Reevaluation of Mid Snake/Upper Snake-Rock Subbasin TMDL:

Data Summary, Evaluation, and Assessment

Prepared for

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1. Background

EPA originally approved the Mid Snake/Upper Snake Rock Phosphorus total maximum daily load (TMDL) in 1997, representing Idaho's first nutrient TMDL of consequence that involved point sources. The premise for development of the 1997 Mid Snake TMDL was growths of nuisance aquatic plants (e.g., algal mats and macrophytes), which were occluding the Middle Snake River. Previously in 1988, the Mid Snake Study Group, consisting of local citizens and representatives from industries, coordinated with the Idaho Department of Environmental Quality (DEQ) and the Environmental Protection Agency (EPA) to determine a method for reducing these aquatic plant growths. Based on water quality monitoring information and modeling using EPA's RBM-10 Model, it was determined that the river was impaired for cold-water aquatic life and salmonid spawning because of excess nutrients (total phosphorus; TP) and excess sediment (total suspended solids; TSS). DEQ and EPA later determined that TP was the limiting nutrient contributing to the excess nuisance aquatic plant growths, particularly in the Crystal Springs Reach, which was considered the hot bed for macrophytes and algal mats.

Nearly 10 years later (in 1997), the Mid Snake TMDL was finalized with two in-stream targets: (1) a TP in-stream target of 0.075 milligrams per liter (mg/L) at Gridley Bridge and (2) a 30 percent reduction (on average) of nuisance aquatic plant growths in the Crystal Springs Reach. These targets are interrelated in that a reduction of TP will result in a reduction in macrophytes. The 1997 TMDL (revised 1998) did not incorporate wasteload allocations (WLAs) for point sources. Although approved by EPA, the TMDL had a data gap of wasteload allocations for the point sources (fish farms and municipalities).

The Upper Snake-Rock TMDL (approved by EPA in 2000) included wasteload allocations for the municipalities for TP and TSS; however, the aquaculture wasteload allocations were not developed by the industry. The TMDL was developed with placeholders for the aquaculture wasteload allocations, thereby giving the industry the opportunity to develop its own allocations. The allocations were eventually finalized and incorporated into the 2005 TMDL along with some wasteload allocations for TSS to publicly owned treatment works (POTWs), attenuation estimates, and updated information and data. In addition, the 2000 and 2005 TMDLs incorporated "decision units" in dividing the Middle Snake River into six river segments. The TMDL incorporated in-stream targets for TP (0.075 mg/L) and TSS (52 mg/L) in all six segments, thus making the entire river system compliant with the TP and TSS in-stream targets of 0.075 mg/L and 52 mg/L, respectively. A TP target of 0.1 mg/L was developed for the tributaries.

DEQ conducted a five-year review in 2010. As part of the review, the water quality data summary indicated that the Middle Snake River was compliant for TSS and *Escherichia coli*, but the TP targets had not been achieved in the mainstem and multiple tributaries during 2000 to 2008. The review illustrated that flows have been reduced in the most recent decade, suggesting that the ability of the TMDL to support beneficial uses should be reevaluated. Possible causes of reduced flows are water withdrawals, drought, and climatic patterns (DEQ 2010).

Several other changes have occurred, or will occur soon, within the subbasin related to regulatory and economic conditions. Specifically, EPA recently vacated the use of the trading ratios in a re-issued National Pollutant Discharge Elimination System (NPDES) permit for the City of Twin Falls and a draft City of Jerome NPDES permit because of a dispute regarding the use of 1:1 ratios. In addition, the aquaculture general permit expired in 2012 and is currently administratively extended. EPA anticipates holding a public comment period on a revised aquaculture permit in October 2014, with a goal of finalizing the permit by Spring 2015. Finally, population and economic growth has occurred within the subbasin since initial TMDL development.

In light of the above circumstances, DEQ and EPA Region 10 initiated an assessment and evaluation of all readily available data to determine the need for a TMDL revision. As the first step, EPA Region 10

contracted with Tetra Tech, Inc. to develop this report. This document provides a summary, evaluation, and assessment of all relevant reports and existing data. The assessment focuses on conditions related to hydrology and phosphorus loading, with particular emphasis on phosphorus attenuation throughout the watershed. EPA, DEQ, and Idaho Department of Water Resources (DWR) provided data, technical guidance, and review of this assessment report.

2. Setting

2.1 General Watershed Characteristics

The Middle Snake River flows from Milner Dam (river mile [RM] 638) to the town of King Hill, Idaho (RM 545). The river's length extends approximately 93 miles from an elevation of 4,135 feet at Milner Dam to 2,498 feet at King Hill. This 2,438-square-mile drainage area is designated as United States Geological Survey (USGS) hydrologic unit code (HUC) 17040212, referred to as the Upper Snake-Rock Subbasin (Figure 1). The subbasin intersects with nine counties and those counties with the largest percentage of area are Jerome, Twin Falls, and Gooding. There are 13 incorporated cities within the subbasin boundary (U.S. Department of Commerce 2007).

As defined, the Upper Snake-Rock Subbasin includes 16 major tributaries to the Middle Snake River. The watershed boundaries exclude the drainages of Salmon Falls Creek and Big Wood River (which contributes to the Malad River). These streams drain to the Middle Snake River within the subbasin, but DEQ has defined the drainages as separate and distinct subbasins and has addressed them in separate TMDLs. Another 8-digit HUC draining to the Upper Snake-Rock Subbasin that is not included in this TMDL is the Lake Walcott Subbasin (HUC 17040209).

Over 95 percent of the watershed is within the Snake River Basin/High Desert ecoregion. The topography of this ecoregion consists of tablelands with medium to high relief. Sagebrush and grass dominate throughout the ecoregion and minimal riparian vegetation exists along the Middle Snake River or its tributaries. Elevation within the watershed is illustrated in Figure 2.

The Snake River Canyon is a steep-sided trench, cut into the relatively flat, surrounding plain. Table 1 summarizes the width of the main channel, slope (feet/river mile), elevations, and elevation drop of the Middle Snake River at three river mile locations. Channel width ranges from 50 to 1,500 feet.

Table 1. Width of Middle Snake River (channel) at Various Reaches (DEQ and Mid Snake TAC 1999)

River Miles	River Width (feet)			Reach Miles	Slope (feet/RM)	Elevation (feet)	Elevation Drop (feet)
	Mean	Max	Min				
638–619	103	225	50	20	29.5	4,135-3,380	755
618–559	441	1,500	100	60	15.2	3,380-2,580	800
558–545	254	600	150	14	7.7	2,580-2,497	83

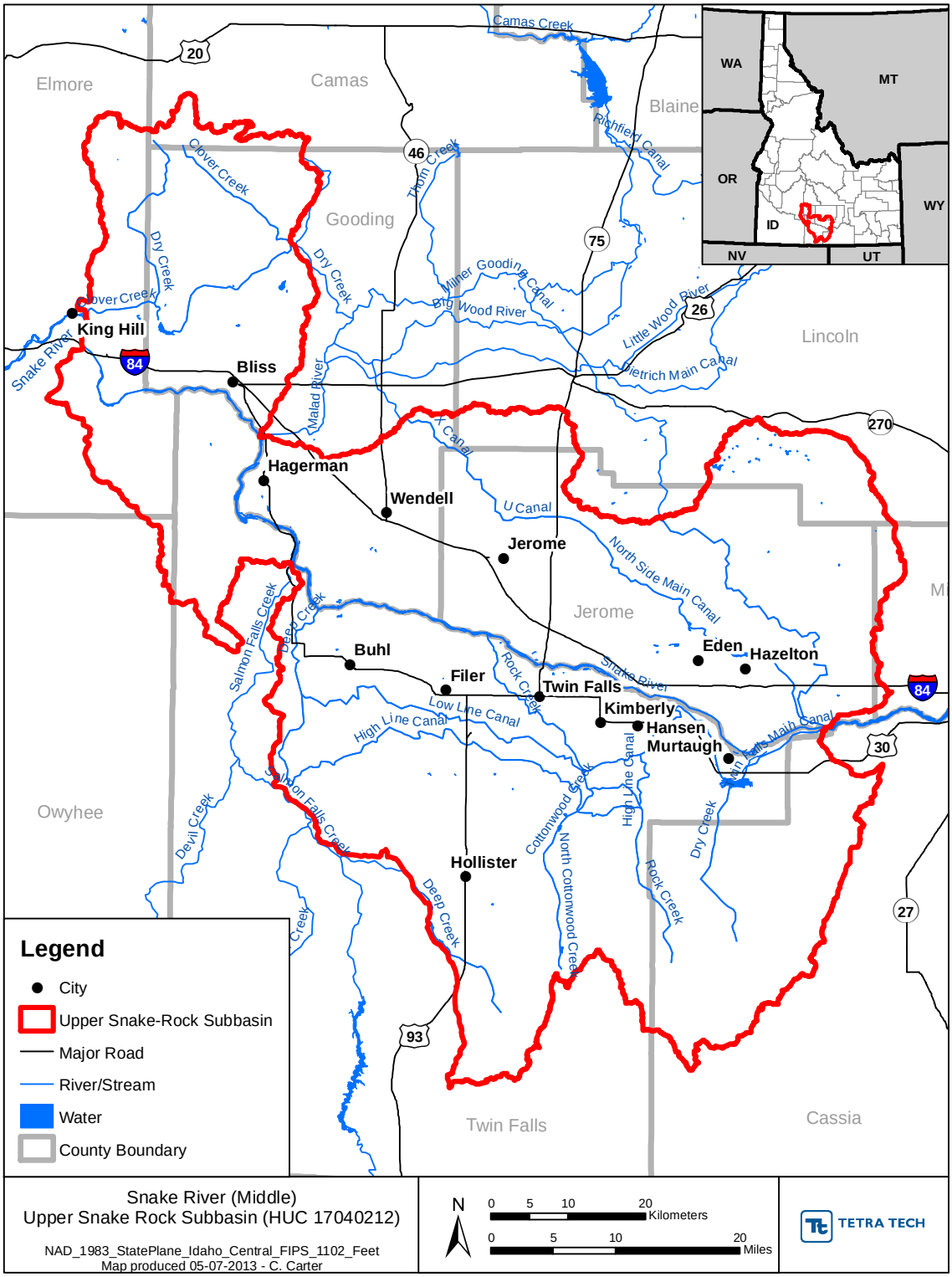

Figure 1. Study Area.

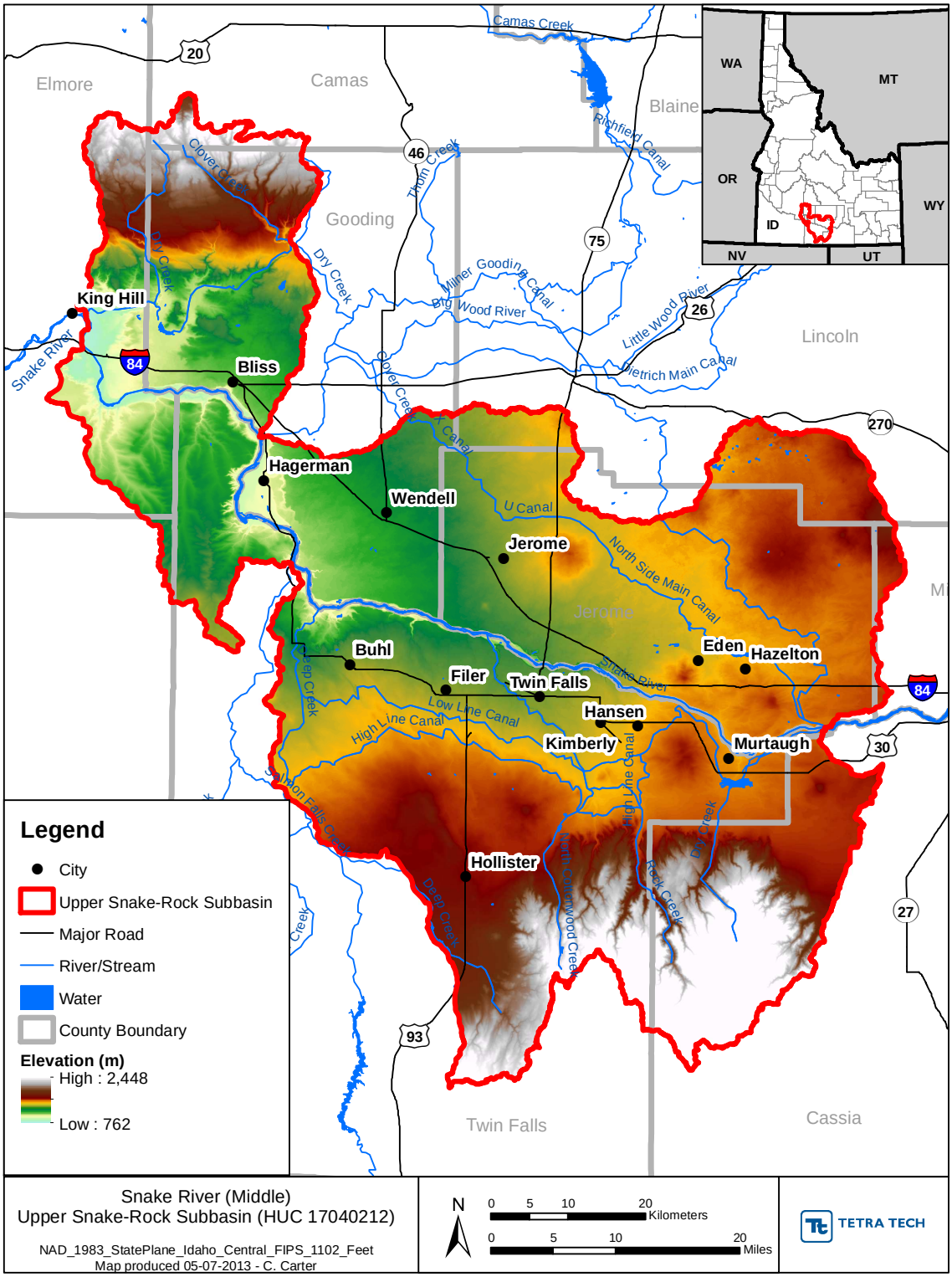

Figure 2. Elevation.

2.2 CLIMATE

The Upper Snake-Rock Subbasin has a semiarid climate with low annual rainfall; moderately hot, dry summers; moderate to cold winters; and relatively windy springs. Average annual air temperature ranges from 40 to 51 degrees Fahrenheit (F). January and July are typically the coldest and warmest months with average temperatures of 29 and 73 degrees F, respectively. During the summer, temperatures commonly reach 100 degrees F and above. In general, precipitation is consistent throughout the year, except in July through September, when the total for the three months may be less than one inch. Higher-than-average annual precipitation tends to be attributed to rains during the winter and spring. Snowmelt is an important hydrologic input, particularly in the spring and early summer (DEQ and Mid Snake TAC 1999).

Figure 3 illustrates annual precipitation for the entire period of record (water years [WY] 1918 through 2011) at Jerome Station 104670. Figure 4 provides the annual precipitation for the most recent two decades (WY 1990–2011). Precipitation variability appears to have decreased in the 2000s compared to the 1990s. In particular, fewer extreme lows and highs are apparent in the 2000s. Although the most recent decade differs from the 1990s, the recent trends appear to be within the variability observed across the period of record (Figure 3).

Climate variability in the Pacific Northwest (PNW) is influenced by both the Pacific Decadal Oscillation (PDO) and the El Nino Southern Oscillation (ENSO) large-scale climate cycles. In general, PDO is a pattern of longer-term variability (inter-decadal) in which changes in patterns are observed every 20 to 30 years, whereas ENSO events occur approximately every two to seven years and represent inter-annual variability. PDO cycles are represented by the PDO Index (negative = cooler, wetter PNW winter; positive = warmer, drier PNW winter). ENSO cycles are represented by the Southern Oscillation Index (SOI), where negative values occur during El Nino episodes that tend to result in drier PNW winters and positive values occur during La Nina episodes that tend to result in cooler, wetter PNW winters (USGCRP 2012).

Year-to-year changes in total precipitation for the Upper Snake-Rock Subbasin (Jerome weather station 104670) appear to be fairly consistent with the year-to-year oscillations apparent in the ENSO record (SOI; Figure 5). However, climate trends within the subbasin are not consistent with the PDO (Figure 6). In the 1990s, the PDO had a more frequent and stronger occurrence of warmer (positive) values than in the 2000s, which would support the opposite trend for precipitation in the subbasin. The Upper Snake-Rock Subbasin is in very close proximity to the central intermountain region (IR) of the United States, and Wang et al. (2009) explain that this region is shielded from the direct influence of ENSO, as well as the PDO. Variability not attributable to ENSO or PDO can be related to other possible factors, including (1) random chance, (2) poorly understood episodic phenomena (including other forms of natural climate variability or possible interactions of the effects of PDO and ENSO), (3) changes in the observing system, (4) global warming, and (5) anthropogenic influences (Higgins et al. 2007).

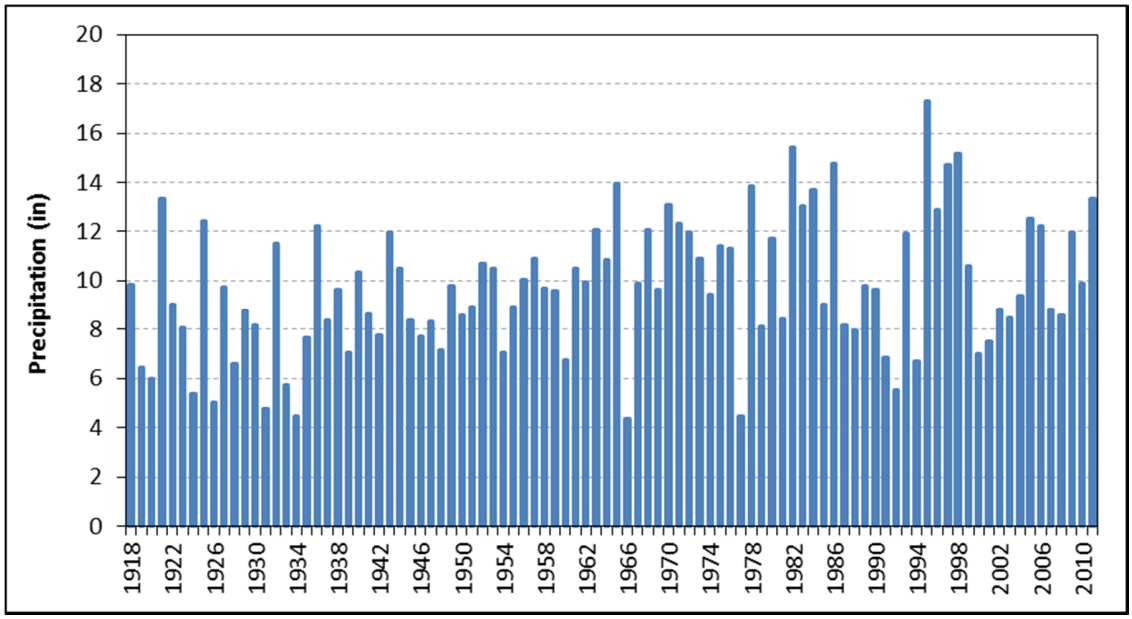

Figure 3. Precipitation (Jerome Station 104670) from water years 1918–2011.

