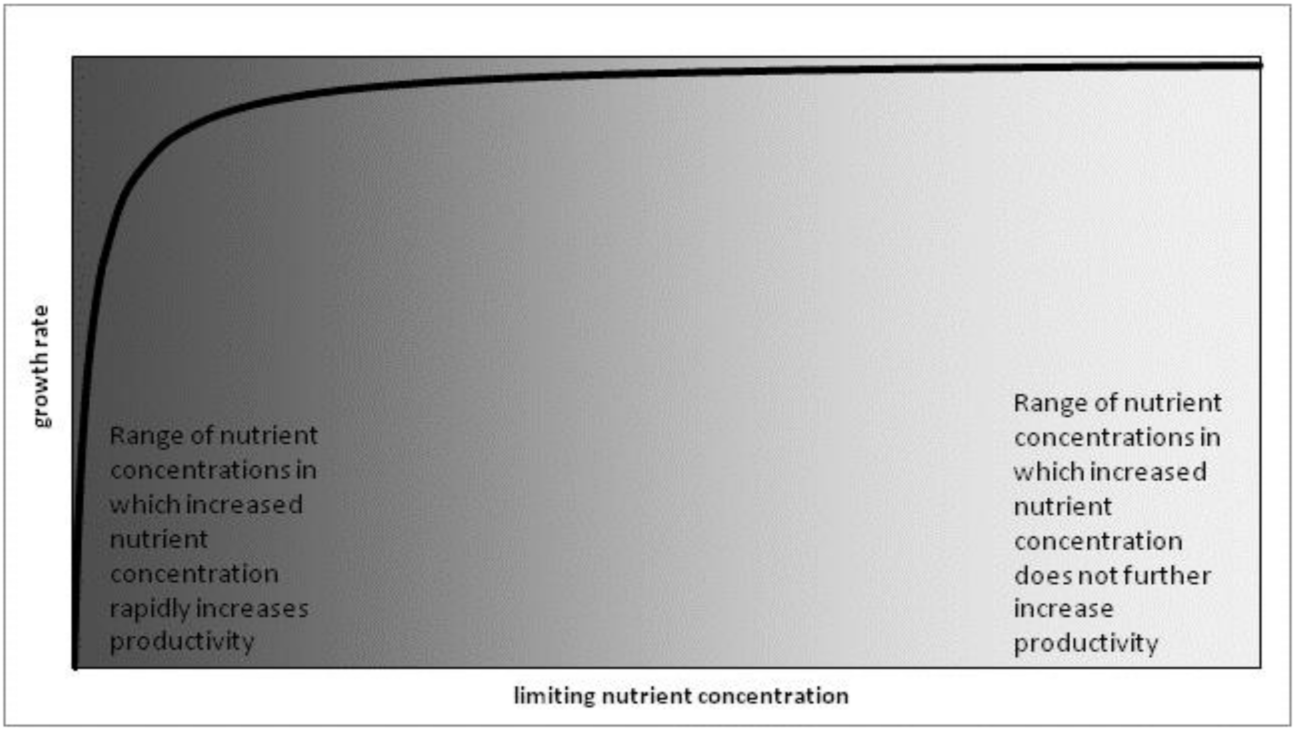


Figure 58. Conceptual diagram of the relationship between limiting nutrient concentration and algal growth rate, using Monod equation (Monod, 1950; see Borchardt, 1996).

We observed periphyton in the Little Spokane watershed to be dominated by diatom algae. In particular, diatom taxa which are low-nutrient indicators predominated within periphyton communities (See Appendix K). The growth rates of these taxa can be saturated by very low levels of nitrogen and phosphorus (Bothwell, 1985; Rier and Stevenson, 2006; see Appendix G). Inorganic phosphorus (SRP) concentrations observed throughout the Little Spokane watershed were broadly too high to effectively limit periphyton growth. This was true even at phosphorus-limited sites and at sites with little or no upstream human impact. Observed dissolved inorganic nitrogen (DIN) concentrations were low enough to effectively limit periphyton growth at some nitrogen-limited sites, particularly in the Dragoon Creek and Deadman Creek sub-basins.

Summary of relationship between nutrients, shade, DO, and pH

Total maximum daily load studies for DO and pH often place primary emphasis on reduction of nitrogen and/or phosphorus as a means to improving DO and pH, by reducing algal productivity. Reducing nutrients can be an effective means of improving DO and pH wherever the following are both true:

- Diel patterns of DO and pH are largely driven by algal productivity (see Figure 55, top graph).
- Nutrient concentrations either are low enough to effectively limit algal productivity, or can be reduced to levels that low (see Figure 58).

We have found both of these conditions to be the case in many systems in Eastern Washington where DO and pH TMDL studies have been conducted, including the Wenatchee River (Carroll et al, 2006), the North Fork Palouse River (Snouwaert and Stuart, 2015), and others.

In the Little Spokane River watershed, at the vast majority of stream locations, one or both of these conditions does *not* hold true. For example, diel patterns of DO and pH in the Little Spokane River are driven by algal productivity, but even natural background phosphorus concentrations appear to be too high to limit algal growth. For another example, in some nitrogen-limited tributary locations, background nitrogen levels are low enough to limit algal growth, but algal growth is not a primary determinant of DO and pH. Thus nutrient reduction will only be a viable strategy to improve DO and pH at a few locations. These include those tributary locations previously mentioned as having a nutrient impact to DO greater than 0.2 mg/L (Dragoon Ck. at Montgomery Rd., Deadman Ck. at Heglar Rd., Deadman Ck. at Holcomb Rd., and S.F. Little Deep Ck. at Big Meadows Rd.). This also includes the reach of the upper Little Spokane River between Chain Lake and the West Branch LSR confluence, where nutrient reductions (in conjunction with shade restoration) are necessary to keep human pH impacts to less than 0.1 S.U.