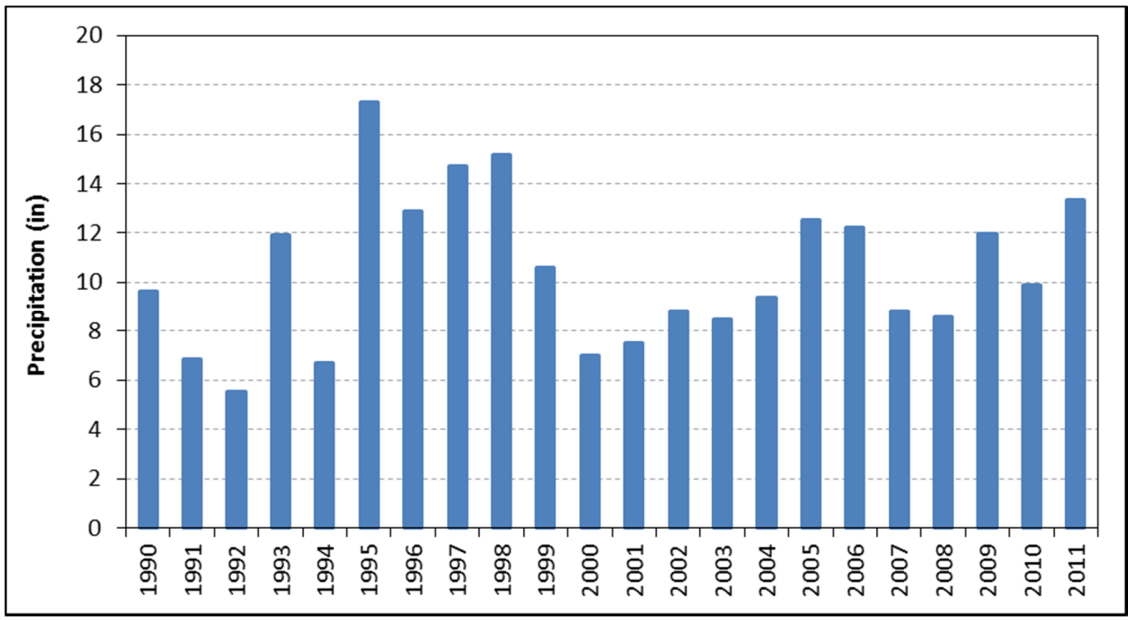

Figure 4. Precipitation (Jerome Station 104670) from water years 1990–2011.

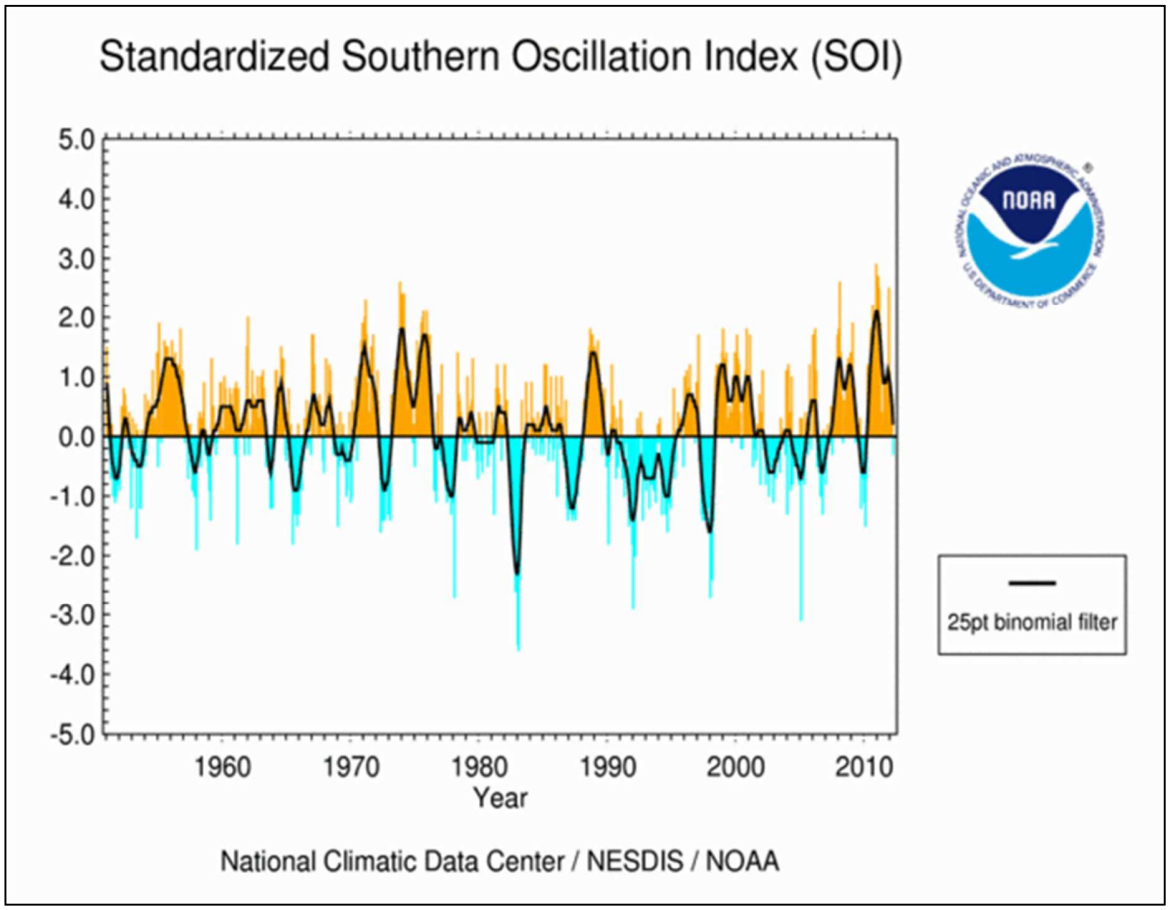

Figure 5. Southern Oscillation Index, 1950–2012 (NCDC 2012).

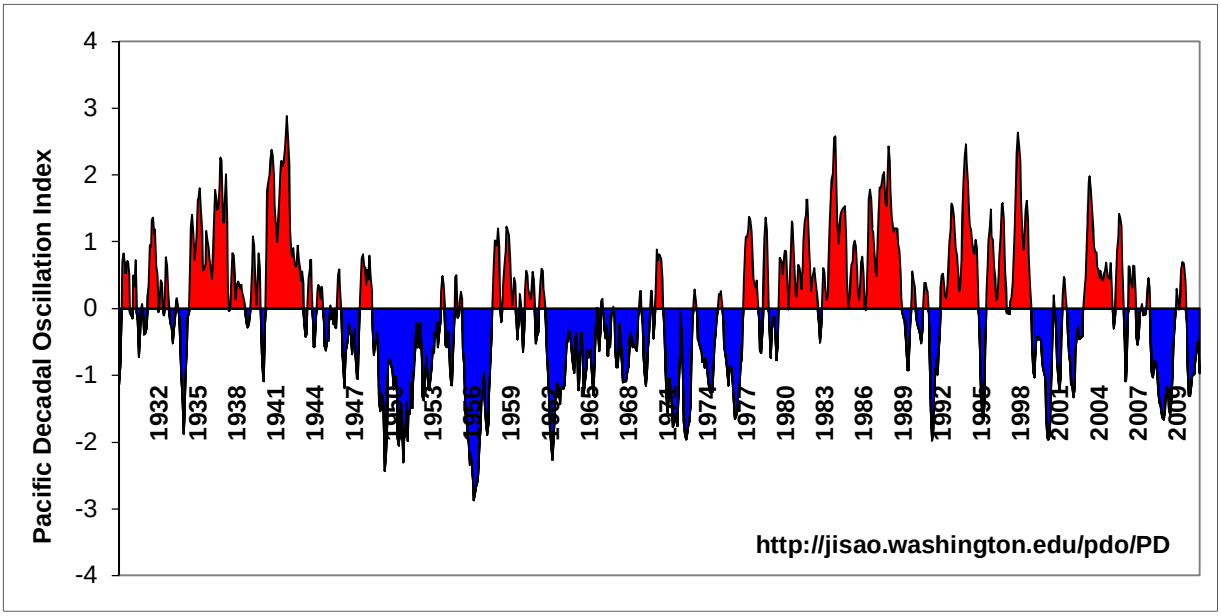

Figure 6. Pacific Decadal Oscillation, 1929–2011 (JISAO 2011).

2.3 SOILS

Watershed soils are composed of 87 percent aridisols and 13 percent mollisols according to the 1999 Upper Snake-Rock TMDL. Aridisols are salty mineral soils that are low in organic matter and may contain soluble salts and lime. Mollisols are similarly alkaline but have greater organic matter content compared to aridisols. A portion of the watershed soils (37 percent) is from loess, which represents a soil structure more susceptible to water and wind erosion, particularly when vegetation cover is removed. The remaining 63 percent contain residium, colluvium, and alluvium (DEQ and Mid Snake TAC 1999).

The rate of aquifer recharge depends on both the soil infiltration rates and the porosity of the underlying geology. Figure 7 illustrates the hydrologic soil groups (HSGs) in the watershed. The Natural Resources Conservation Service (NRCS 2001) has defined four HSGs for soils, as listed in Table 2. The majority of the watershed contains HSG B, C, or D, and a concentrated area of HSG A soils is present along the northern side of the mid to lower reaches of the Middle Snake River. Soils with high infiltration rates (primarily HSG B) tend to occur in the more upstream portion of the watershed, with a larger percentage north of the Middle Snake River. For additional details on soils and underlying geology, see EPA (2002).

Table 2. NRCS Hydrologic Soil Groups

Hydrologic Soil Group	Description
A	Soils with high infiltrations rates. Usually deep, well-drained sands or gravels. Little runoff.
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well-drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

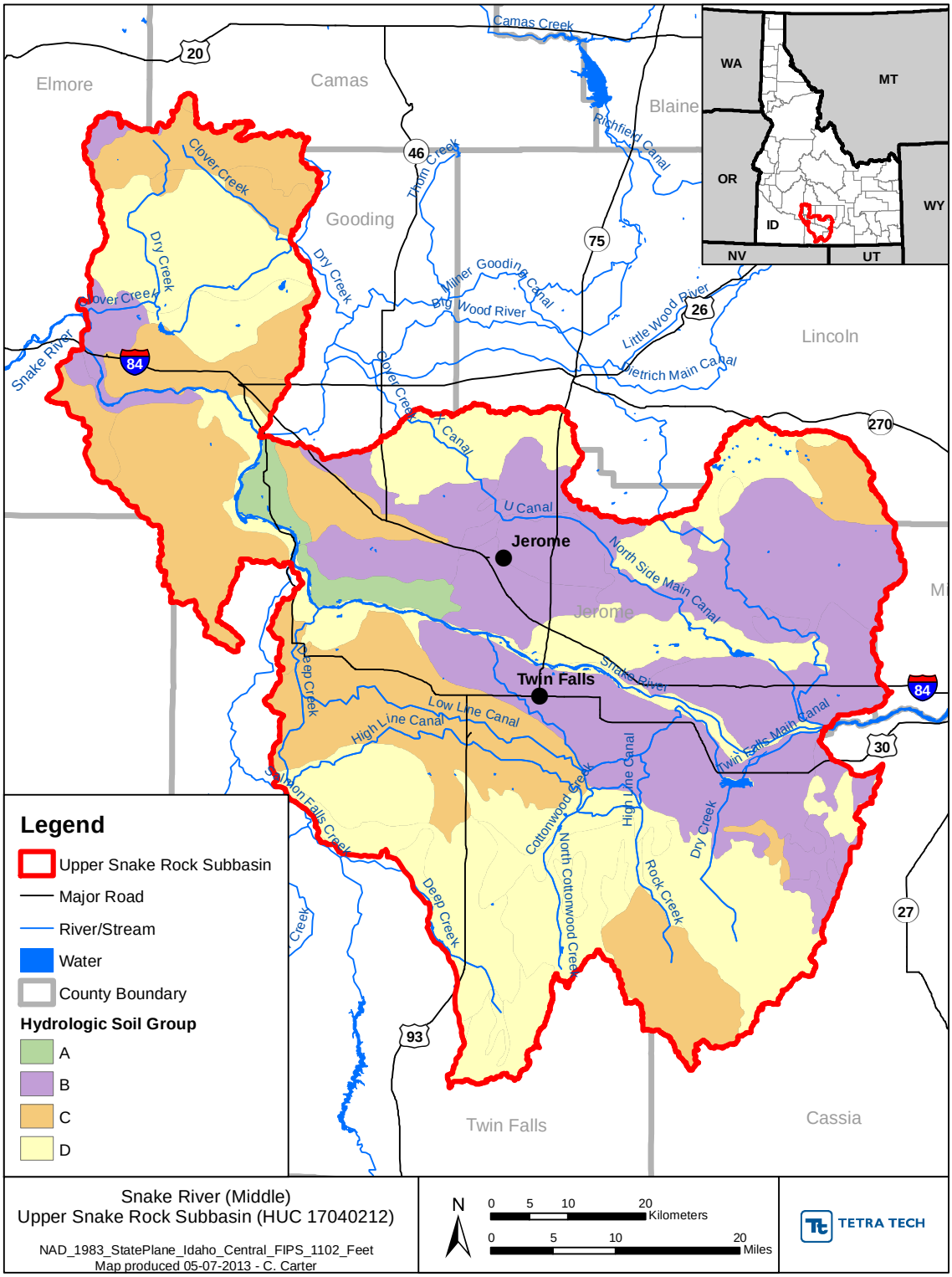

Figure 7. Hydrologic soil groups.

2.4 LAND USE/ LAND COVER

Figure 8 illustrates the land use/ land cover within the watershed using the 2006 National Land Cover Dataset (NLCD) and Table 3 presents the area and percent of each land use/land cover class within the watershed. Cropland, grassland, and scrub shrub vegetation dominate the land cover within the watershed (covering 30 percent, 22 percent, and 34 percent, respectively). Using 2006 land use data from NRCS, the TMDL five-year review estimated that about 56 percent of the subbasin (which excludes the Salmon Falls Creek, Big Wood River, and Lake Walcott drainages) is used as agricultural lands and 42 percent is occupied by rangelands. Some of the grassland classified by the NLCD may actually be agricultural lands (DEQ 2010). Much of the land in grass or scrub/shrub vegetation is likely used for livestock grazing, managed by the U.S. Bureau of Land Management or the Idaho Department of Lands. Urban area represents about 1.3 percent of the watershed.

Table 3. Land Use in the Watershed

Land Use	Area (square miles)	Percent of Watershed (%)
Open Water	12.40	0.49
Developed, Open Space	91.53	3.59
Developed, Low-Intensity	23.45	0.92
Developed, Medium-Intensity	8.48	0.33
Developed, High-Intensity	1.62	0.06
Barren Land	0.06	<0.01
Deciduous Forest	1.38	0.05
Evergreen Forest	10.83	0.42
Scrub/Shrub	871.69	34.21
Grassland/Herbaceous	556.18	21.82
Pasture/Hay	205.80	8.08
Cultivated Crops	763.18	29.95
Woody Wetlands	1.48	0.06
Emergent Herbaceous Wetland	0.27	0.01

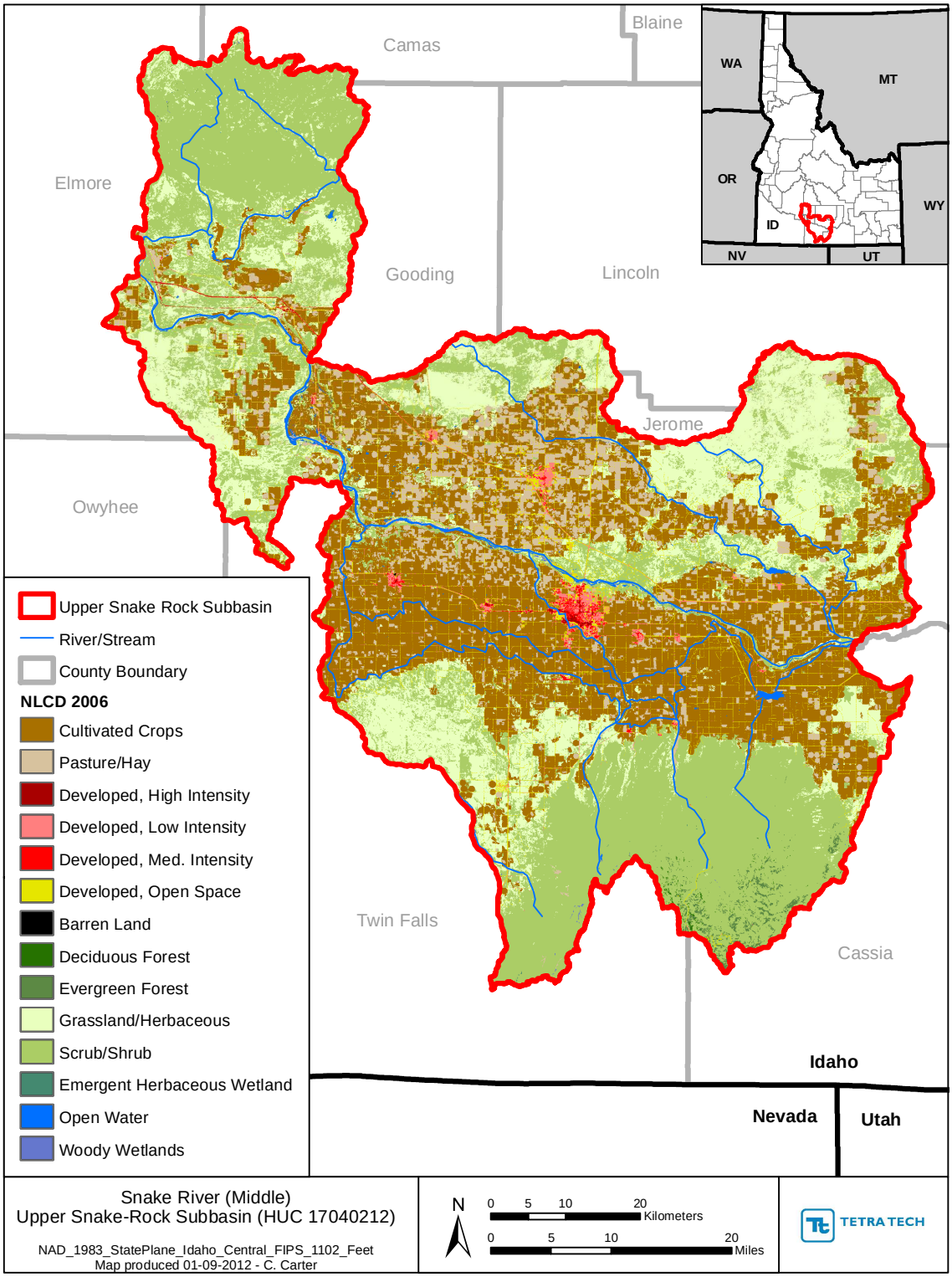

Figure 8. Land use/land cover.

2.5 HYDROLOGY

The hydrology of the Upper Snake-Rock Subbasin reflects a complex network of springs, streams, aqueducts, canals, irrigation drains, lakes, reservoirs, and geothermal sites. The major waterbodies, based on percent of total reach length, are intermittent streams (46 percent), canals (35 percent), and perennial streams (15 percent) (DEQ and Mid Snake TAC 1999). This section documents past knowledge of hydrology and flow trends in the subbasin. For additional details on the hydrology of the Upper Snake-Rock Subbasin, see EPA (2002).

Flow through Milner Dam

Flow to the Middle Snake River depends largely on upstream storage, irrigation diversion rights in the Upper Snake River, and spring water discharge from the Snake River Plain aquifer. The upstream discharge to the Middle Snake River, which is highly variable, is managed by U.S. Bureau of Reclamation (BOR) and Water District No. 1. Canal companies divert water from the Snake River at Milner Dam through traditional gravity diversion systems (DEQ and Mid Snake TAC 1999). According to DEQ (1998), diversion for irrigation averaged approximately 5,000 cubic feet per second (cfs) above Milner Dam during TMDL development, reducing flow to an average of 3,450 cfs above the dam. Flow downstream of the Middle Snake River ranged, on average, from 200 to 1,500 cfs in the summer. Some of the water diverted for agriculture percolates into the Eastern Snake Plain Aquifer and returns to the Middle Snake River through springs and diffuse ground water inputs. Diverted water also returns to the river through surface channels.

Flows through Milner Dam vary both annually and seasonally. The Idaho State Water Plan states that the minimum release from Milner Dam, once irrigation demand exceeds natural flow, is zero. Under the Federal Energy Regulatory Commission license for the Milner Power plant, a minimum flow of 200 cfs is required when water is available. Even in surplus water years, the flow available for release from Milner Dam reaches zero by the middle of July, when the natural flow drops below the irrigation demand (DEQ 1998).

BOR operates a flow augmentation program that manages releases from Milner Dam to protect fish species listed under the Endangered Species Act. The most recent change in these operations occurred after the release of the 2008 National Oceanic and Atmospheric Administration (NOAA) Fisheries biological opinion, which called for shifting releases from August to July or earlier. The ability to shift releases depends on whether a water year is dry, average, or wet. The quantity and timing of releases also depends on the total flow augmentation volume available, as well as from which basin the augmentation originates. BOR generally anticipates that augmentation releases can be provided in May or June in most average or lower water years and by the end of July in most wet years. Most recently, 2011 provided an example of unanticipated circumstances in which flood control releases past Milner Dam were required from April through the end of July, and flow augmentation releases were extended into August in that year (BOR 2011).

Tributaries

Downstream from Milner Dam, flows increase substantially from diffuse ground water discharge, irrigation returns, and tributaries. Tributaries include streams, canals, springs, and irrigation return drains. Natural tributaries extend for 2,045 miles (mi) within the subbasin. The four largest tributaries, according to the 1998 TMDL, are Rock Creek, Salmon Falls Creek, Malad River, and Clover Creek. Rock Creek and Clover Creek are within the Upper Snake-Rock Subbasin while Salmon Falls Creek and Malad River represent different subbasins but flow into the Middle Snake River within the Upper Snake-Rock Subbasin.

Irrigation canals connect tributaries and cross subbasin boundaries, adding to the complexity of the hydrologic system. The subbasin contains 1,179 miles of canals and ditches. Some of the major canals are Low Line Canal (46 mi), High Line Canal (35 mi), North Side Main Canal (32 mi), Twin Falls Main

Canal (30 mi), and Milner Main Canal (27 mi) (USGS 2012). The irrigation return drains receive irrigation return flow during the irrigation season. The return flow enters the Snake River directly from numerous conduits on both sides of the canyon and indirectly via the tributaries. Flow in irrigation return streams is highly variable, but many are fed by diffuse ground water inputs and flow year-round (DEQ 1998). Figure 1 labels the major tributaries, and Section 4.1 provides more detailed maps of the irrigation drains.

Ground Water

Ground water enters the Middle Snake River as diffuse inflow or from springs, which are discrete locations where ground water emerges as concentrated flow. This section discusses ground water relevant to total ground water flow that includes both diffuse and spring inflow.

In the 1998 TMDL, ground water inflows to surface waters (both from diffuse ground water and spring inputs) were cited as significant and important for maintaining surface water flows and water quality in the Middle Snake River. The TMDL document observed that during drought years on the Middle Snake River, ground water discharge may contribute as much as 60 percent of the river's flow. The largest inflow to the Middle Snake River is from the Snake River Plain Aquifer on the north and east sides of the canyon. This aquifer underlies the Snake River Plain (Figure 9) from the vicinity of St. Anthony, Idaho (northeast of the subbasin) to the western portion terminus of the Middle Snake River, and ground water flows through the aquifer in a southwesterly direction. Sources of aquifer recharge include seepage from the Snake River, streams entering or crossing the plain, percolation of irrigation water, precipitation, and underflow from tributary basins.

A second significant source is the aquifer underlying the Twin Falls tract, which discharges about 500 cfs according to USGS and city of Twin Falls estimates in the late 1990s (DEQ 1998). Sukow (2011) estimated the average contribution from the Twin Falls tract was 635 cfs for 1981–2008; this value includes an estimate of tributary underflow from the upper Salmon Falls drainage area. Downstream of Kimberly, most of the contribution from the aquifer underlying the Twin Falls tract is discharged to tributary streams (including Rock Creek, Cedar Draw, Mud Creek, Deep Creek, and Lower Salmon Falls Creek), rather than directly to the Snake River (Sukow 2012).

The soil characteristics and geology contribute to high aquifer recharge rates. As noted in Section 2.3, soils with higher infiltration rates tend to occur in the more upstream portions of the subbasin, with a higher proportion on the north side of the Middle Snake River. In general, the underlying basalt on the south side of the Middle Snake River is much less permeable than the basalt on the north (DEQ 1998).

Throughout the history of the subbasin, ground water inflow to surface waters varied as recharge conditions changed. Ground water inflows to surface waters increased between 1902 and the early 1950s, likely because of recharge from irrigation north and east of the springs. Since the highest recorded flows in the mid-1950s, the 1998 TMDL observed that aquifer flows have been steadily declining. This decline is believed to be associated with aquifer withdrawals and increased efficiency in irrigation application. The 1998 TMDL hypothesized that aquifer outflows would approach equilibrium with inputs and upstream withdrawals (DEQ 1998).

The highest aquifer flows typically occur in October as a result of the cumulative effects of recharge by surface water irrigation (DWR 2013). Low aquifer water flows occur in April or May before the effects of the new irrigation season recharge become significant (DEQ 1998).

Discharge from the Snake River Plain Aquifer occurs throughout the Milner to King Hill reach, but the largest gains from this source occur between the Buhl (13094000) and Hagerman (13135000[1]) gages. While there are many small springs and seeps throughout the subbasin, the 11 major springs (discharge of 100 cfs or more) are shown in Figure 9 (DEQ 1998). The greatest number of springs is in the Thousand Springs area of the Hagerman Valley and the springs run year-round (DEQ and Mid Snake TAC 1999). For 1980, the USGS estimated that 90 percent of the spring discharges come from springs north of the river and 10 percent from springs south of the river (Kjelstrom 1995).

Impoundments

There are seven impoundments along the Middle Snake River and eight along the tributaries (Figure 10). They were constructed and operated for agriculture and hydropower. Approximately 25 percent of the Middle Snake River between RM 639.1 and RM 565.7 is reservoir-like (DEQ and Mid Snake TAC 1999). The dams and associated reservoirs along the mainstem are Milner, Murtaugh, Twin Falls, Shoshone Falls, Upper Salmon, Lower Salmon, and Bliss. Milner Dam is owned by the Twin Falls Canal Co. and North Side Canal Co.; the six other dams along the mainstem are owned by the Idaho Power Company (DEQ and Mid Snake TAC 1999). The largest impoundments are at Milner Dam and Bliss Dam, completed in 1905 and 1950, respectively.

[1] Although two USGS gages have been established near Hagerman, this was the number referenced in the river mile index of the 1999 Watershed Management Plan (DEQ and Mid Snake TAC 1999). Since a site number was not referenced, it was assumed that the 1998 TMDL is also referring to this gage. The site number for the other Hagerman gage is 13134500.

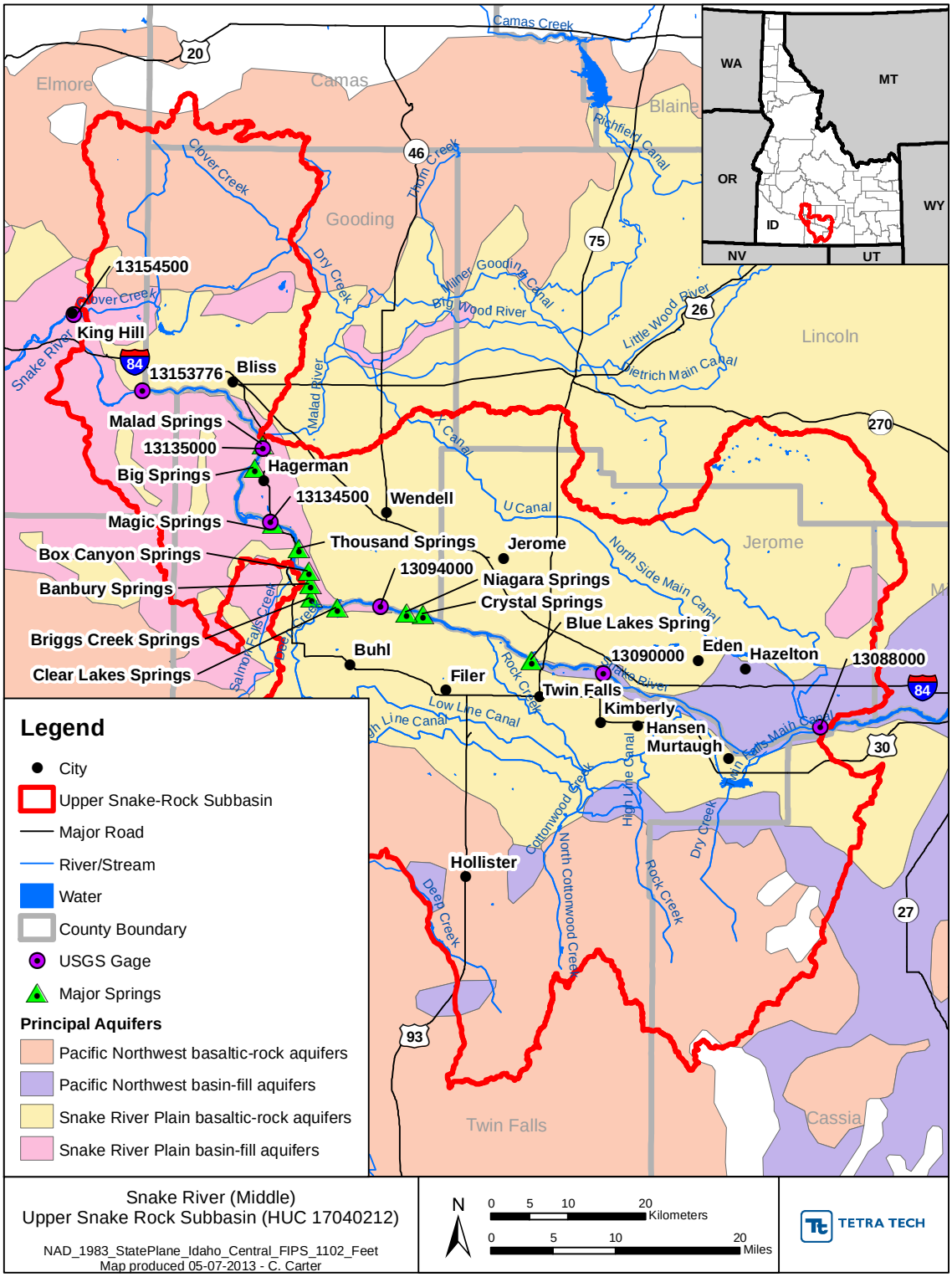

Figure 9. Aquifers and major springs.

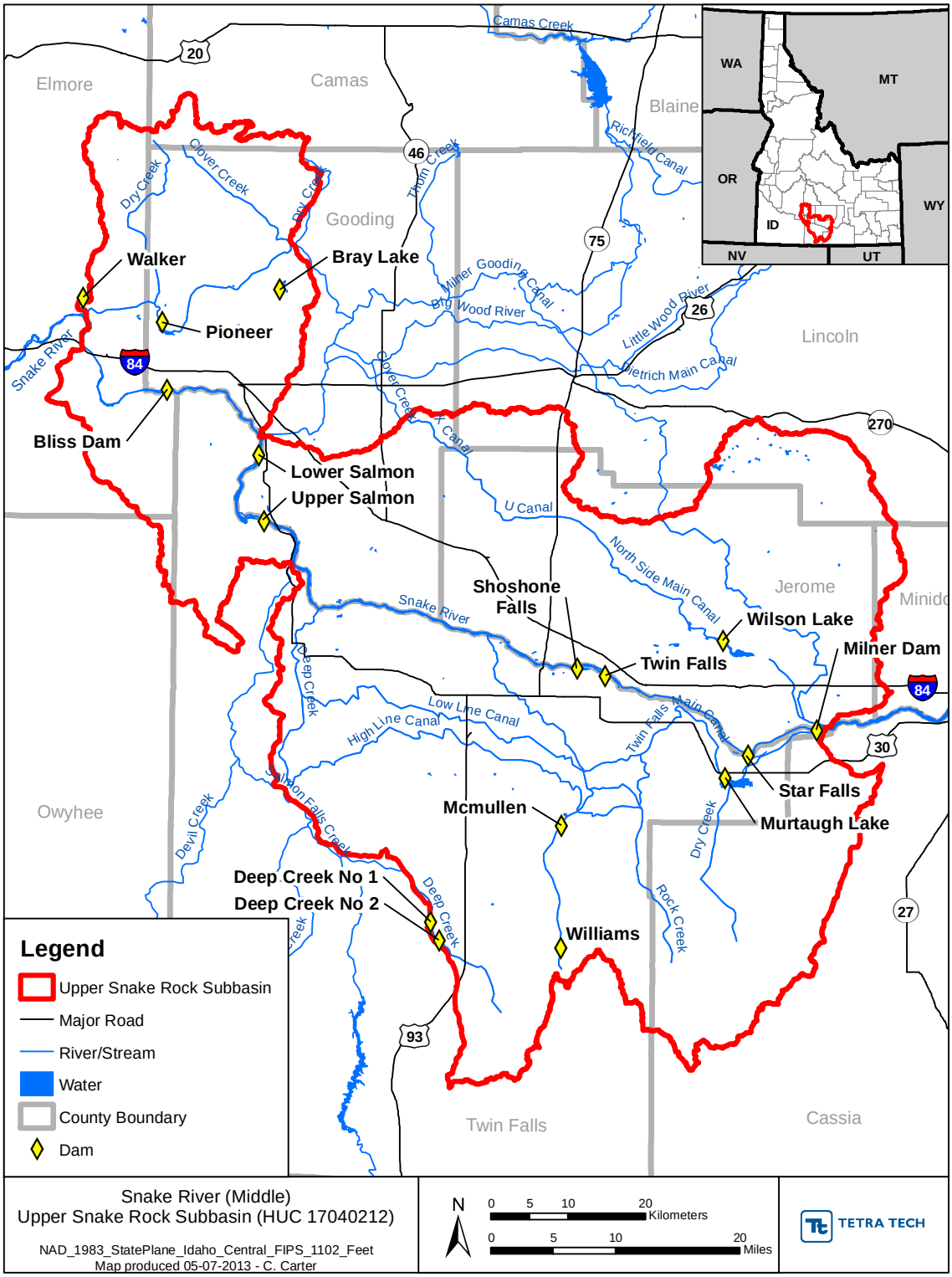

Figure 10. Dams.

2.6 NUISANCE AQUATIC PLANTS

Nuisance aquatic plants have been a documented concern in the Middle Snake River since the late 1980s, and a major goal of the Mid Snake/Upper Snake-Rock Subbasin TMDL was to reduce TP concentrations contributing to excessive aquatic plant growth. Macrophytes – aquatic plants with leaves, stems, and root or root-like structures – have been the focus of this concern due to their extensive presence in the River. Past studies have linked sediment phosphorus to plant biomass in the Middle Snake River (Falter et al. 1995; Falter and Burris 1996), and dense aquatic plant beds tend to occur downstream of agricultural return flows and aquaculture discharges, which have been significant sediment sources (EPA 2002).

The linkage between sediment, nutrients, and aquatic plant growth is complex and involves several feedback loops that lead to continual new growth and expansion of the aquatic beds. The aquatic plant beds initially form where sedimentation reduces depths and provides light availability and an ideal substrate for rooted macrophytes. Once established, the plant beds slow the river's velocity and increase sedimentation, encouraging further growth and establishment of aquatic plants.

Within the beds themselves, the aquatic plants extract nutrients from the sediment and the water column. High dissolved nutrient concentrations during the late growing season can lead to the dominance of epiphytic algae and non-rooting macrophytes since these species obtain nutrients exclusively from the water column. This plant growth forms a feedback loop in which nutrients are removed from the water column and deposited to the bed sediments during senescence, which are then available for uptake by rooted macrophytes. These processes can lead to an increase in nutrients in the bed sediments and perpetuate macrophyte growth. Figure 11 illustrates these processes and feedback loops.