In contrast, there is considerable opportunity to improve DO and pH in the Little Spokane River and its tributaries through restoration of shade. There are many locations in the Little Spokane River watershed where riparian vegetation has been removed or degraded, and the current amount of stream shade is less than system potential shade (Joy and Jones, 2012). Restoring system potential shade will improve DO and pH by reducing water temperatures and limiting light availability.

The watershed loading analysis earlier in this report demonstrated the need for phosphorus reductions in the Little Spokane watershed to meet the load allocations at the mouth of the Little Spokane River. The ultimate purpose of these reductions is to protect and improve DO further downstream, in Lake Spokane. These phosphorus reductions will have a very limited impact on streams within the Little Spokane watershed. However, we note that many of the same best management practices (BMPs) that will reduce phosphorus inputs are the same as those that are needed to restore shade, such as woody riparian buffers.

To the extent that a few nutrient reductions are needed to address DO and pH in the Little Spokane watershed, these overlap well with the reductions required by the watershed loading analysis. For example, areas in Deadman Creek and upper Dragoon Creek are high priorities both for phosphorus reduction and nitrogen reduction. The BMPs that will reduce nitrogen to improve instream DO locally will be the same as those needed to reduce phosphorus to protect DO downstream in Lake Spokane.

Seasonal variation

In most river systems in Washington, dissolved oxygen and pH violations tend to occur during the summer and early fall. The following factors tend to lead to low DO and high pH during this season:

- High water temperatures result in water having less capacity to hold dissolved gasses including carbon dioxide, which helps keep pH down, and oxygen.
- High water temperatures promote algae growth.
- Long days, high solar angle, increased PAR, and generally sunny weather all contribute to algae growth.
- Groundwater inflows, after recharge during the spring freshet, tend to decline through the summer. This contributes to lower streamflows and higher water temperatures.
- Low streamflows mean:
    - Less dilution to provide assimilative capacity for nutrient inputs
    - Shallower water, which means less water depth to assimilate algal gas exchange
    - Slower travel times, allowing water a longer time to equilibrate to warm weather and algal impacts
- Clearer water means more light penetration to the stream bed, which promotes algae growth.

The instream TMDL analysis is based on extreme critical weather conditions, reflected by the lowest 7-day average streamflows that are expected to occur once every 10 years (7Q10), and 90^{th} percentile air temperatures. The key assumption is that streams in the Little Spokane watershed are most sensitive to nutrients, shade, and other variables during extreme critical conditions, and that allocations designed to protect streams under such conditions will also be protective under less extreme conditions.

We evaluated this assumption by using the QUAL2Kw model to run a set of scenarios under less critical conditions as well. We represented these “moderate critical conditions” by using the lowest 7-day average streamflows that are expected to occur once every 2 years (7Q2), and 50^{th} percentile air temperatures. Figure 49 shows that for DO, the “dissolved oxygen deficit from natural” is usually higher for any given scenario under extreme critical conditions than under moderate critical conditions. This means that various types of human modifications generally have their greatest impact under extreme critical conditions. Conversely, this means that restoration efforts will also have their greatest relative impact for DO under extreme critical conditions.

This is less true for pH. For most scenarios throughout most of the system, Figure 50 shows the predicted system sensitivity to be similar under both sets of critical conditions. One exception is that pH is expected to be more sensitive to shade and channel changes in the Elk area under extreme critical conditions.

Overall these QUAL2Kw model predictions indicate that allocations designed for extreme critical conditions will also be protective under less extreme conditions.

Loading capacity for instream DO and pH

As previously discussed, the loading capacity is defined as "the greatest amount of loading that a water body can receive without violating water quality standards" (40 CFR § 130.2(f)). Loading capacities can be expressed in a variety of ways, such as nutrient reductions, solar radiation heat loads, restoration of microclimate, and mitigation of hydromodification.

This section details the loading capacity for nutrients that will protect DO in certain tributary locations, as well as some reaches of the upper Little Spokane River mainstem. We presented the loading capacity for phosphorus to meet the Load Allocation for the mouth of the Little Spokane River specified in the *Spokane River and Lake Spokane DO TMDL* earlier in the **Watershed Loading TMDL Analysis** section of this report.

Figures 59 and 60 present maps of the modeled human impacts to DO from temperature/light, and nutrients, respectively.

As noted, human impacts to DO and pH in the Little Spokane River and its tributaries are mostly the result of increased water temperatures and light penetration due to riparian vegetation removal and alteration of channel geometry. Therefore, fully restoring DO and pH will require restoring system potential riparian vegetation throughout the watershed. We defined a loading capacity for solar shortwave radiation (see **Loading Capacity** section) based on system potential shade for all streams in the watershed. Appendix I and the **Climate and Shade Inputs** and **Natural Conditions Scenarios > Shade** sections of Appendix G detail the methods for calculating system potential shade.

In the portion of the Little Spokane River between Chain Lake and the West Branch Little Spokane River confluence, we predict that it would be possible to achieve water quality standards for pH (restricting human impacts to less than 0.1 S.U.) either by restoring both shade and channel morphology, or by restoring shade and reducing nutrients. Because of the inherent uncertainty around channel morphology, this TMDL specifies shade restoration and nutrient reductions for those reaches.

Also, at several tributary locations, there is a human DO impact due to nutrients and algal productivity. At these locations, nutrient reductions are needed in addition to the shade and channel restoration. In most cases, pH does not exceed the numeric criterion in the tributaries. In the few tributary locations where pH exceeds the criterion, our analysis does not indicate sensitivity to nutrients (see Figure 52). DO rather than pH is the limiting parameter for nutrients in the tributaries.

The locations where nutrient reductions are needed to protect instream DO and pH fall into two categories:

- The reach of the Little Spokane River near Elk, between Chain Lake and the West Branch Little Spokane River confluence. In this reach, the DIN:SRP ratios are close to the Redfield ratio, indicating uncertainty about which nutrient is more limiting. However, all phosphorus in this reach appears to be natural, whereas much of the nitrogen appears to result from human sources.
- Nitrogen-limited tributary locations.

Therefore, we specify the nutrient reductions in terms of dissolved inorganic nitrogen (DIN), which is calculated as the sum of nitrate-nitrite nitrogen and ammonia nitrogen. Table 39 summarizes the loading capacity for DIN, which is based on limiting any DO impact to 0.2 mg/L and any pH impact to 0.1 S.U.

At most tributary sites where a DIN load reduction is needed, we ran two RMA models, one each based on data from July 2015, and August 2015. At the two sites on Deadman Creek, the July 2015 model indicated the need for a greater DIN reduction than the August 2015 model. This is because the difference between observed DIN concentrations and assessed natural condition DIN concentrations was greater in July 2015 than August 2015. We calculated loading capacities for DIN at the two Deadman Creek sites using RMA model results, measured nutrient concentrations, and measured streamflows from July 2015.

For Upper Dragoon Creek, which did not have data to support an RMA model during July 2015, and South Fork Little Deep Creek, where only the RMA model for August 2015 indicated a nutrient reduction, we used the RMA model results from August in conjunction with measured nutrient and flow values from July.

Flow conditions throughout the basin during the July 2015 survey period were extremely low, with 81.5 cfs recorded at the USGS gage at Dartford, as compared to the 7-day, 10-year (7Q10) low flow value of 87.2 cfs.

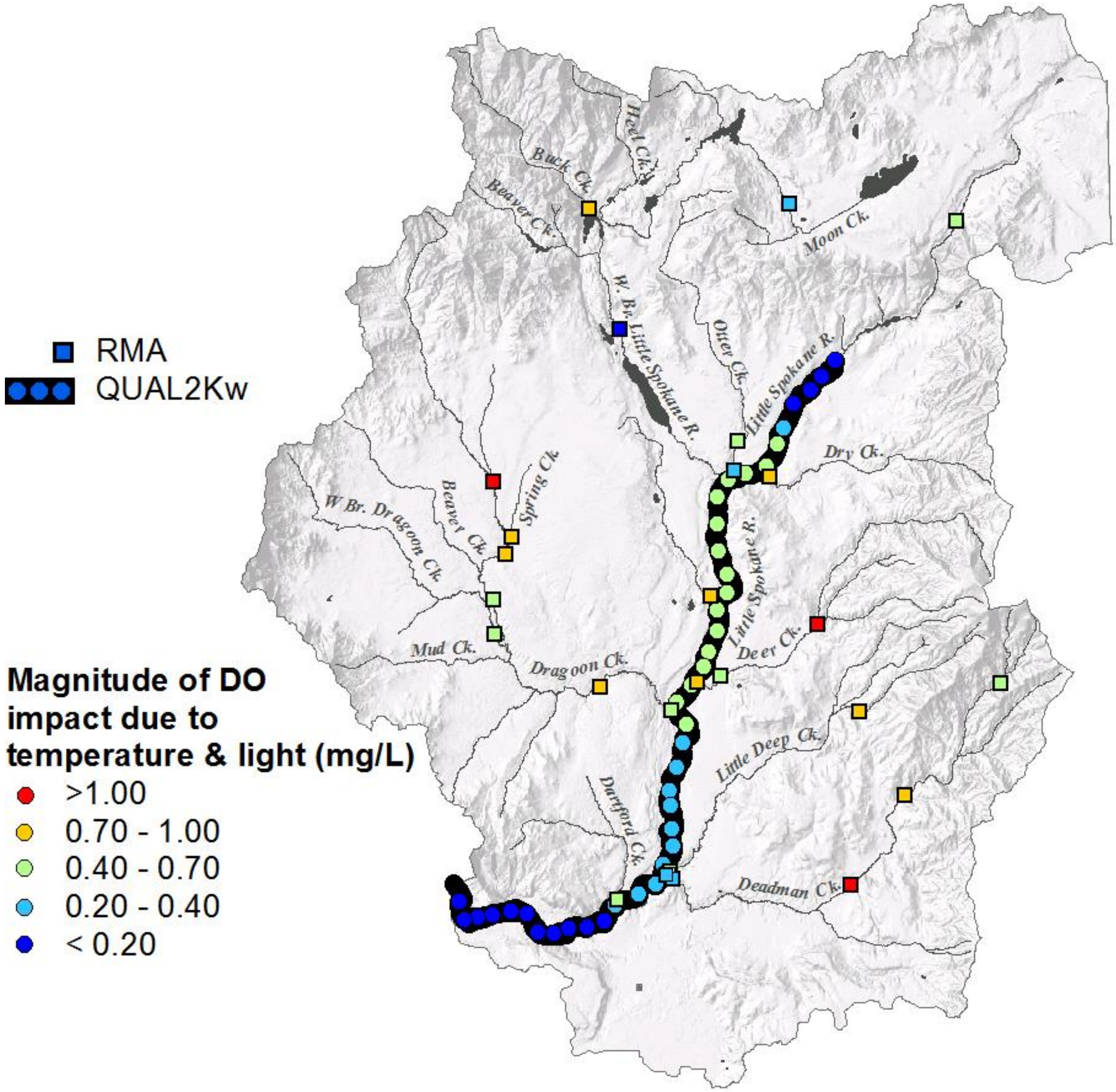


Figure 59. QUAL2Kw and RMA predicted magnitude of human DO impact due to temperature[13] and light.