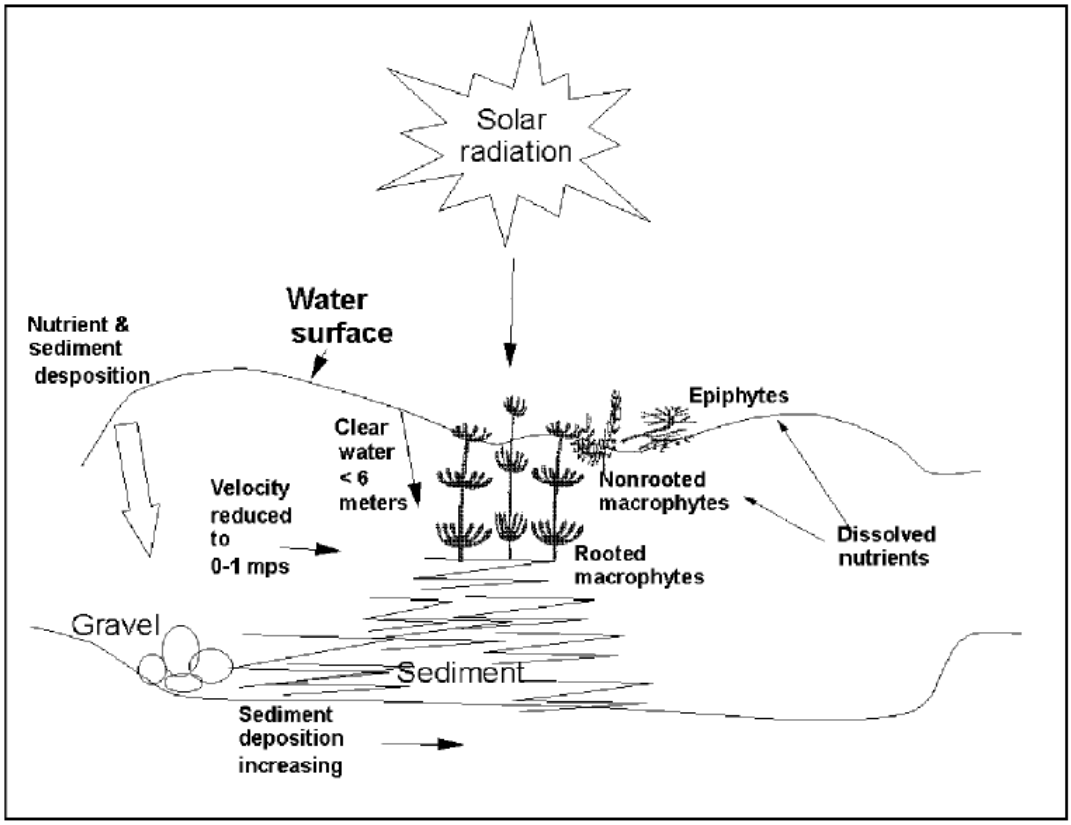

Figure 11. Factors controlling aquatic plants in the Middle Snake River, reproduced from EPA (2002).

It is important to note that aquatic plant growth includes both algal mats and macrophytes. Algae and macrophytes tend to coexist, especially in the aquatic plant beds found within the Middle Snake River. Since control of macrophytes is a management priority for the Middle Snake River, this section focuses on available macrophyte information and, when relevant, a general consideration of aquatic plant beds in the River, which include some species of algae.

The following subsections document research and data on aquatic plants in the Middle Snake River with a focus on the interaction between TP and aquatic plants as well as related retention or removal mechanisms. Dominant aquatic plant species are considered first, followed by information on macrophyte growth rates and density.

2.6.1 Dominant Aquatic Plant Species

Information on dominant aquatic plant species in the Middle Snake River is available from studies published in the 1990s and discussed in EPA (2002). In reaches of significant attached aquatic plant growth, Falter and Carlson (1994) found that *Ceratophyllum demersum*, *Potamogeton pectinatus*, and *P. crispus* dominated the aquatic vascular plants. The latter two species tend to occur in well-buffered, nutrient-rich waters (Filbin and Barko 1985; Best and Mantai 1978). Other less dominant vascular species observed within the River include *P. foliosus, Elodea nuttallii, and E. canadensis*. Of this list of dominant and subdominant vascular species, *Ceratophyllum and Elodea* are considered functional epiphytes because they lack true roots and obtain the majority of their nutrients from the water column. In addition to the vascular epiphytes, the Middle Snake epiphyton community includes the filamentous green algae *Cladophora sp*., *Hydrodictyon sp*., and *Enteromorpha*. While rooted macrophytes dominate in the spring months, epiphytes have been observed to dominate the total summer-fall macrophyte biomass at many locations in the Middle Snake River (Falter and Carlson 1994; Falter et al. 1995, Falter and Burris 1996). EPA (2002) provides a detailed life history of dominant attached aquatic plants (see Appendix C of EPA (2002)).

2.6.2 Aquatic Plant Density and Growth Rates

Growth of aquatic vegetation begins in the spring and growth rates increase as temperatures and light availability increase. Table 4 summarizes 1994 monthly biomass estimates at Crystal Springs from Falter and Burris (1996). For rooted macrophytes, the most dramatic increase in biomass occurred between April and May. According to EPA (2002), it is likely that the perennial root masses provide sufficient nutrient and energy reserves to permit earlier, faster plant development than in epiphytes and rootless plants.

Accordingly, growth of epiphytes and non-rooted macrophytes in 1994 remained relatively slow in the spring. Then epiphytes exhibited a sharp increase in biomass between May and June. The highest monthly growth rate for non-rooted macrophytes occurred in August, when mean biomass increased to almost nine times the July mean. As described in EPA (2002), epiphytic algae growth increases in June when temperatures have increased sufficiently and rooted plants have grown high enough to provide a growth surface with high light availability.

Evidence exists that once the temperature and light availability requirements are met, high water column nutrients can allow epiphytes and non-rooted macrophytes to obtain high biomass levels. Howard-Williams (1981) studied the effects of fertilizer on rooted *P. pectinatus* communities with epiphytes (*Cladophora*). When nitrogen and phosphorus were applied to the water column, the epiphytes experienced a sharp increase in growth, but the rooted plant biomass did not increase.

EPA (2002) posited that epiphytes and non-rooted macrophytes outcompete rooted macrophytes by midsummer due to their faster growth rates in the presence of elevated nutrient concentrations as well as their higher position in the water column. As illustrated in Table 4, non-rooted macrophytes were

reaching peak biomass between July and August 1994 while rooted macrophyte biomass was already beginning to decline.

This seasonal variation in growth rates results in changes in species dominance during the growing season. Rooted macrophytes dominated aquatic plant beds in the early spring. Epiphyte growth was slow until June, and then epiphytes represented about 35 to 50 percent of total plant biomass through November. Growth of non-rooted macrophytes was slow until August when they dominated the aquatic bed community for that month.

The variations in species dominance presents implications for management of nutrient loading towards control of aquatic plant growth. Reduction in nutrient concentrations will more directly affect epiphyte and non-rooted growth because of these species' dependence on water column nutrients. For control of non-rooted macrophytes, Falter and Burris (1996) suggests that a narrow window exists between July and August in which a reduction in nutrient concentrations could reduce non-rooted macrophyte growth rates. This suggests short or very short averaging periods for achieving target nutrient levels to limit growth during critical periods.

Table 4. Riverwide mean plant biomass and percent of the total biomass, Crystal Springs, Idaho, 1994 (from Falter and Burris, 1996)

Month	Epiphytes, mean g/m^2	Non-rooted, mean g/m^2	Rooted, mean g/m^2	Total, g/m^2	Epiphytes, % of total	Nonrooted, % of total	Rooted, % of total
Apr	0.1	34	30.6	64.7	0.2%	52.5%	47.3%
May	1.3	3.6	230.8	235.7	0.6%	1.5%	97.9%
Jun	231.5	78.5	239.2	549.2	42.2%	14.3%	43.5%
Jul	163.4	25.6	137.1	326.1	50.2%	7.8%	42.0%
Aug	173.8	248.9	81.8	504.4	34.5%	49.3%	16.2%
Oct	214.4	138.3	104.1	456.7	46.9%	30.3%	22.8%
Nov	63.3	46.6	52.9	162.8	38.9%	28.6%	32.5%

2.7 CAUSES OF IMPAIRMENT

The TMDL documentation established that point and non-point sources of phosphorus throughout the Upper Snake-Rock Subbasin are the major causes of the nuisance aquatic vegetation impairing beneficial uses in the Middle Snake River and its tributaries. As discussed in Section 2.6 and documented in EPA (2002), the aquatic plant beds initially form from sedimentation, which reduces river depths and provides light availability and an ideal substrate for macrophytes. This concept was supported by findings that dense aquatic plant beds in the Middle Snake River exist downstream of agricultural return flows and aquaculture discharges, which were significant sediment sources during TMDL development. Once established, the plant beds slow the river's velocity and increase sedimentation, encouraging further growth and establishment of aquatic plant beds.

The processes within the beds form a feedback loop in which nutrients are removed from the water column and deposited to the bed sediments during senescence, which are then available for uptake by rooted macrophytes. These processes can lead to an increase in nutrients in the bed sediments and perpetuate macrophyte growth. Continued sedimentation and nutrient loading feeds this process and expansion of the aquatic plant beds.

Point sources that discharge nutrients to the Middle Snake River include food processors, municipalities (POTWs), and aquaculture facilities. Currently, 84 permitted point source dischargers are located within the subbasin (Figure 12). Twenty-five facilities discharge directly to the Middle Snake River; they include 20 aquaculture facilities (which include fish hatcheries and fish processing facilities), four POTWs, and one food processor. Fifty-nine facilities discharge indirectly to the Middle Snake River through tributaries or irrigation return drains; they include 55 aquaculture facilities (which include fish hatcheries and fish processing facilities), two POTWs, and two food processors. TP load contributions from each type of point source were quantified from discharge monitoring report (DMR) data and are compared to current WLAs in Section 4.3.3.

Nonpoint source pollution in the Upper Snake-Rock Subbasin comes from a variety of sources, including concentrated animal feeding operations (CAFOs), irrigated agriculture, improper grazing practices, stream bank erosion, septic systems, construction activities, and off-highway vehicles. Hydroelectric impoundments/projects, particularly Federal Energy Regulatory Commission-licensed facilities, were listed in the TMDL documents as nonpoint sources because of potential changes in water quality occurring within the impoundments. These facilities are exempt from NPDES permits because the change in water quality is not considered a discharge of pollutants. In-stream processes within the Middle Snake River and background loading are also relevant nonpoint sources of phosphorus loading.

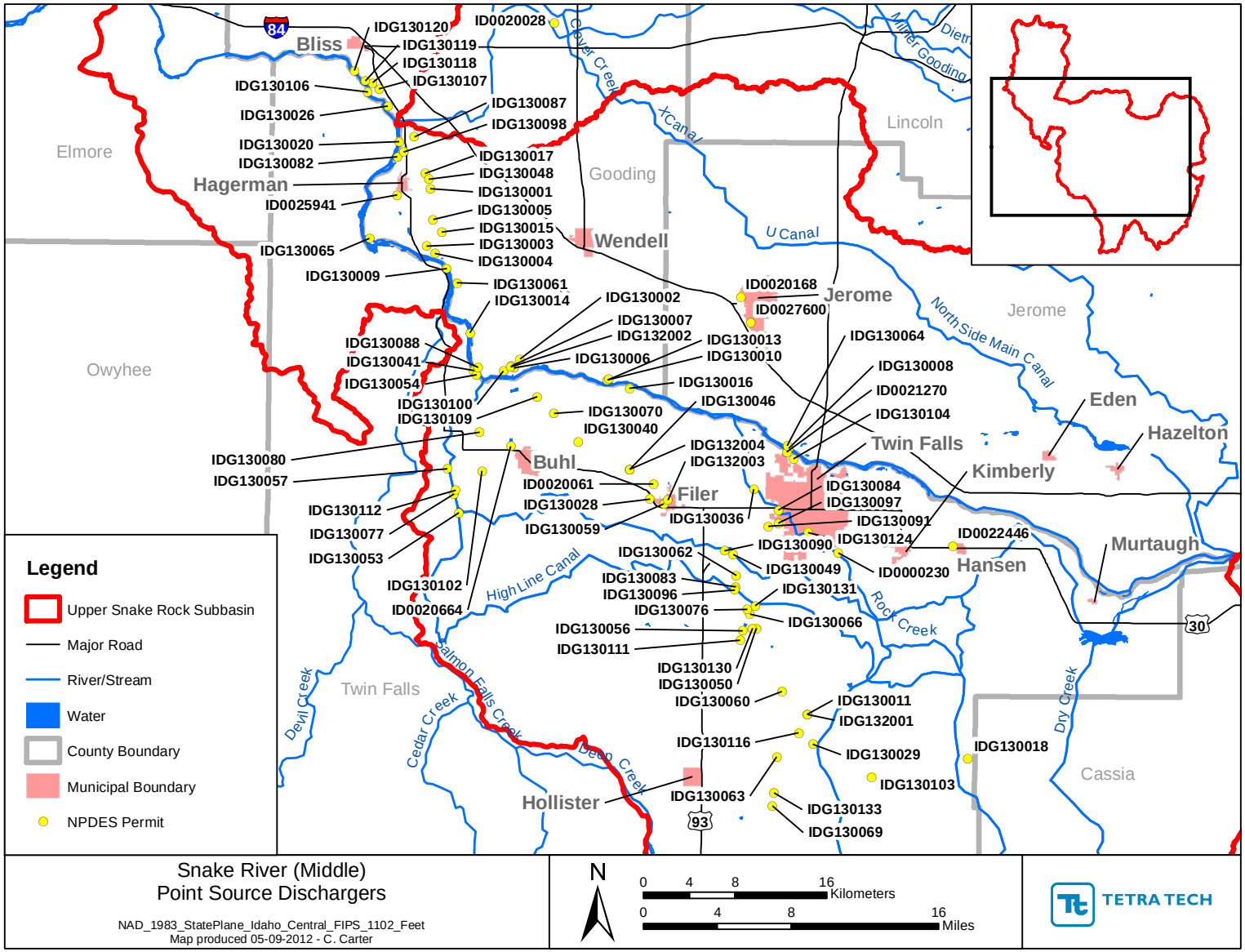

Figure 12. Point source dischargers.

3. Current TMDL and Allocations

EPA has approved the following TMDLs in the Upper Snake-Rock Subbasin:

- Middle Snake River Watershed Management Plan, 1997; revised 1998
- Upper Snake-Rock Watershed Management Plan, 1999
- Upper Snake-Rock TMDL Modification, 2005.

The *Middle Snake Watershed Management Plan Phase I TMDL for Total Phosphorus* (DEQ 1998) provided an approach to improve water quality by establishing a TP load applicable on the mainstem of the Middle Snake River. The Upper Snake-Rock Watershed Management Plan (DEQ and Mid Snake TAC 1999) followed suit by providing loads for TP on water quality-limited tributaries and TSS on both the Middle Snake River and affected tributaries. As part of the TMDL approval process, the Upper Snake-Rock TMDL Executive Summary was created by EPA as a condensed version of the 1999 document (EPA 2000). The Upper Snake-Rock TMDL Modification (2005) evaluated phosphorus and TSS loads primarily for aquaculture facilities that discharge to the Snake River or one of its tributaries.

The 1998, 1999, 2000, and 2005 documents, collectively, are relevant to the subbasin and the TMDL reevaluation. As part of the TMDL process, DEQ developed and implemented the in-stream TP targets listed in Table 5. The TP targets were developed to provide linkage with beneficial uses and to address the following narrative criteria (IDAPA § 58.01.02.200.06): "[S]urface waters of the state shall be free from excess nutrients that can cause visible slime growths or other nuisance aquatic growths impairing designated beneficial uses."

Table 5. In-stream Total Phosphorus Targets by TMDL in Upper Snake-Rock Subbasin

Waterbody	Target
Snake River - Milner to King Hill (6 assessment units)	0.075 mg/L
Tributaries	0.1 mg/L
Undeveloped springfed tributaries	0.02 mg/L

During TMDL development, election of critical periods primarily considered the beneficial uses for cold-water aquatic life (CWAL) and salmonid spawning (SS). The critical period for CWAL is July and August, and the critical period for SS is April, September, and October. These critical periods are based on the hotter times of the year, when adequate cold water habitat and spawning conditions are most limited.

The TMDL documents established control and monitoring points to determine compliance with the Upper Snake-Rock TMDL. The compliance points for tributaries and canalways were identified at their confluence with the Middle Snake River. Along the mainstem, the following six segments and seven monitoring locations are used to evaluate compliance with the Upper Snake-Rock TMDL for the TP in-stream water quality targets and to determine beneficial use attainment for the Middle Snake River:

- Milner Dam to Twin Falls: Assessment Unit ID17040212SK020_07
- Twin Falls to Rock Creek: Assessment Unit ID17040212SK019_07
- Rock Creek to Box Canyon: Assessment Unit ID17040212SK007_07

- Box Canyon to Lower Salmon Falls: Assessment Unit ID17040212SK005_07
- Lower Salmon Falls to Clover Creek: Assessment Unit ID17040212SK001_07
- Clover Creek to King Hill: Assessment Unit ID17050101SW005_07.

Although these are the most recent assessment units, they are not the original segments used in the TMDLs. In addition, these segments do not correspond to the current monitoring locations that provide data important for assessing changes in concentration, load, and flow. To compare previous TMDL assumptions to current monitoring data (Section 4) and the mass balance results (Section 7), segments are defined in this document as:

- Milner Dam to Pillar Falls
- Pillar Falls to Crystal Springs
- Crystal Springs to Box Canyon
- Box Canyon to Gridley Bridge
- Gridley Bridge to Shoestring Bridge
- Shoestring Bridge to King Hill

Hereafter, these segments are referred to as "study segments." When reporting loads and flows for these segments, the study segment definitions refer to the reach beginning just below the upstream location up to and including the downstream location. For example, the second study segment begins just below the Pillar Falls gage and ends just below Crystal Springs gage, so the load and flow at Crystal Springs would be included in any estimates for this segment.

By achieving the in-stream target of 0.075 mg/L, the TP reductions outlined in the TMDL documents are intended to meet beneficial uses by reducing nuisance aquatic plant growths by 30 percent (on average) at the Crystal Springs reach portion of the Middle Snake River. The Upper Snake-Rock TMDL Modification (2005) is the most current TMDL with the load capacity calculations and allocations for each specific industry and facility. Under the TMDL process, the load capacity may be described with the following formula:

TMDL = load capacity = WLA + LA + MOS + BK + FG

where

WLA = wasteload allocation for point sources

LA = load allocation for nonpoint sources

MOS = margin of safety (sometimes combined with BK)

BK = background (sometimes combined with WLA or LA)

FG = future growth reserve.

More specifically:

TP load capacity = TP target (mg/L) x flow (cfs) x 5.39 (conversion factor) = TP load, pounds per day (lb/day)

TP target: Middle Snake River = 0.075 mg/L TP

Tributaries = 0.100 mg/L TP.