[13] We estimated temperature impacts by accounting for human alterations to:

- Shade
- Channel geometry
- Microclimate (QUAL2Kw only)
- Flow (QUAL2Kw only)

As can be seen in Figures 49 and 50, the vast majority of this impact comes from shade, followed by channel geometry. Impacts due to microclimate and flow are very minimal.

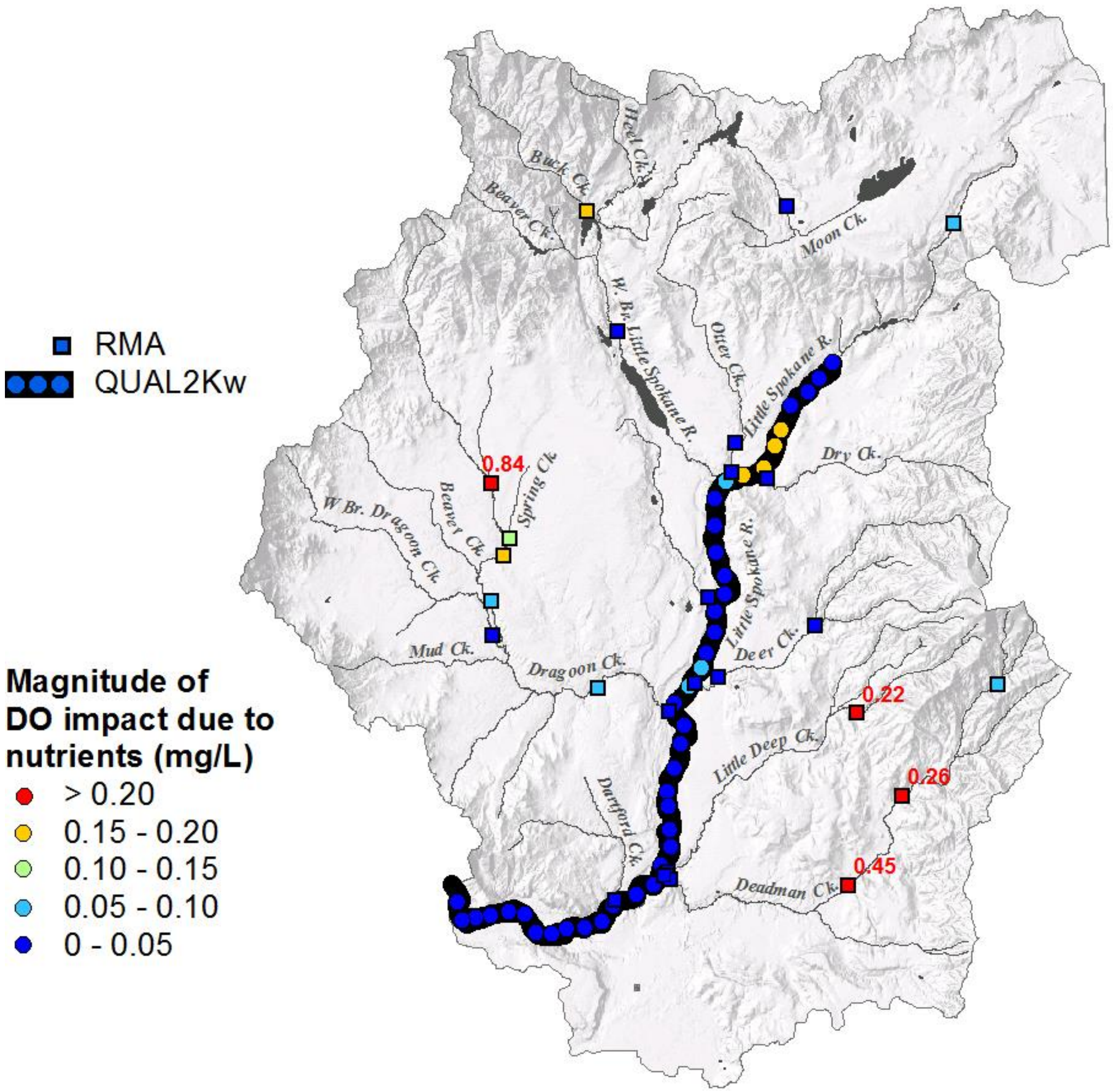


Figure 60. QUAL2Kw and RMA predicted magnitude of human DO impact due only to nutrients.[14] [15]

[14] We generally calculated DO impacts due to nutrients based on whichever nutrient is more limiting. In the Little Spokane River, this is generally phosphorus, except just downstream of Chain Lake, where nitrogen is more limiting. In the tributaries, it can be either nitrogen or phosphorus. See Figure 57 for a map of N vs P limitation.

[15] Note that the color scale for Figure 59 differs from Figure 60. DO impacts from temperature/light are generally larger than those from nutrients.

Table 41. Nutrient loading capacities to protect instream DO and pH.

Location ID	Applicable reach	Current conditions DIN (ug/L)	System potential DIN (ug/L)	TMDL DIN (ug/L) [a]	7Q10 flow (cfs)	DIN Load capacity (kg/day)	% reduction needed [b]
55LSR-37.1	Little Spokane R. between Chain Lake and Elk	29.4	13.9 [c]	16.5	33.6	1.36	44%
55LSR-33.2	Little Spokane R. between Elk and WBLSR confluence	335	55.6 [c]	281	45	30.9	16%
55DRA-19.6	Upper Dragoon Ck., abv Spring Ck.	146	11 [d]	24.5 [e]	0.58	0.035	83%
55SFLD-01.1	S.F. Little Deep Ck	107	11 [d]	94.3 [f]	0.10	0.023	12%
55DEA-13.8	Deadman Ck. from state park bdy to Holcomb Rd.	68	11 [d]	35.8	1.6	0.14	47%
55DEA-09.2	Deadman Ck. in Peone Prairie from Holcomb Rd. to Heglar Rd.	60.5	11 [d]	24.7	1.4	0.085	59%
All other tributary and mainstem LSR locations in the LSR watershed		Nutrient loading capacity not limited by instream DO and pH. Overall loading capacity will be limited by: • Anti-degradation/anti-backsliding considerations • Phosphorus reductions indicated by watershed analysis					

[a] TMDL DIN is the concentration of DIN that the QUAL2Kw or RMA model predicted would limit human DO impact to 0.2 mg/L and pH impact to 0.1 S.U.