For the Middle Snake River, Table 6 lists the baseline loads estimated during the 1999 TMDL development, as well as the wasteload, load, and total allocations expressed in the current TMDL (2005).

Among the segments, Pillar Falls to Crystal Springs has the highest estimated point source load and wasteload allocation among the study segments. Four of the six study segments, Pillar Falls to Shoestring Bridge, have the highest estimated nonpoint source baseline loads as well as load allocations. The loading capacity for the Middle Snake River was based on achieving the target of 0.075 mg/L at Gridley Bridge at low flow conditions for 1991 (5,510 cfs) (DEQ 1998). RBM-10, the model used for the 1998 TMDL, predicted a TP loading goal of 2,227.4 lb/day.

Table 6. Comparison of Baseline Load and Current Allocations (TP lb/day) for Point and Nonpoint Sources in the Middle Snake River Study Segments (DEQ 2010)

Study Segment	Point Sources		Nonpoint Sources		Total: Point +Nonpoint		Percent Change, Baseline to 2000/2005 Allocations
	Baseline Load 1990–1991	WLA	Baseline Load 1990–1991	LA	Total Baseline Load	Total Allocations	
Milner Dam to Pillar Falls	5.1	3.3	993.8	407.2	998.9	410.5	-58.9%
Pillar Falls to Crystal Springs	1,081.7	722.1	1,217.0	1,374.6	2,298.7	2,096.7	-8.8%
Crystal Springs to Box Canyon	655.5	474.0	1,684,8	1,345.6	2,340.3	1,819.6	-22.3%
Box Canyon to Gridley Bridge	72.3	50.1	1,381.2	1,524.9	1,453.5	1,575.0	8.4%
Gridley Bridge to Shoestring Bridge	98.5	73.1	2,072.1	1,278.9	2,170.6	1,352.0	-37.7%
Shoestring Bridge to King Hill	0.0	0.0	525.2	210.6	525.2	210.6	-59.9%
Total	1913.1	1,322.6	7,874.1	6,141.7	9,787.2	7,464.3	-23.7%

Baseline = baseline water years 1990–1991 as defined in the Mid Snake TMDL and the Upper Snake-Rock TMDL. The nonpoint source calculation is primarily based on the overall load capacity for the river segment and subtracting out the point source component, but not subtracting out the margin of safety. Some of the ton/year estimates are based on converting to lb/day or vice versa.

Milner Dam to Pillar Falls. Baseline based on USR TMDL (1999). Point sources include City of Hansen only. Point source after 2000/2005 based on the Upper Snake-Rock TMDL Modification (2005). Nonpoint source load after 2000/2005 is based on the net calculation between the total load at the discharge from one segment to another and the total load at the input part of the segment.

Pillar Falls to Crystal Springs. Baseline based on USR TMDL (1999). Point sources include City of Twin Falls and GAP-104. Point sources after 2000/2005 based on the USR TMDL Modification (2005).

Crystal Springs to Box Canyon. Baseline based on USR TMDL (1999). Point sources include City of Jerome, GAP-016, GAP-100, GAP-041, GAP-054, GAP-014, and GAP-010. Point source after 2000/2005 based on the USR TMDL Modification (2005).

Box Canyon to Gridley Bridge. Baseline based on USR TMDL (1999). Point sources include U of I Research Center Lab and GAP-009. Point source after 2000/2005 based on the USR TMDL Modification (2005).

Gridley Bridge to Shoestring Bridge. Baseline based on USR TMDL (1999). Point sources include City of Hagerman, GAP-111, GAP-065, GAP-056, GAP-082 (formerly GAP-081 [Rainbow Falls/Dunn] combined with GAP-082 [Eckles]), GAP-098 (formerly GAP-098 [Barrett], GAP-020, GAP-090, GAP-118, GAP-119, GAP-120 and GAP-076. Point source after 2000/2005 based on the Upper Snake-Rock TMDL Modification (2005).

Shoestring Bridge to King Hill. No point sources discharge directly to the Snake River. Point sources after 2000/2005 based on the Upper Snake-Rock TMDL Modification (2005).

The Upper Snake-Rock TMDL (DEQ and Mid Snake TAC 1999) and the 2005 modification (DEQ 2005) applied mean flow conditions using a mean flow scenario (WY 1983–1998) when calculating existing loads and allocations. The baseline flows used to estimate the Middle Snake River existing and target loads were drawn from low flow conditions for 1991 (5,510 cfs). Subsequently, the load and wasteload allocations were calculated using a mean flow scenario (WY1983–1998) for the Upper Snake-Rock TMDL (DEQ and Mid Snake TAC 1999) and 2005 modification (DEQ 2005).

Impacts of phosphorus on aquatic life use support through eutrophication are chronic in nature, rather than acute, so it makes sense to evaluate the TMDL based on a representation of a flow over a somewhat longer exposure time then an extreme low flow (e.g., 7Q10). However, use of an annual average flow does not represent summer low flow critical conditions during which excess plant growth occurs. A 30-day average low flow may provide a more appropriate representation of critical conditions for establishing the loading capacity. Also of concern is the observation that WY 1983-1998, on which the current allocations are based, was a wetter period than has been observed in the years since the TMDL. This issue is discussed further in Section 4.2.

The proportion of the baseline load contributed by natural tributaries, canalways, point sources, and river corridor nonpoint sources varied by study segment (Figure 13). Corridor nonpoint sources were estimated to represent at least half or more of the baseline load to the first four study segments (Milner Dam to Gridley Bridge). Point sources contributed reasonably large loads to the two segments from Crystal Springs to Gridley Bridge, and tributaries were estimated to account for the majority of loading to the segment from Gridley Bridge to Shoestring Bridge. A reasonably large portion of the load was unaccounted for in all study segments. The proportion of load allocated to each source (Figure 14) differs somewhat from the baseline load (Figure 13). Tributaries are assigned a larger proportion of the total allocation, and corridor nonpoint sources are assigned a smaller proportion. Some of the differences are explained by the fact that baseline loads could not be estimated for all point sources.

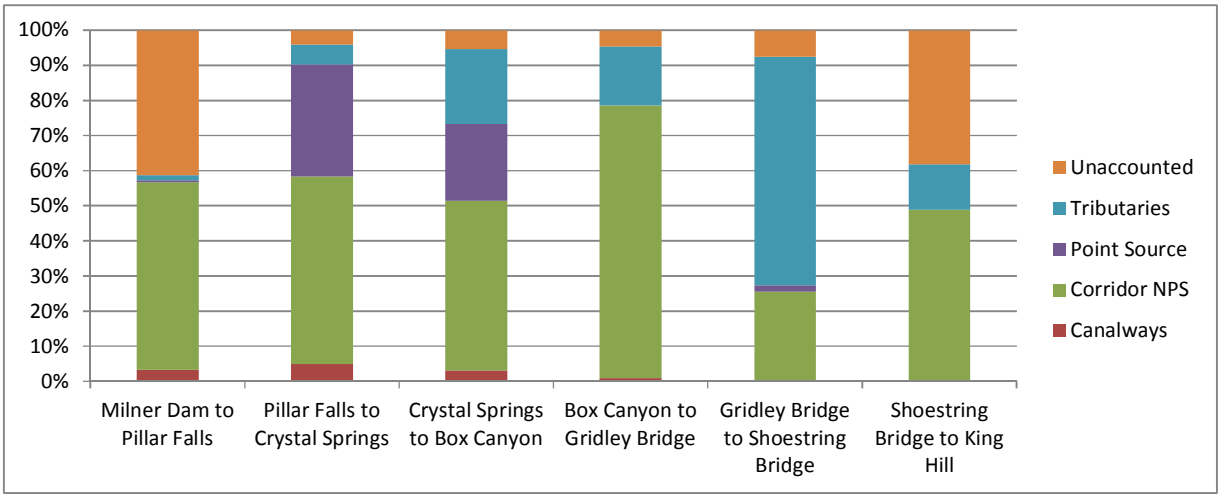

Figure 13. Proportion of baseline load (1990–1991) contributed by each major source (DEQ 2010).

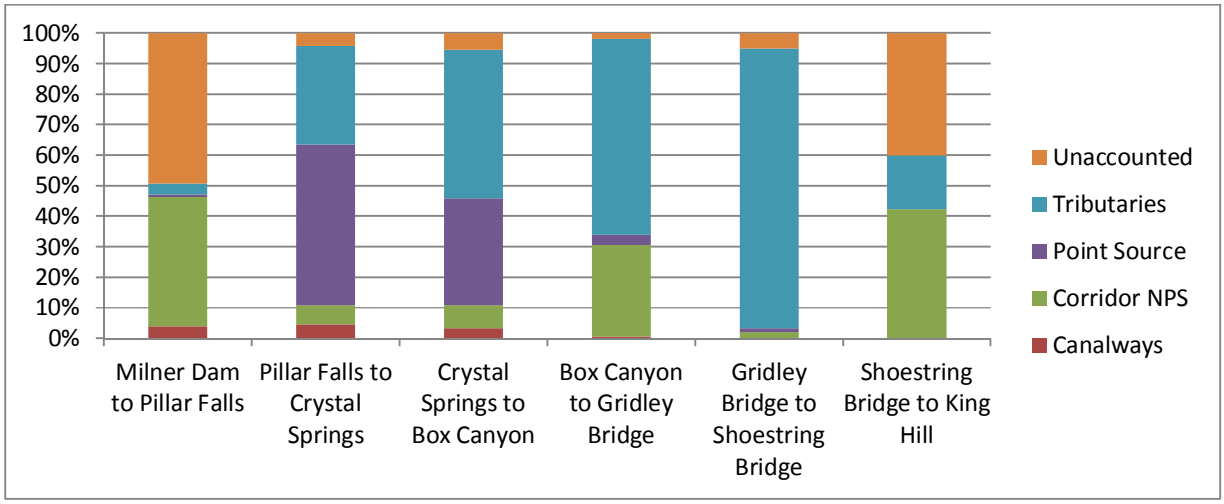

Figure 14. Proportion of total allocations assigned to each major source (DEQ 2010).
(Note: The negative load allocation, due to diversions, for the two canalways in Shoestring Bridge to King Hill, is represented as a zero load allocation for display purposes.)

A source of TP included in the corridor nonpoint source load category is discharges from failing septic systems in rural and urbanizing areas. It is difficult to estimate the magnitude of TP from failing septic systems because of uncertainty regarding their number, location, and condition. Septic system permit data from the South Central Idaho Health District for three counties (Jerome, Gooding, and Twin Falls) indicate that septic systems continue to be installed as rural land is converted to urban uses (e.g., subdivisions). Table 7 shows the estimated number of septic systems assumed to be installed in each county prior to 2001 (on the basis of the conservative assumption that 30 percent of rural households had septic systems) and the number of permits issued for septic system installation or replacement between 2001 and 2012. Because maintenance of septic systems is the owner's responsibility and performance information and failure rates are not tracked, the contribution of TP from this growing category of nonpoint sources is unknown. These data provide an indication of trends in septic system use, but it is important to note that the data are county-wide and not specific to land within the subbasin.

Table 7. Septic system trends in three counties that border the Upper Snake River Subbasin

County	Estimated Number of Septic Systems Installed Before 2001	Septic Systems Installed or Replaced Between 2001 and 2012
Jerome	1,284	1,078
Gooding	963	810
Twin Falls	2,848	2,391
Total	**5,095**	**4,279**

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4. Data Review and Analysis

This section summarizes available data and reviews the data for trends related to how well the existing TMDL assumptions are achieving the targets, including a consideration of critical flows, attenuation (reduction, retention, and dilution), loading, and ground water influences (note: Appendix A inventories the sources of data). In addition, several analyses provide insight on recent trends in total phosphorus and available studies on nuisance aquatic plant growth are discussed.

4.1 MONITORING STATIONS

There are monitoring stations along the Middle Snake River mainstem as well as along natural tributaries, irrigation drains, and springs. Figure 15 illustrates the DEQ, USGS, Clear Springs Foods (CSF), Idaho Power Company (IPC), and University of Idaho (U of I) Idaho Water Resources Research Institute monitoring stations along the mainstem and tributaries that were considered in this assessment. The location of the Jerome climate monitoring station is also included. Some USGS stations were not included because they did not have relevant data. Figure 16 and Figure 17 provide the monitoring locations for the Twin Falls Canal Co./USDA-ARS Kimberly and North Side Canal Co., respectively.

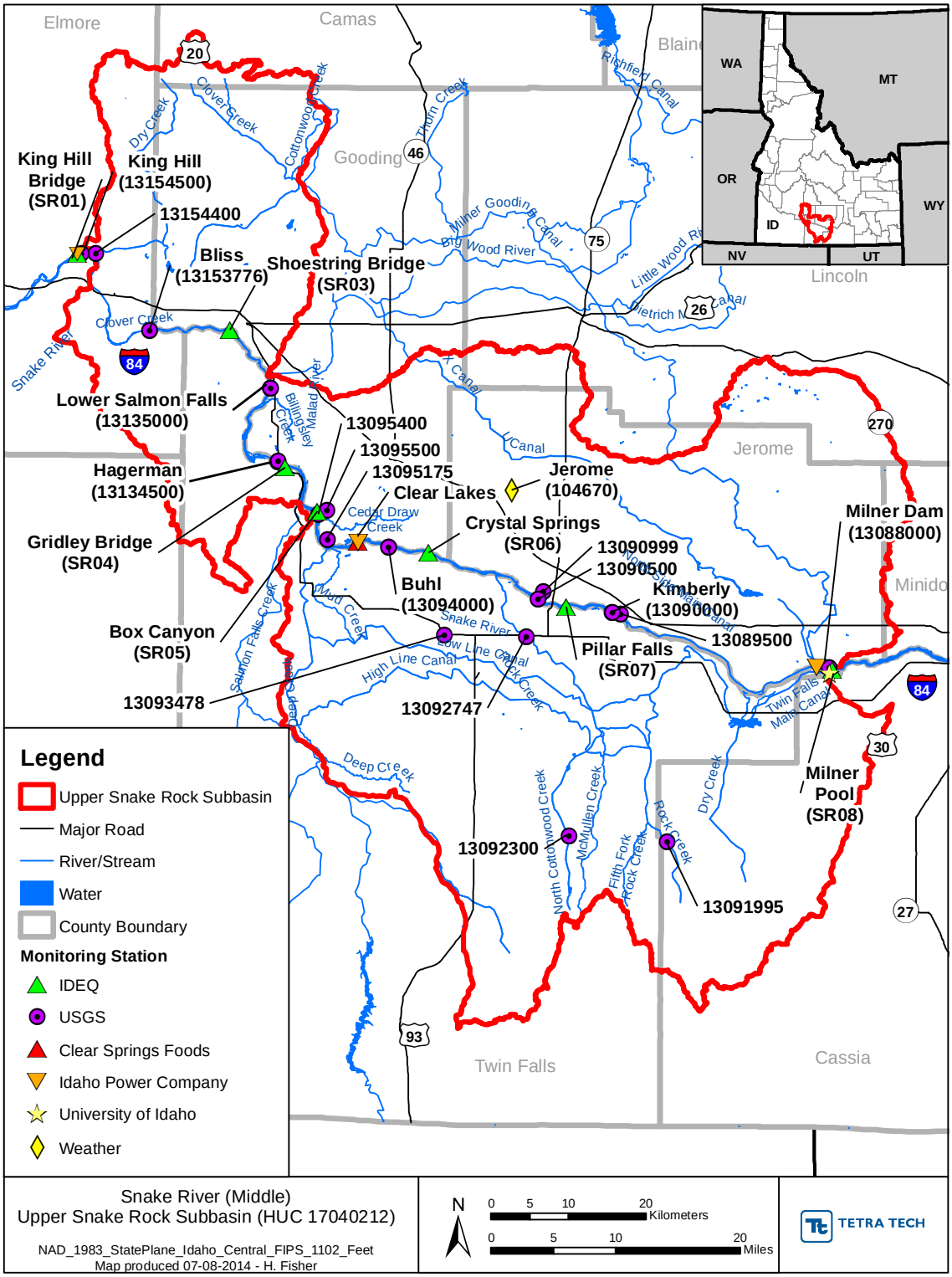


Figure 15. DEQ, USGS, CSF, IPC, and U of I monitoring stations.

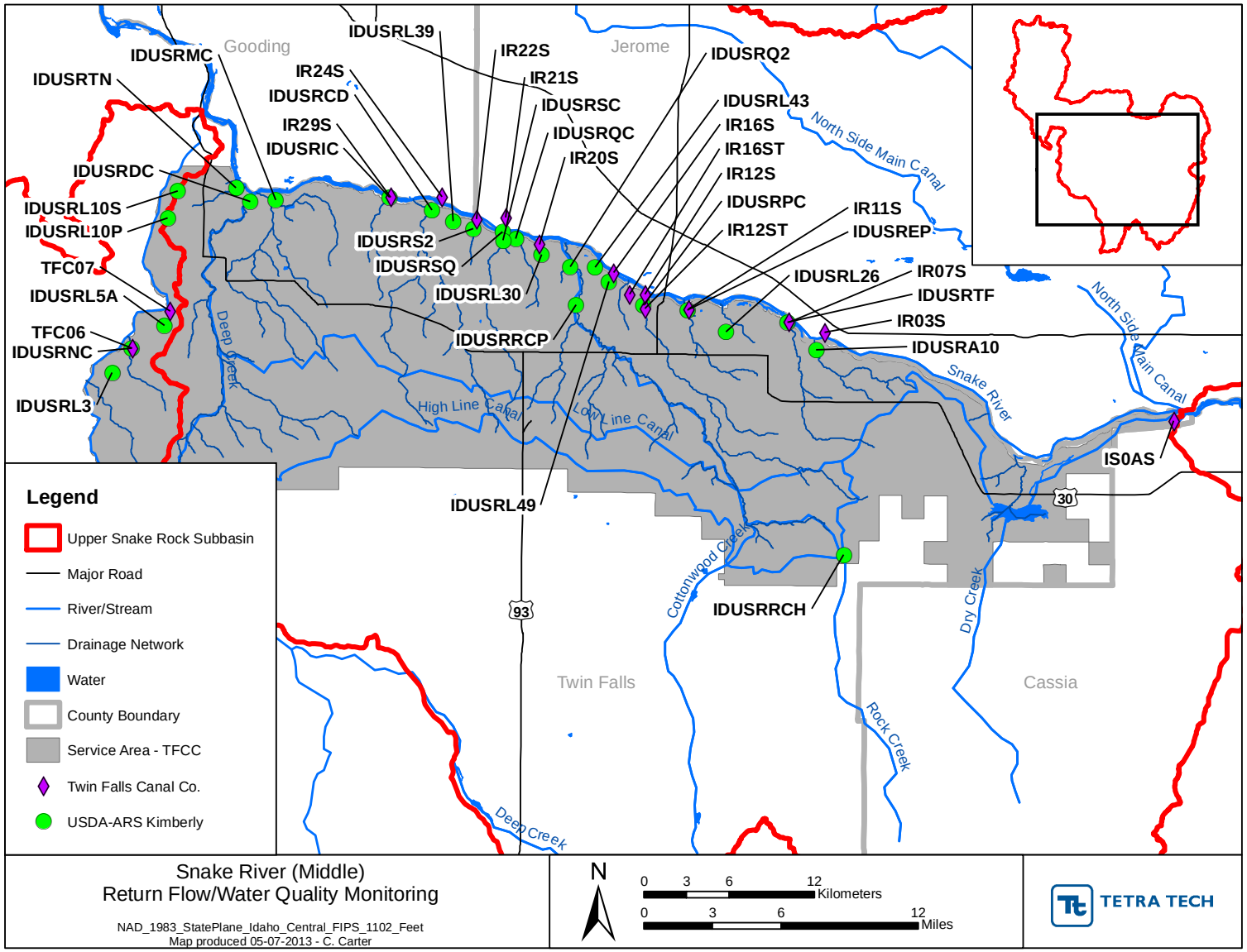


Figure 16. Irrigation return flow and water quality monitoring stations for the Twin Falls Canal Co. and USDA-ARS Kimberly.

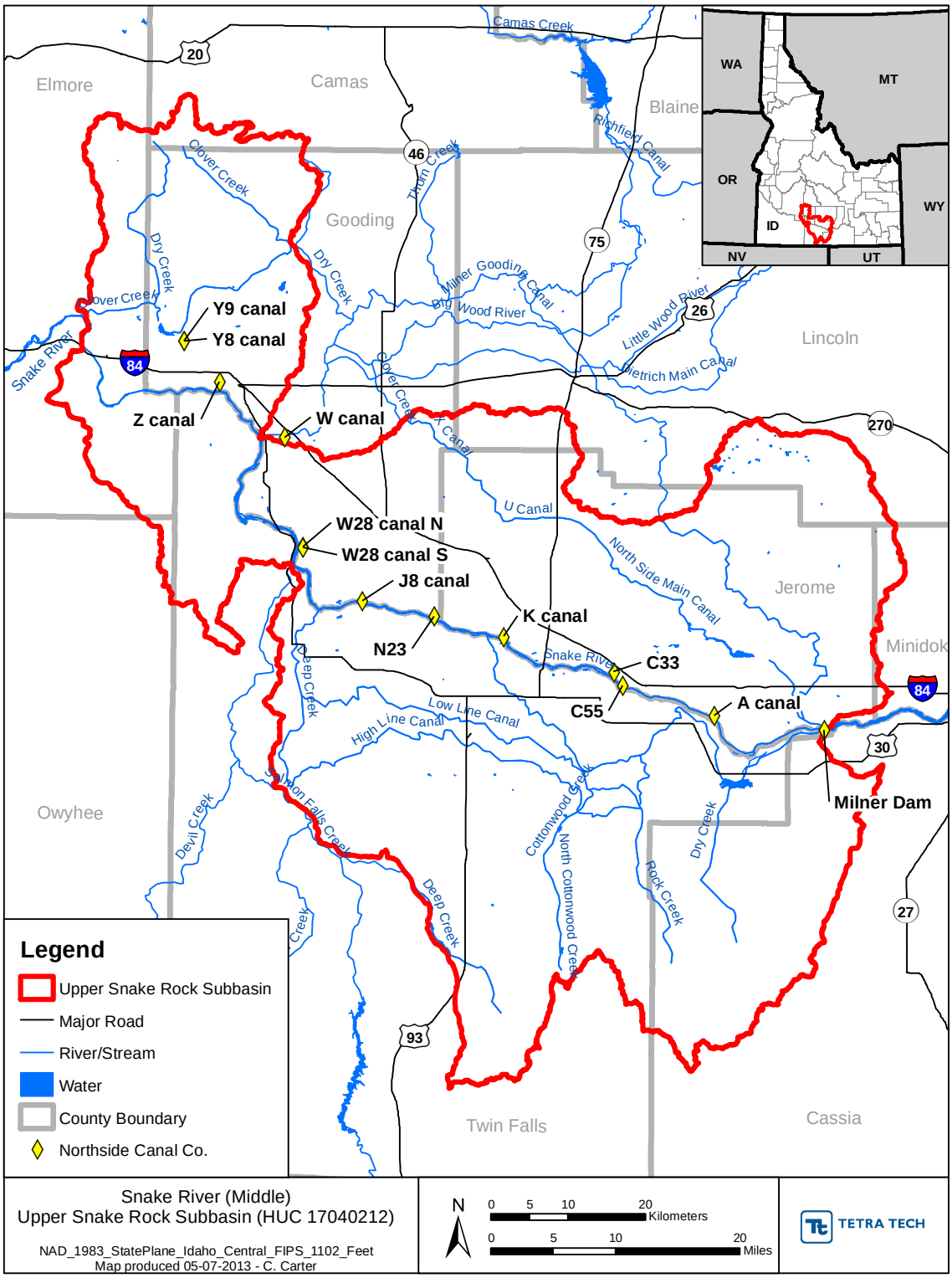


Figure 17. Irrigation return flow and water quality monitoring stations for the North Side Canal Co.

4.2 FLOW

Flow data have been collected by USGS since 1909 at the Milner Dam and King Hill gages, since 1924 at the Kimberly gage, and since 1947 at the Buhl gage. Flow data have also been collected in tandem with water quality monitoring.

DEQ (2010) indicated that the Middle Snake River has experienced water volume reductions in recent years. TMDL development in the 1990s assessed low flow (1988–1995) and high flow (1983–1987, 1996–1998) scenarios as well as the baseline years (1991–1992). DEQ compared these flow scenarios to post-TMDL flows and found that post-TMDL lower-than-average flow conditions in the Middle Snake River have been below those for the baseline years and the low flow years. Since 2000, the greater-than-average flow conditions in the Middle Snake River have been above those for the baseline years and the low flow years, but the overall flow conditions in the Middle Snake River since 2000 have not approached the high flow scenario considered in the TMDL (DEQ 2010).

Figure 18 compares the flows used to calculate the loading capacity and allocations from the previous TMDLs to recently-calculated flow statistics (see also tabulated version in Appendix B). All three sets of TMDL flows are based on what was considered low flow conditions at the time of analysis. The flow statistics include 2000—2009 mean annual flow and the following statistics for the period of record (POR): 10th percentile flow, the 7Q10, and the 30Q10[1]. Where USGS gages did not coincide with the exact study segment beginning or ending location, the proportion that did coincide was used to approximate the flow represented for each study segment (see Appendix H for more explanation).

Recent mean annual flows are well below the 2000 and 2005 TMDL assumptions across the six locations. The 1999 draft TMDL flow is similar to the 2000—2009 mean annual flow. The 10th percentile, 7Q10, and 30Q10 fall below all three TMDL flow assumptions (1999, 2000, and 2005). This comparison suggests that, if the TMDL is meant to reflect low flow conditions, lower flows should be used when calculating the loading capacity and allocations. In addition, the mean annual flow from the most recent decade falls only slightly above the low flow measures, which indicates that lower than average flows have occurred during the 2000—2009 period. The trend toward decreased flows in the Middle Snake River indicates that the flow assumptions used to set load and wasteload allocations might no longer be applicable.

A review of the most recent flow monitoring data supports the findings from DEQ (2010). USGS daily flows, as well as average and median daily flows by decade, are displayed for each of the four gages in Appendix B. Average and median daily flows are displayed for the full year, as well as separately, for the irrigation season (April 15 through October 15) and the non-irrigation season (October 16 through April 14).

[1] The 7Q10 flow for this period was defined as the 10th percentile flow among the lowest seven-day average flows for each year in the POR. The 30Q10 flow was defined as the 10th percentile flow among the lowest 30-day average flows for each year in the POR.

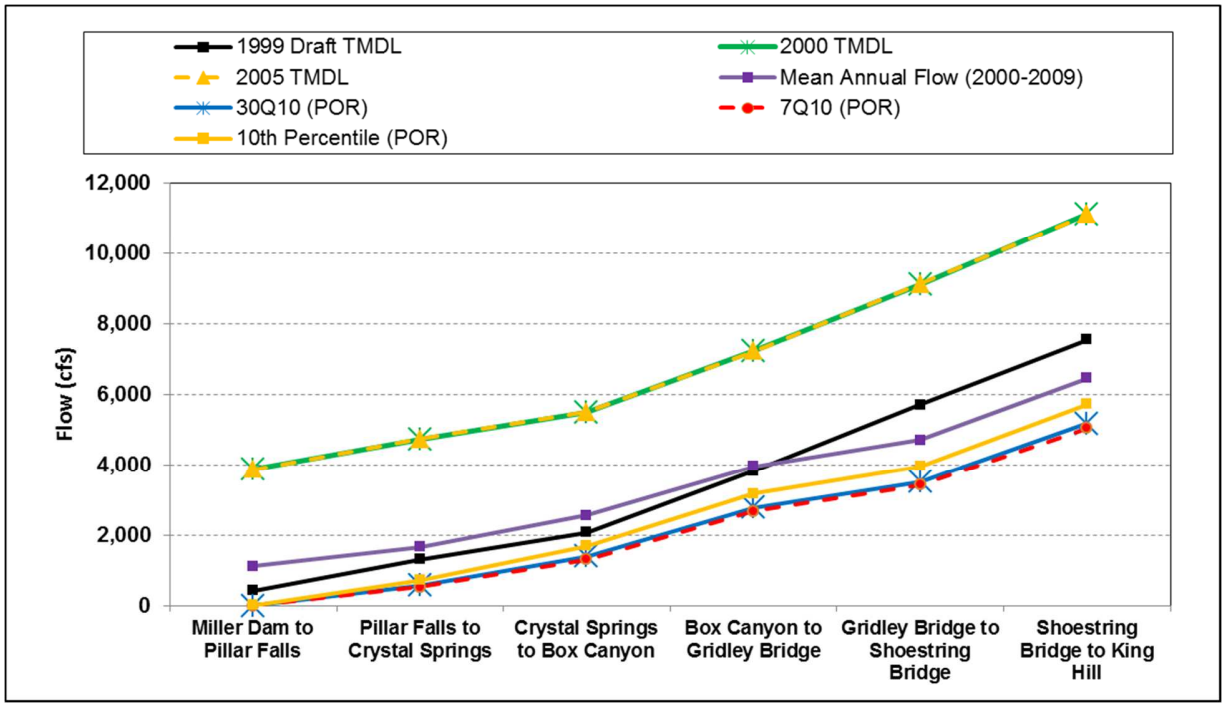


Figure 18. Comparison of TMDL assumptions to 2000-2009 and POR flow statistics.

Across the full record for all four gages, the median and average daily flows in the 2000s are the lowest or among the lowest compared to the other decades. Similar trends occur when comparing these statistics separately for the irrigation season and non-irrigation season. These trends are more pronounced for the two more downstream gages, suggesting that return flow and ground water inflow to surface waters may have declined within the last decade. A review of seasonal and longitudinal trends can provide insight into where and when more significant decreases in flow might be occurring. In particular, ground water inflow is more influential within different river segments and declines in ground water inflow could be affecting TP concentrations to a greater extent in these segments.

Stream flow increases upstream to downstream provide an indicator of the influence from ground water inflow. Time series of mean daily flow, 7-day minimum flow, and average annual mean daily flow (Figure 19 through Figure 27) show an increasing flow trend from upstream to downstream as inflows from ground water (diffuse and spring), tributary, and irrigation return restore flow after diversion at the Milner Dam. The greatest increase in flow occurs between the Buhl and King Hill Bridge gages (13094000 and 13154500). The Thousand Springs area, where the greatest inflow from the Snake River Plains aquifer occurs, is between the Buhl and King Hill Bridge gages. The large increase in flow between these gages is likely due to both the large ground water inputs (diffuse and spring) and the two major tributaries entering from outside the subbasin, Salmon Falls Creek and the Malad River.

A comparison of mean daily flow (Figure 19 through Figure 21) illustrates the seasonal and cyclical variation in flow and provides further insight into ground water influence. From the beginning of the water year (October 1), flows typically increase through the winter and early spring. In dry years, flow is likely dominated by ground water inflow from both springs and diffuse inputs. According to DEQ (1998), the lowest aquifer flows occur in the spring before irrigation increases the aquifer recharge rates. This trend can be seen during WYs 1990 through 1992, 2002 through 2005, 2008, and 2012 during which a brief decrease in stream flow occurs consistently during the middle of the water year, approximately April through May depending on the year. In the driest years, when few if any large storms occur, flows at the two most upstream gages (Milner Dam 13088000 and Kimberly 13090000) remain low until the end of

the irrigation season, when diversions are relaxed. A slight recovery in flow is evident, even during the driest years, for the two most downstream gages (Buhl 13094000 and King Hill 13154500). This difference in trends between upstream and downstream gages further suggests that the influence of spring discharge and irrigation return flow is stronger at the more downstream gages.

In wet years, flow is much more variable compared to dry years. Flow is highly regulated at the Milner Dam as well as other dams throughout the watershed. The flow pattern for any one year reflects the combined effect of irrigation diversions, flood releases, flow augmentation, irrigation return flow, ground water flows (both diffuse and spring), and naturally occurring runoff. The highest stream flows are expected to occur in the early spring, with general declines through the summer as irrigation flows are diverted from the mainstem and precipitation decreases. Occasional storm events create peak flows during the irrigation season. Irrigation return flows are expected to contribute to increasing flows from the beginning of September until the end of October. These trends can be seen in some wet years, but are distorted by the high variability. One distinct observation is that, even during wet years, zero flows were observed at Milner Dam during the irrigation season except for WY 1998, 1999, and 2011.

Generally, a comparison of the flow data between the most recent decades suggests that seasonal and annual trends remain consistent but that flow on average has decreased between the 1990s and 2000s. The differences between decades are most evident at the more downstream gages—Lower Salmon Falls, Bliss, and King Hill. Because these gages occur where ground water inputs (both diffuse and spring) are known to be influential, the declines may be an indicator of declining ground water inflows to the Middle Snake River.

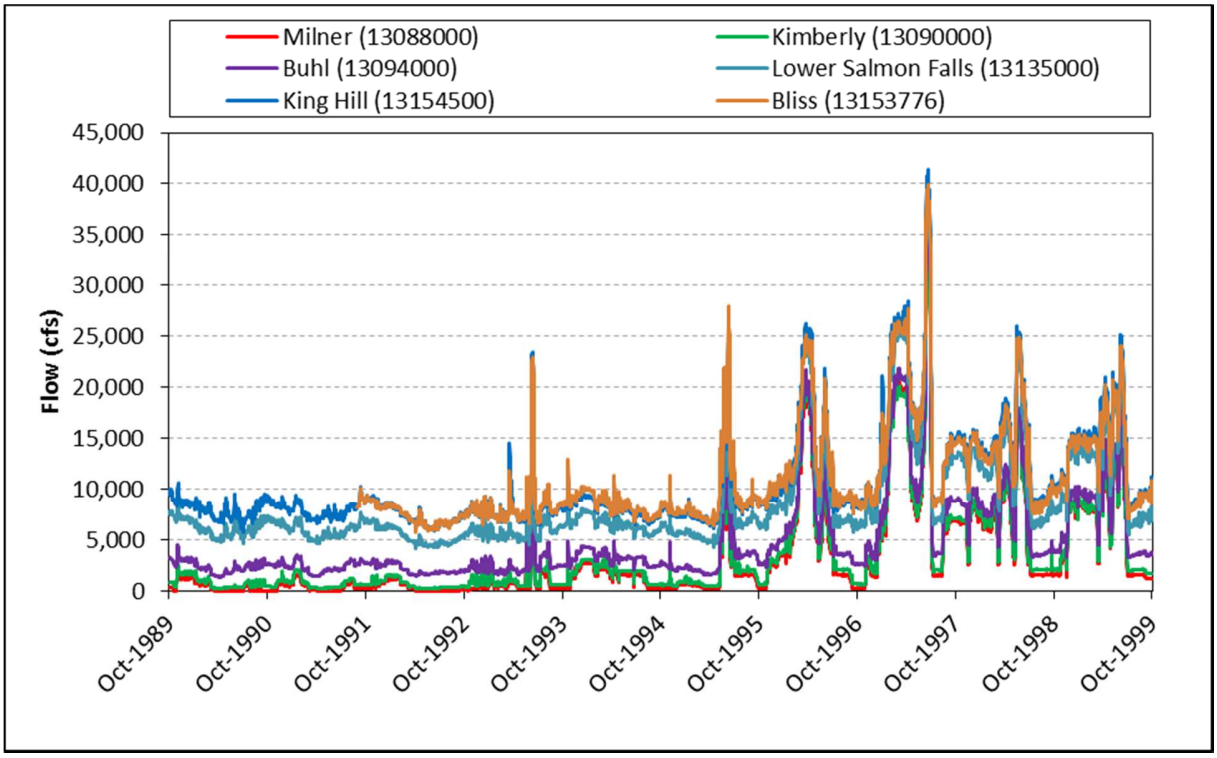


Figure 19. Mean daily flow, pre-TMDL (water years 1990–1999).