[b] Reduction of the total DIN load, not just the human portion.

[c] System potential DIN calculated by QUAL2Kw model.

[d] For all low-DIN N-limited tributary sites, we used a value of 11 ug/L DIN to represent natural conditions. We obtained this value by taking the 10th percentile of observed DIN values at Deadman Ck @ Mt Spokane Park Bdy (55DEA-20.2) and Buck Ck @ Mouth (55BUC-00.3). These two sites have little or no residential or agricultural development in their watershed areas that might increase nitrogen levels.

[e] An RMA model was not available for July 2015. We calculated the % reduction needed using the August 2015 RMA model, and applying concentrations and flows from July 2015.

[f] The July 2015 RMA model did not indicate a reduction. The August 2015 RMA model did indicate a small reduction. We calculated the % reduction needed using August 2015 RMA model, and applying concentrations and flows from July 2015. This is a conservative approach.

Other Analyses

Time of travel and nutrient transport

The amount of time that water takes to travel from one place to another in a watershed has profound implications for water quality and pollutant transport. With respect to nutrients, dissolved oxygen, and pH, here are some of the key differences between slow-moving and fast-moving streams:

- In slow-moving systems, there is ample time for algae and aquatic plants to absorb nutrients. This means that much of the nutrient load entering the system may be processed within the system, reducing the nutrient load reaching downstream locations. However, there is more potential for these algae and aquatic plants to create dissolved oxygen and pH problems near nutrient sources. In the context of the Little Spokane watershed, slow moving streams are more likely to have their own nutrient-linked DO and pH problems.
- In fast-moving systems, there is less time for algae and aquatic plants to absorb nutrients. This means that much of the nutrient load entering the system will simply be transported downstream and flow out of the system unchanged. However, there is less potential for dissolved oxygen and pH problems to occur near nutrient sources. In the context of the Little Spokane watershed, fast-moving streams are more likely to send their nutrients downstream to have an impact somewhere else, e.g., Lake Spokane.

The Little Spokane watershed contains a wide variety of streams, from high-gradient mountain streams to low-gradient meandering rivers; from snow-fed streams where streamflow varies enormously through the year to spring-fed streams where streamflow barely changes at all. The watershed also includes a large number of lakes and wetlands where water can reside for a long time before continuing to travel downstream.

Time of travel analysis basis and purpose

Ecology performed an analysis of velocities and stream times of travel during multiple seasons in a variety of streams throughout the watershed. We principally based this analysis on:

- Time-of-travel estimates from the dye study on the Little Spokane River
- Channel surveys conducted on tributaries and on the upper Little Spokane River
- Lake volumes
- Flow conditions estimated from measured and gaged flows

Appendix J provides detailed documentation of calculation methods and an assessment of confidence in the accuracy of the calculations.

We undertook this analysis for three purposes:

- To provide crucial overall context for understanding transport patterns within this very complex watershed.
- The QUAL2Kw model of the Little Spokane River mainstem required time-of-travel data to correctly characterize the channel geometry (see Appendix G).

- The shade analysis for the RMA models required average shade for 12 hours upstream of each RMA model site. This time-of-travel analysis provided the ability to translate that 12-hour travel time into a distance (see Appendices H and I).

Time of travel analysis results and discussion

Figures 61 and 62 illustrate estimated water velocities and times of travel throughout the watershed. Figure 61 shows typical March-May runoff season conditions, and Figure 62 shows critical low-flow conditions. Appendix J provides additional figures showing other flow conditions as well.

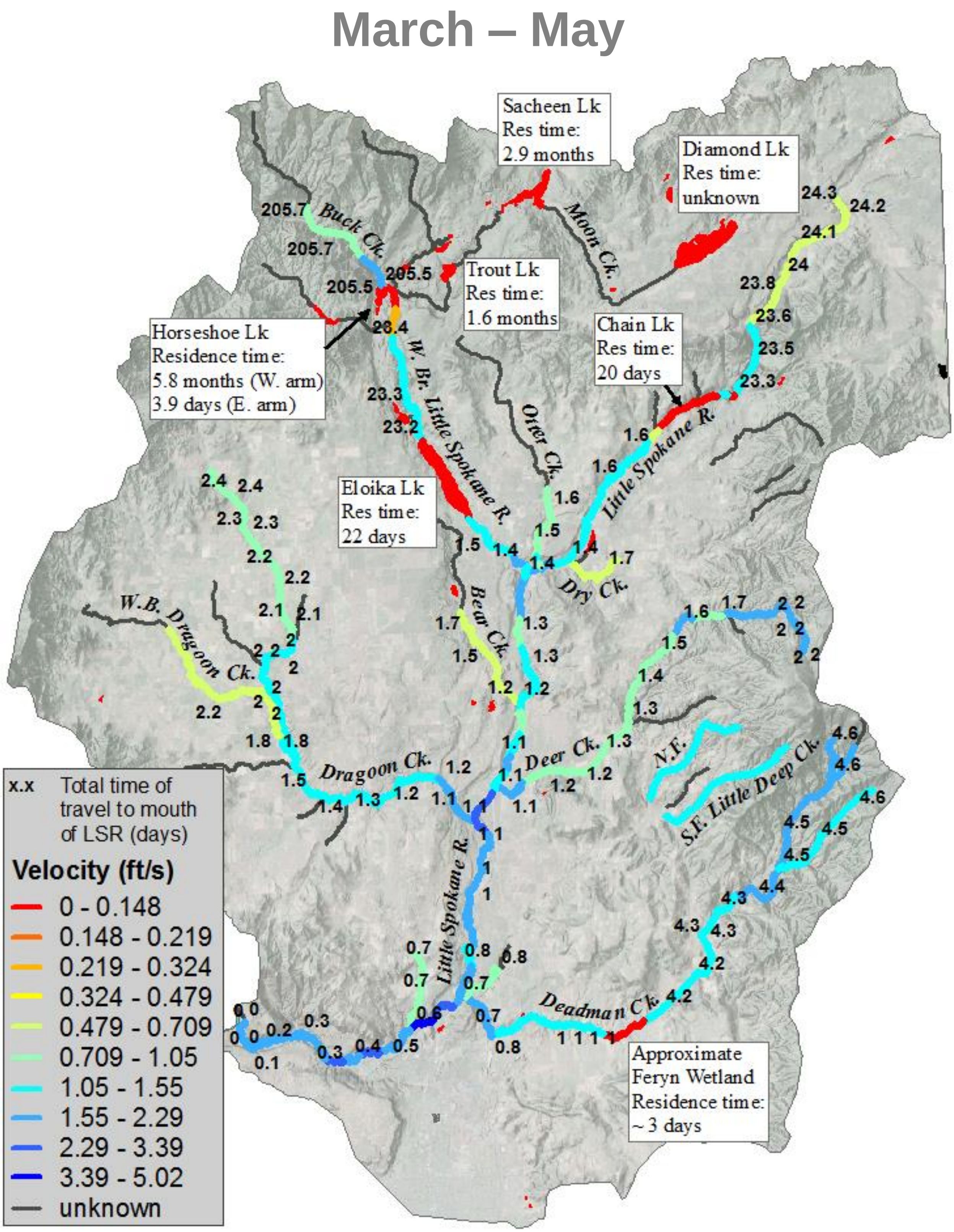


Figure 61. Water velocity and travel times for median flow condition during March – May.

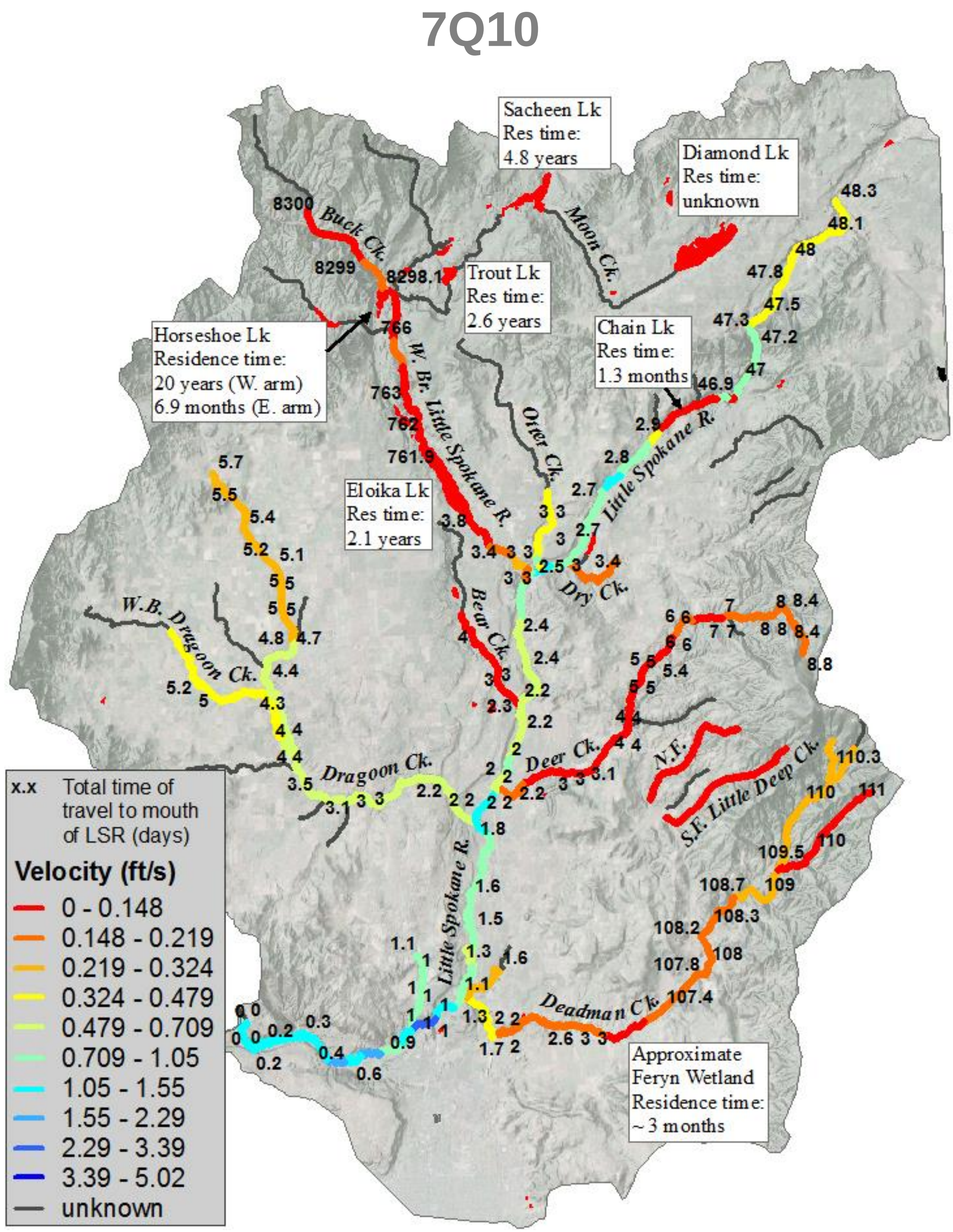


Figure 62. Water velocity and travel times for 7 day, 10 year (7Q10) critical low flow condition.