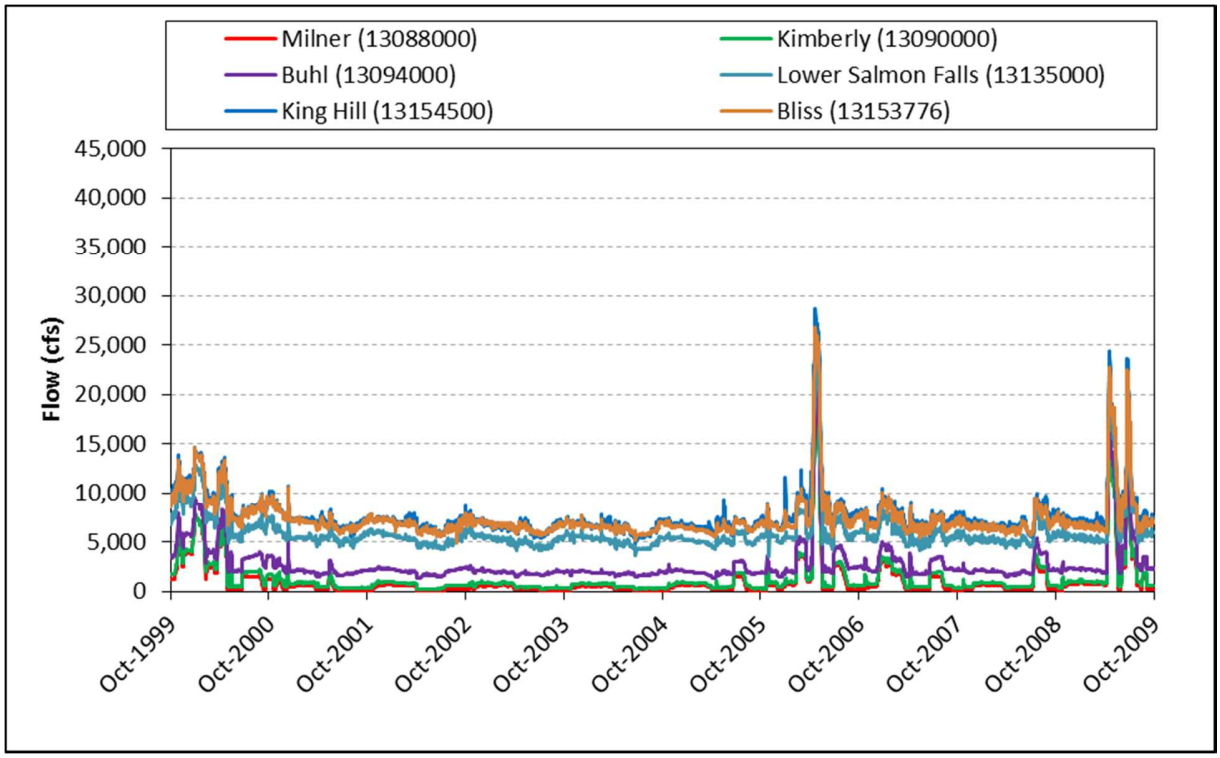


Figure 20. Mean daily flow, post-TMDL (water years 2000–2009).

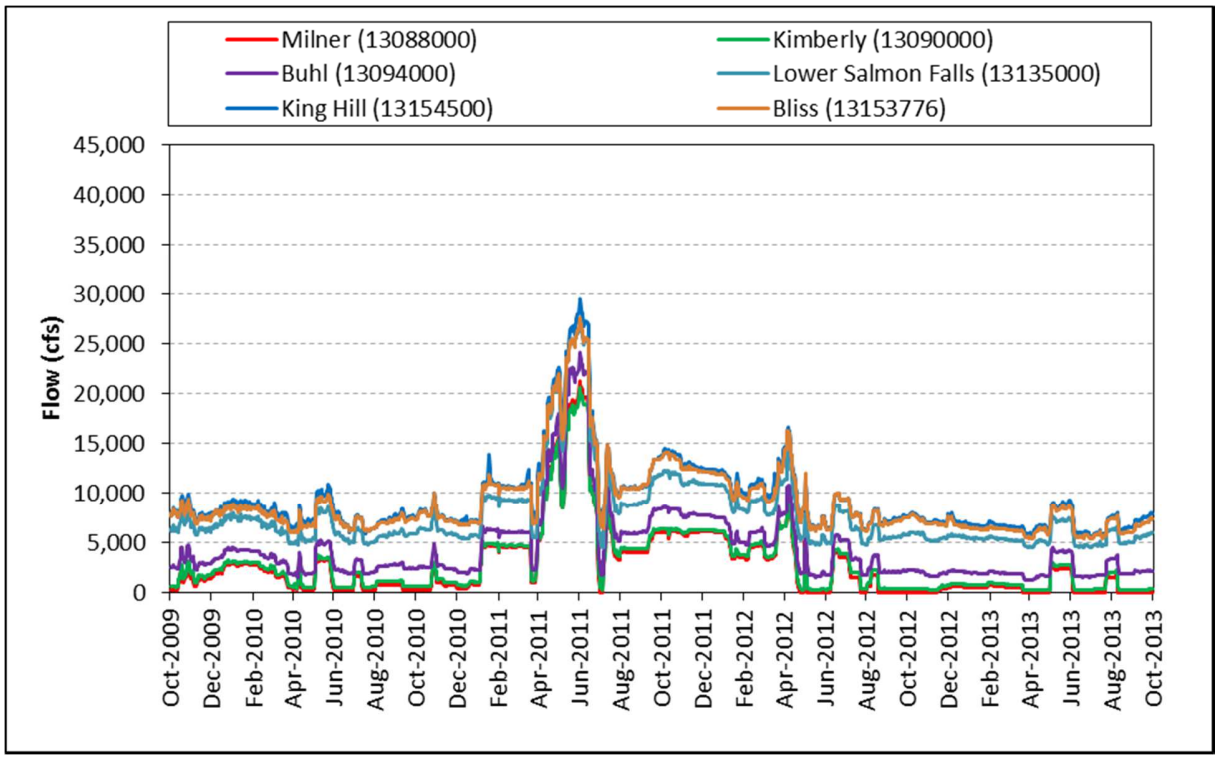


Figure 21. Mean daily flow, post-TMDL (water years 2010–2013).

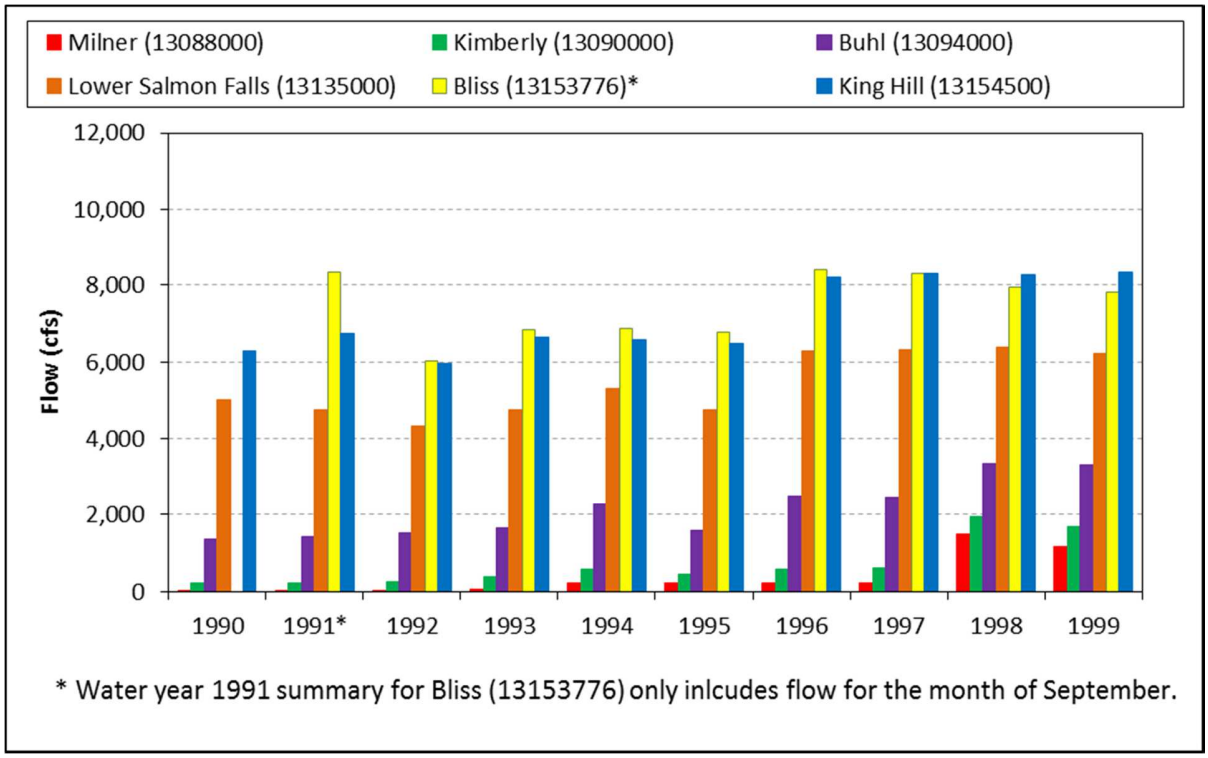


Figure 22. Seven-day minimum flow, pre-TMDL (water years 1990–1999).

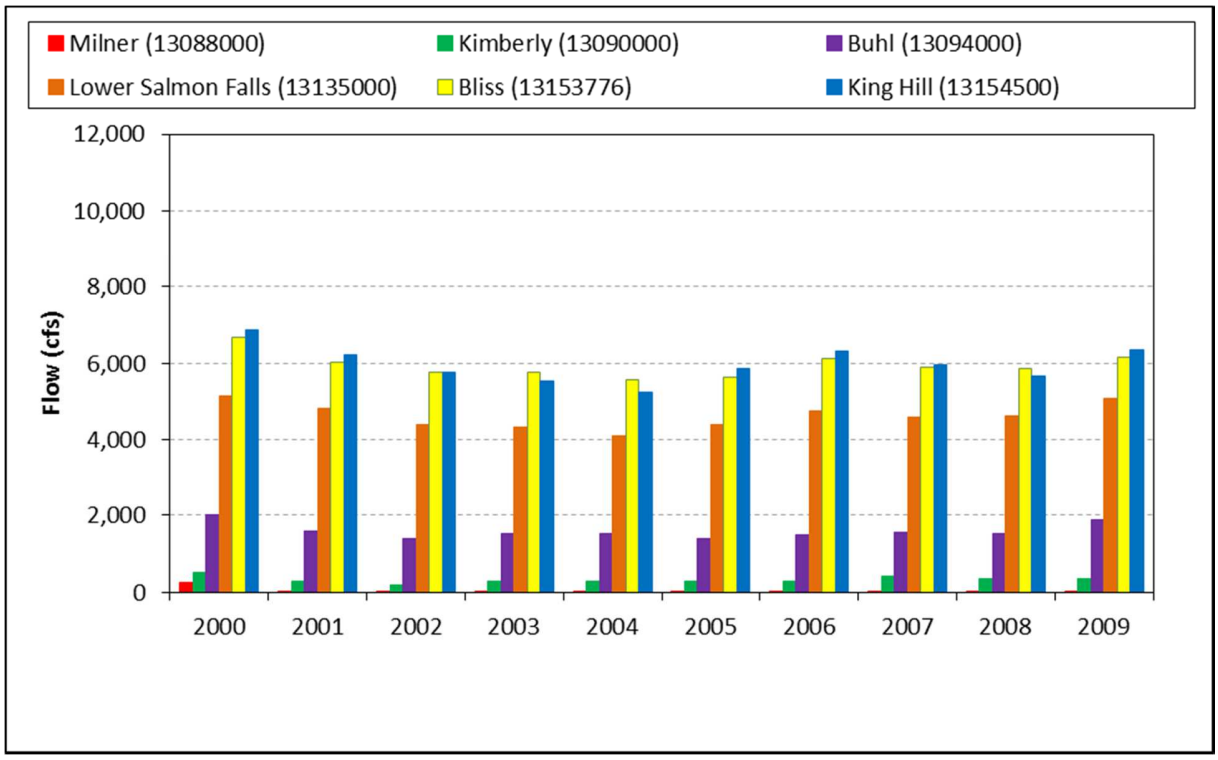


Figure 23. Seven-day minimum flow, post-TMDL (water years 2000–2009).

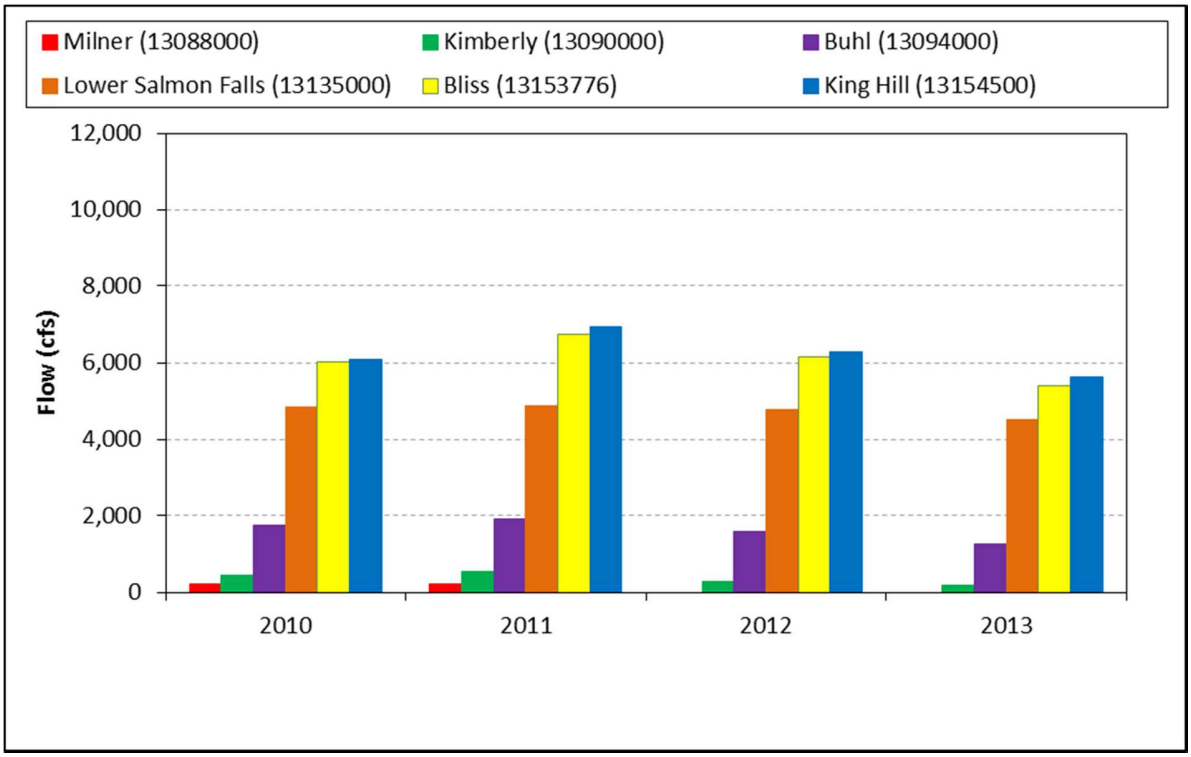
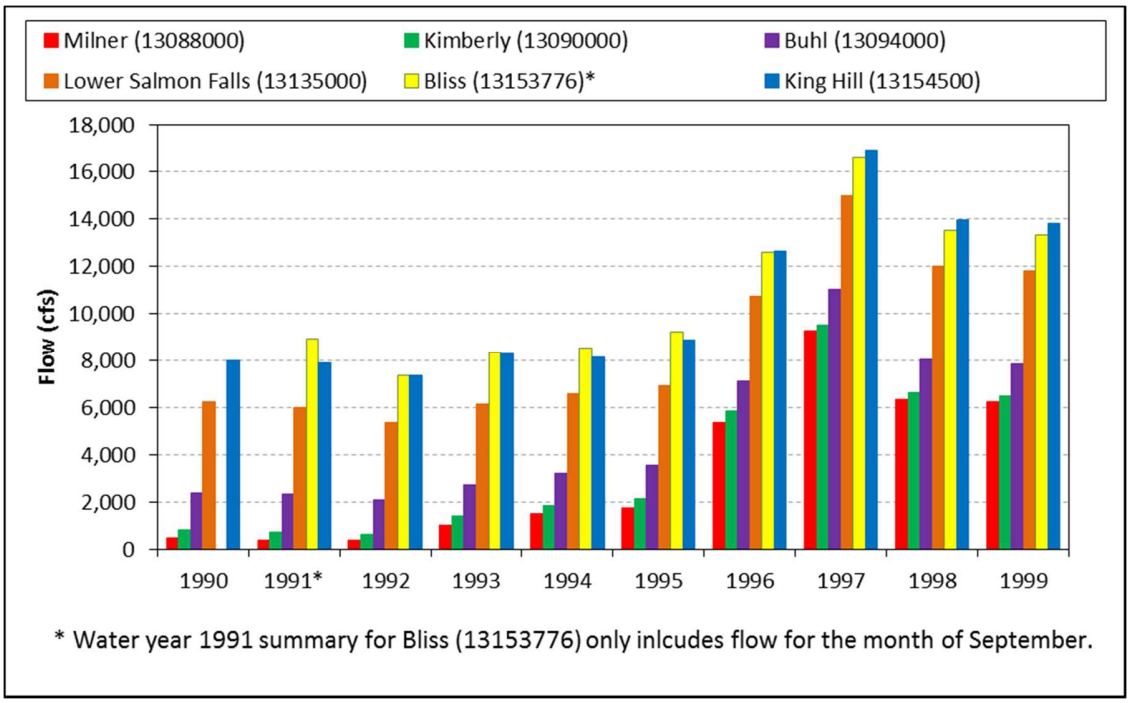
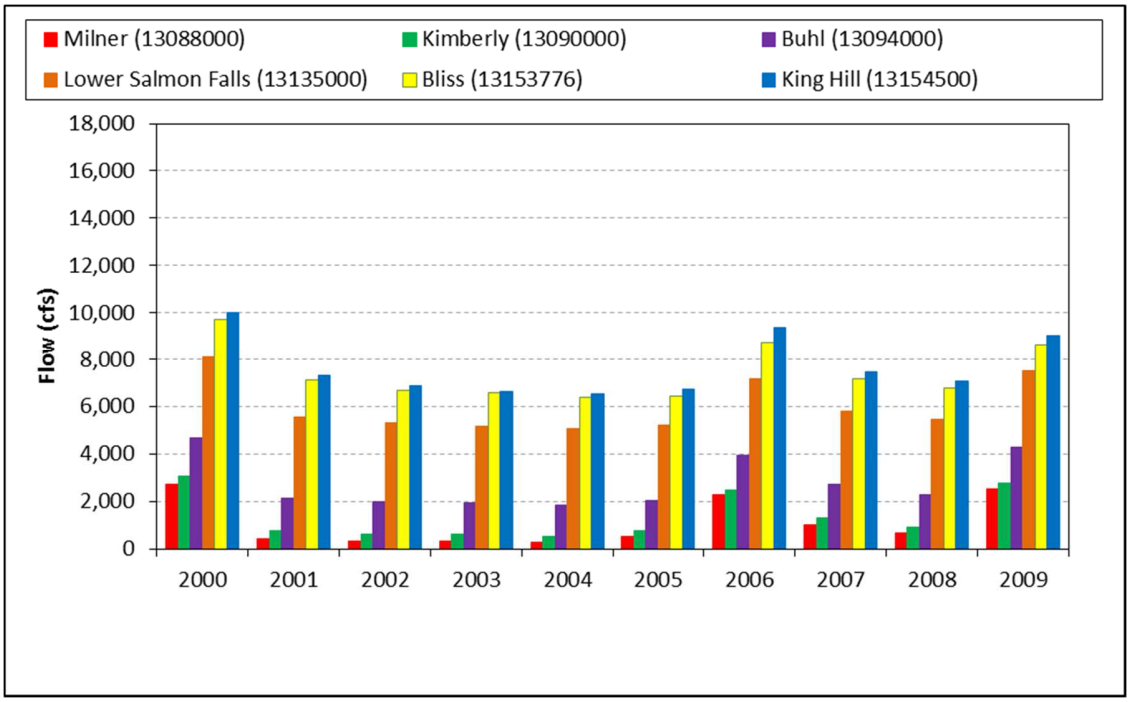


Figure 24. Seven-day minimum flow, post-TMDL (water years 2010–2013).