During higher flow springtime conditions, all flowing streams in the watershed move fairly quickly. The primary distinction, for purposes of considering downstream transport of nutrients, is between areas that are upstream of a lake and areas that are not. Any water that can flow to the Little Spokane River mouth without encountering a lake will exit the watershed within a few days or less. Water that must flow through one or more lakes will reside weeks or even months within those lakes.

During low flows, those streams which have sustained groundwater-fed baseflows move fairly quickly. These include the mainstem Little Spokane River, Dragoon Creek, and Otter Creek. Streams which do not have strong baseflows, such as Deadman Creek, Deer Creek, and the West Branch Little Spokane River (WBLSR), experience very low velocities as flows drop. Lake residence times increase, further isolating areas upstream of those lakes. Residence times for lakes in the WBLSR system extend to over a year, which essentially means that water upstream of Eloika Lake remains trapped in the WBLSR sub-watershed until the next spring's high flows flush it out. Wetland residence times extend during low flow conditions. For example, we expect that the wetland on Deadman Creek in the Peone Prairie, which does not impede transport much at high flows, significantly isolates surface water in upper Deadman Creek at low flows.

The WBLSR sub-basin warrants special mention as being especially "isolated in time" from the rest of the watershed by its several lakes. For example, the sum of the mean annual residence times of lakes separating Buck Creek[16] from the lower watershed is 1.2 years. The sum of the mean annual residence times of lakes[17] separating Moon Creek from the lower watershed is 11 months, not accounting for the abundant beaver ponds and wetlands separating Sacheen, Trout, and Horseshoe Lakes.

This suggests that physical distance may be less important to water quality than temporal distance in the WBLSR. A drop of water in Moon Creek near Hwy 211 could take many months to a year to pass to the mouth of the Little Spokane River. However, a drop of water just a few miles over the hill in the Little Spokane River at Camden will reach the mouth in just a couple of days.

Areas located "near in time" to the mouth of the Little Spokane River have more potential to contribute nutrient loads to Lake Spokane within the same averaging season. In setting priorities for nutrient load reductions to protect Lake Spokane, it makes sense to prioritize sources closer in time to the mouth.

[16] This counts both arms of Horseshoe Lake.
[17] This counts the East arm of Horseshoe Lake, but not the West arm.

Lakes

Trophic state and anoxic depth

Table 40 presents a summary assessment of the observed conditions in Chain, Diamond, Sacheen, Horseshoe, and Eloika Lakes, based on Ecology data collected September 1-3, 2015. Complete nutrient data as well as dissolved oxygen, temperature, pH, and conductivity profiles of the five monitored lakes can be found in the **Lakes data** section of Appendix D.

The trophic state index (TSI) used in our analyses is the one developed by Carlson (1977). It is calculated from Chlorophyll a data, epilimnion total phosphorus data, or Secchi depth data. We present TSI calculations based on all three of these parameters in Table 39, however the one calculated from Chlorophyll a is considered the most reliable.

The trophic state index is an index of the total amount of biological material (biomass) in the lake at a given time. The index has a scale of approximately 0 – 100, with 0 representing an ultra-oligotrophic state and 100 representing a hypereutrophic state. It is important to note that although the trophic state index is an indication of water quality – clarity, "greenness," and nutrient levels – it primarily describes the biological condition of the lake. A more eutrophic lake is one with more plant/algae biomass and higher levels of primary productivity.

There is more information about how to interpret a trophic state index available.[18]

Table 42. Summary assessment of five major lakes in the Little Spokane watershed (September 1-3, 2015).

Lake	Location	Depth (m) [a]	Approx. depth where lake becomes anoxic (m) [b]	Trophic determination	Trophic State Index (Chl a)	Trophic State Index (Total P)	Trophic State Index (Secchi)
Chain	West basin (55CHAI-W)	36	10	Oligo-mesotrophic	35	45	35
Chain	East basin (55CHAI-E)	15.3	8	Oligo-mesotrophic	--	--	35
Diamond	Deepest point (55DIAM)	15	14	Oligo-mesotrophic	35	29	33
Sacheen	Main/East basin (55SACH-E)	12	8	Mesotrophic	42	35	37
Sacheen	Deep location near outlet (55SACH-W)	21.3	6	Mesotrophic	45	40	35
Horseshoe	East arm (55HORS-E)	12.5	7	Eutrophic	54	42	45
Horseshoe	West arm (55HORS-W)	43.7	32	Meso-eutrophic	50	37	43
Eloika	Near north end (55ELOI-N)	3.4	N/A [c]	Eutrophic	61	52	--
Eloika	Near south end (55ELOI-S)	3.3	N/A [c]	Eutrophic	48	48	--

[a] Depth recorded using Hydrolab

[b] Defined here as DO of 1 mg/L or less; DO usually drops quickly to zero below this point.

[c] Eloika Lake is very shallow, lacking a true hypolimnion. No part of the water column is anoxic.

[18] http://www.secchidipin.org/index.php/monitoring-methods/trophic-state-equations/

Table 40 also notes the approximate extent of anoxia (lack of dissolved oxygen) in the hypolimnion (lower portion of the lake). More eutrophic lakes are more likely to have anoxia, and to have it at shallower depths. However, other factors such as depth and circulation patterns also affect this.

We provide this assessment as a general overview to assist in interpreting nutrient cycling in the watershed and provide a general status check on the lakes. A comprehensive assessment of the mechanisms linking nutrient loading, lake nutrient concentrations, trophic state, and dissolved oxygen and pH condition is beyond the scope of this TMDL study, which primarily focuses on flowing streams.

The data from Sacheen Lake may be of particular interest. At the time we sampled during 2015, the Sacheen Lake Water and Sewer District was in the process of constructing a new sewer system. This residential community previously used on-site septic systems. The new community sewer system came online during 2016 (Rounds, 2018). The switch from on-site septic to a community sewer system has the potential to significantly reduce nutrient loading to Sacheen Lake, to make the lake less eutrophic, and to improve oxygen levels. Sacheen Lake data collected in 2015 may prove useful as a pre-sewer baseline for comparison to future data, for assessing improvement.

Nutrients and eutrophication in linked rivers and lakes

When a stream flows through a lake, the lake can have a large impact on the chemistry of the stream. In the Little Spokane watershed, lakes act as nutrient sinks, absorbing a large amount of nitrogen and phosphorus from the streams that pass through them. Figure 63 shows seasonal patterns of dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP), and total phosphorus (TP) above and below Chain Lake and Eloika Lake. Chain Lake, located downstream of a reach with large groundwater inflow, removes a large fraction of DIN, SRP, and TP from the Little Spokane River. Eloika Lake removes a large amount of SRP and TP from the West Branch Little Spokane River but does not apparently reduce DIN. This may be because DIN levels entering Eloika Lake are already low, owing to its location downstream of a string of other lakes.

The mechanisms by which lakes accomplish this nutrient reduction on streams may include algal and plant productivity within the lake, and settling of suspended particles. However, these mechanisms can result in more eutrophic conditions or sedimentation within the lake. It may be the case for the Little Spokane watershed that nutrients discharged into a stream that flows into a lake have a greater impact on the lake than on the flowing stream.

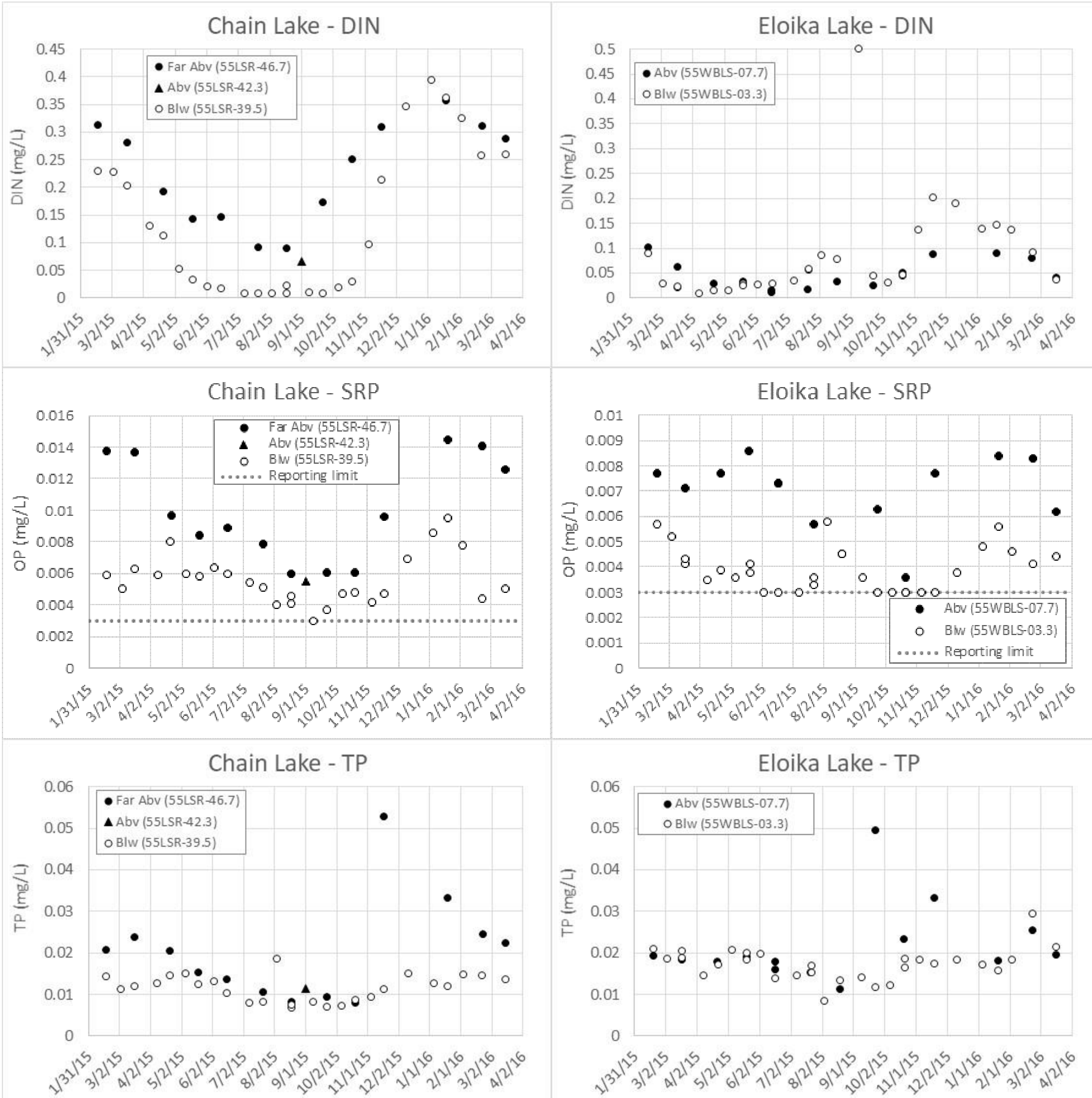


Figure 63. Dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP), and total phosphorus (TP) above and below Chain Lake and Eloika Lake.

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