Note: calculated from mean daily flows

Figure 25. Average annual flow, pre-TMDL (water years 1990–1999).



Note: calculated from mean daily flows

Figure 26. Average annual flow, post-TMDL (water years 2000–2010).

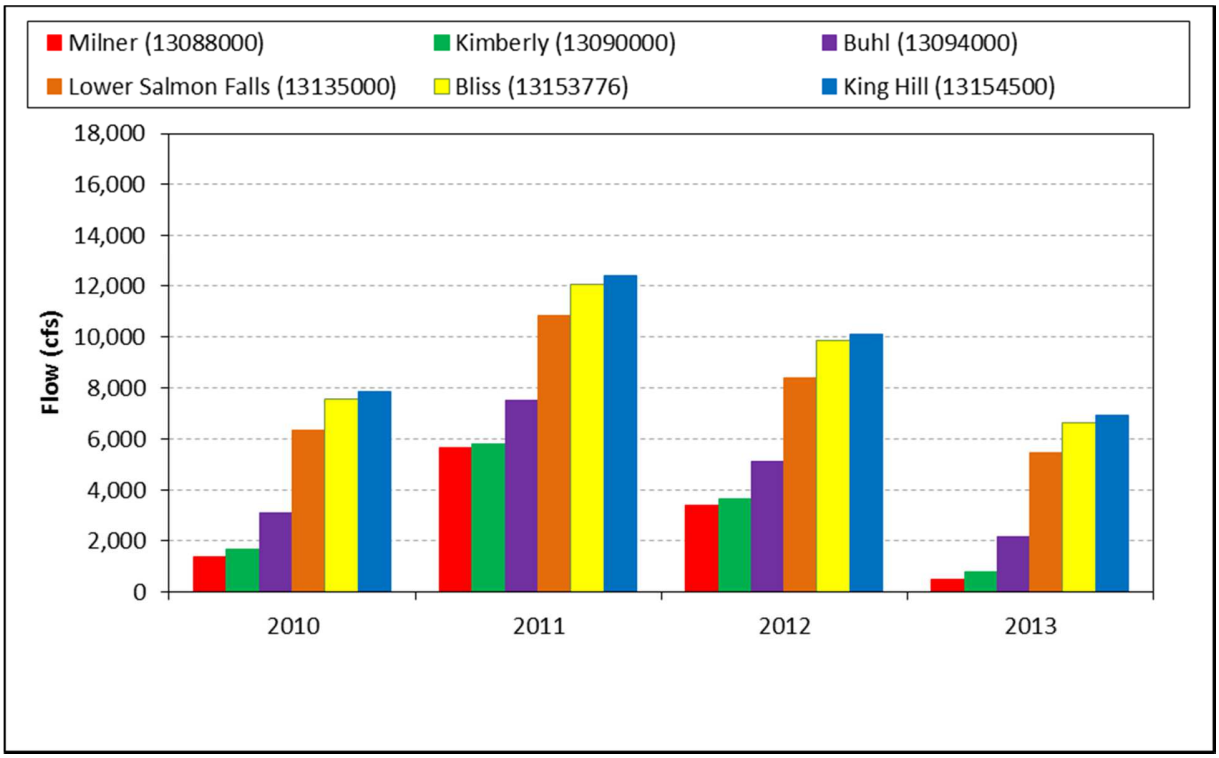


Figure 27. Average annual flow, post-TMDL (water years 2010–2013).

4.3 WATER QUALITY

Water quality monitoring of the Middle Snake River and its tributaries has been ongoing since 1965. The following entities sponsor water quality monitoring efforts: DEQ (seven mainstem stations, 39 tributary stations), USGS (18 mainstem station, 174 tributary stations), Twin Falls Canal Company and USDA-ARS Kimberly (one mainstem station, 37 unique tributary stations), North Side Canal Company (one mainstem station, 12 tributary stations), CSF (1 mainstem station, no tributary stations), IPC (3 mainstem stations, no tributary stations), and U of I (1 mainstem station with post-2001 data). Point source discharge monitoring data are also available from EPA.

Trends in water quality were initially assessed based on visual interpretation of time series, box plots, and descriptive statistics. Then, advanced statistical analyses and nutrient load modeling were performed to determine if total phosphorus concentrations exhibit significant trends over time in the Middle Snake River mainstem.

4.3.1 Mainstem Monitoring

Figure 28 through Figure 30 provide TP time series for WY 1990 through the present from DEQ and USGS. Separate time series are also provided for dissolved ortho-phosphorus (DOP) measured by DEQ/USGS (Figure 31 through Figure 33). The DEQ/USGS time series are limited to Milner Pool, Crystal Springs, and King Hill so that major trends can be illustrated. USGS daily mean flow at Buhl (13094000) is overlaid with the Milner, Crystal Springs, and King Hill time series. Time series reflecting all DEQ/USGS monitoring locations as well as data collected by U of I, IPC, CSF, and the canal companies are provided in Appendix C.

The TP time series suggest an overall decrease in TP across the sampling period at all monitoring locations. A trend analysis and load modeling was performed to verify this trend is independent of changes in flow. Sections 4.3.5 and 4.3.6 discuss the methods and results of these analyses.

Extreme TP concentrations, well above the 0.075 mg/L target, occurred more frequently in dry years across all locations. The magnitude of extreme values appears to have decreased since 2000. Across all stations, TP concentrations have frequently exceeded the TP TMDL target of 0.075 mg/L.

The extreme TP concentrations observed at Milner Pool (SR08) appear to have decreased in magnitude but not necessarily frequency between decades. When these extreme concentrations occur, they tend to exceed concentrations at the other stations during the same sampling events. This trend likely reflects that upstream diversions often limit flow at Milner Pool, and during low flow years, less flushing may lead to much higher concentrations compared to average or high flow years.

In more recent years and higher flow periods, average TP concentrations appear to increase at Crystal Springs and stay elevated through Box Canyon until Gridley Bridge, where they gradually decrease from there to King Hill (see figures in Appendix C and D). In the 1990s, average TP concentrations were elevated at Crystal Springs but declined at Box Canyon. The decrease occurring downstream of Crystal Springs could be attributed to aquatic vegetation uptake and dilution from springs inflow. The effect of aquatic vegetation on nutrient concentrations in the Middle Snake River is discussed in Section 6.

TP concentrations at King Hill Bridge (SR01) appear to have less variability and fewer extremely high values across all years compared to Milner Pool and Crystal Springs. This may be indicative of the springs and irrigation return flow dominating the inflow sources at this location.

DOP trends are similar to the above TP trends although extreme values do not appear to have decreased in magnitude at Milner Pool when comparing the low flow years in the early 1990s and the early 2000s. This difference could reflect a decrease in sediment sources of phosphorus loading. Similar to the TP time series, the DOP data indicate a slight decreasing trend.

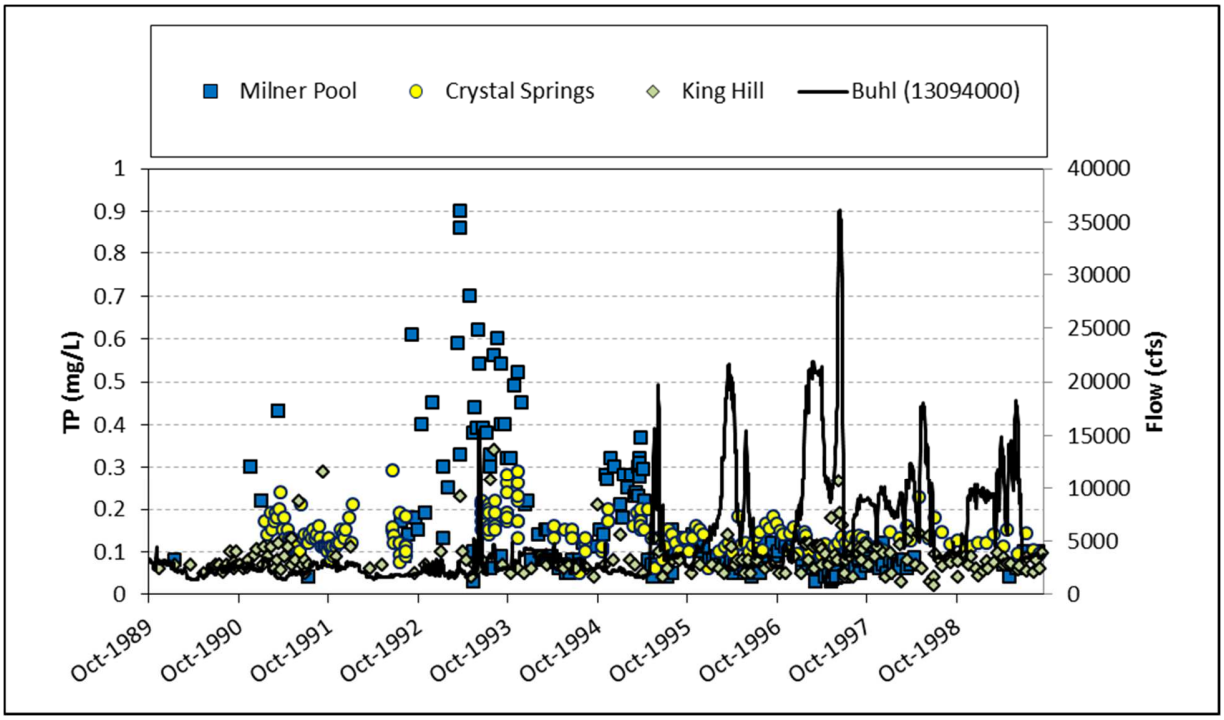


Figure 28. TP from water years 1990 through 1999 for DEQ/USGS select monitoring locations.

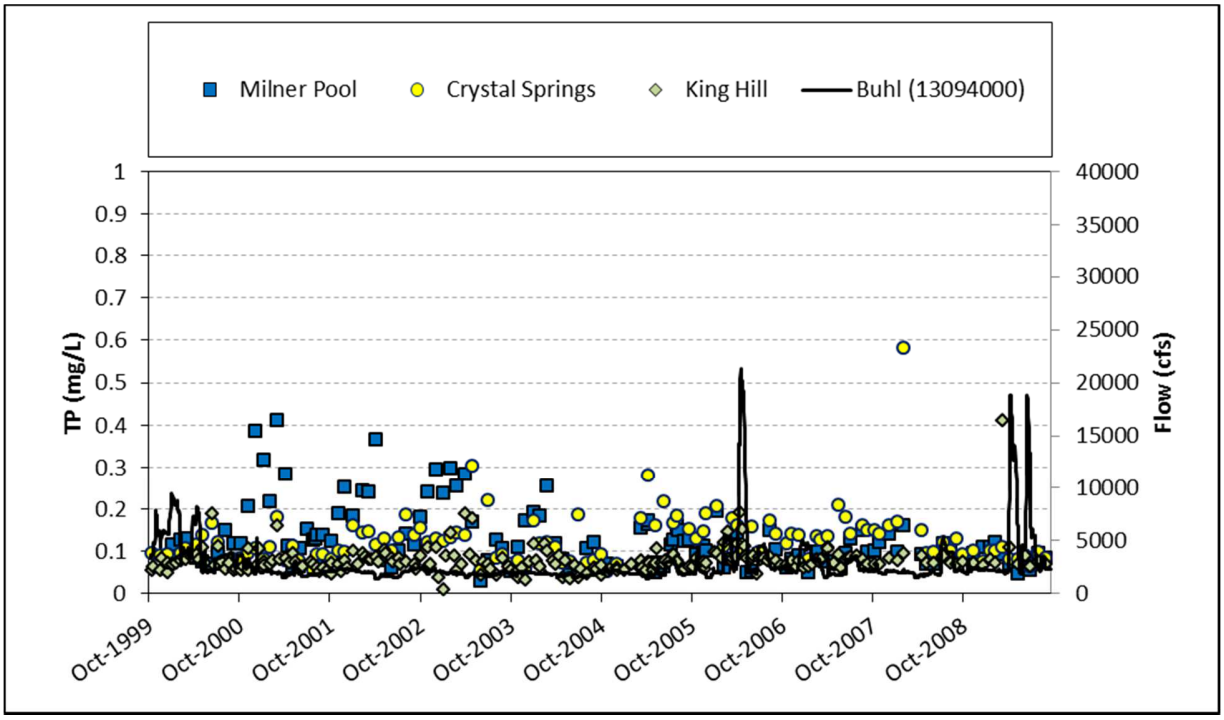


Figure 29. TP from water years 2000 through 2009 from DEQ/USGS at select monitoring locations.

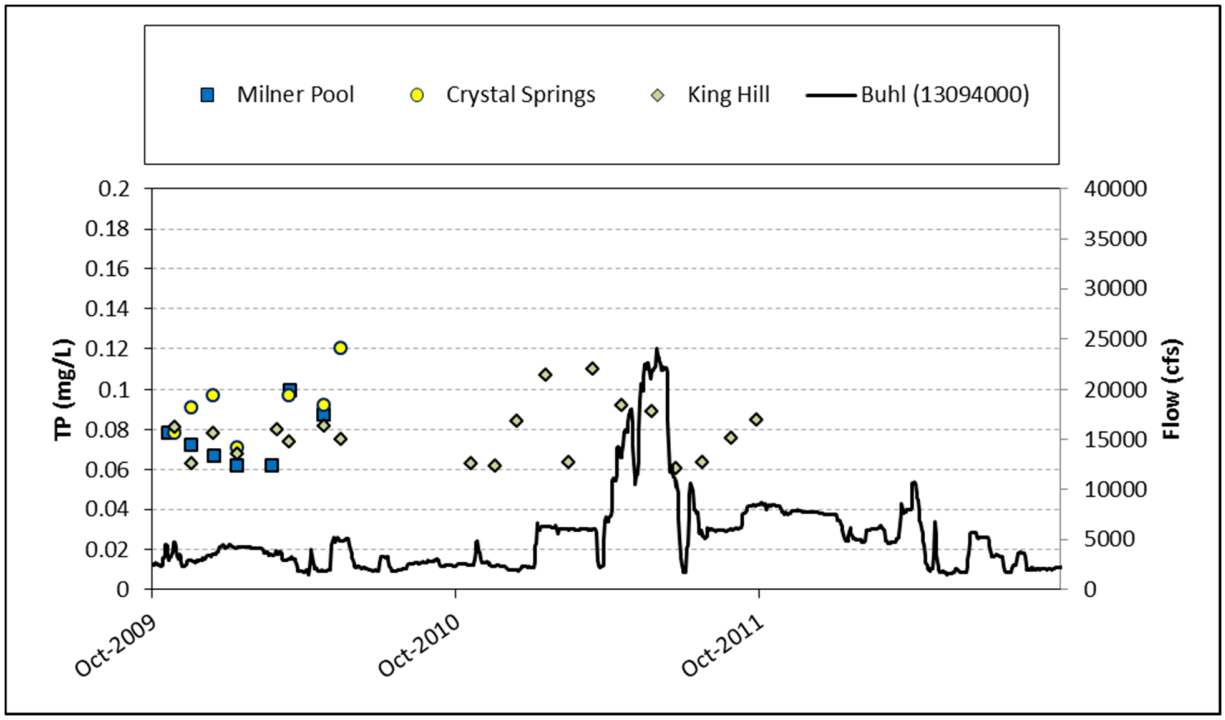


Figure 30. TP from water years 2010 through present from DEQ/USGS at select monitoring locations.

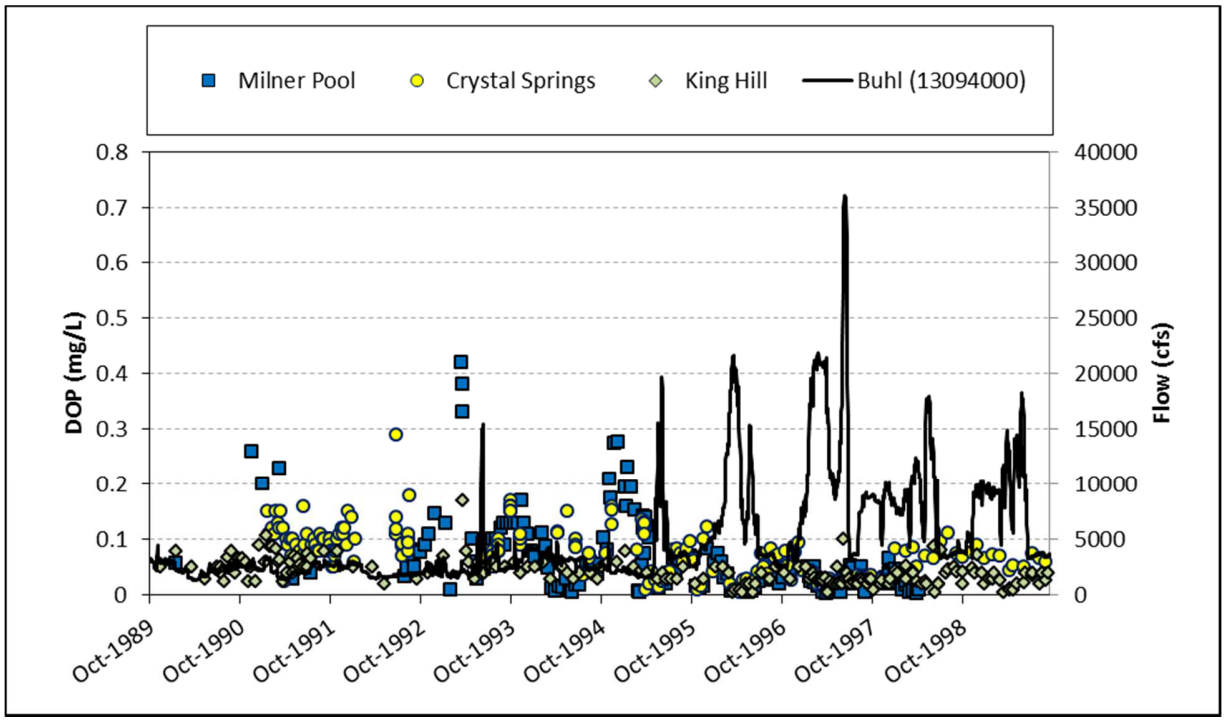


Figure 31. DOP from water years 1990 to 1999 for DEQ/USGS monitoring locations.

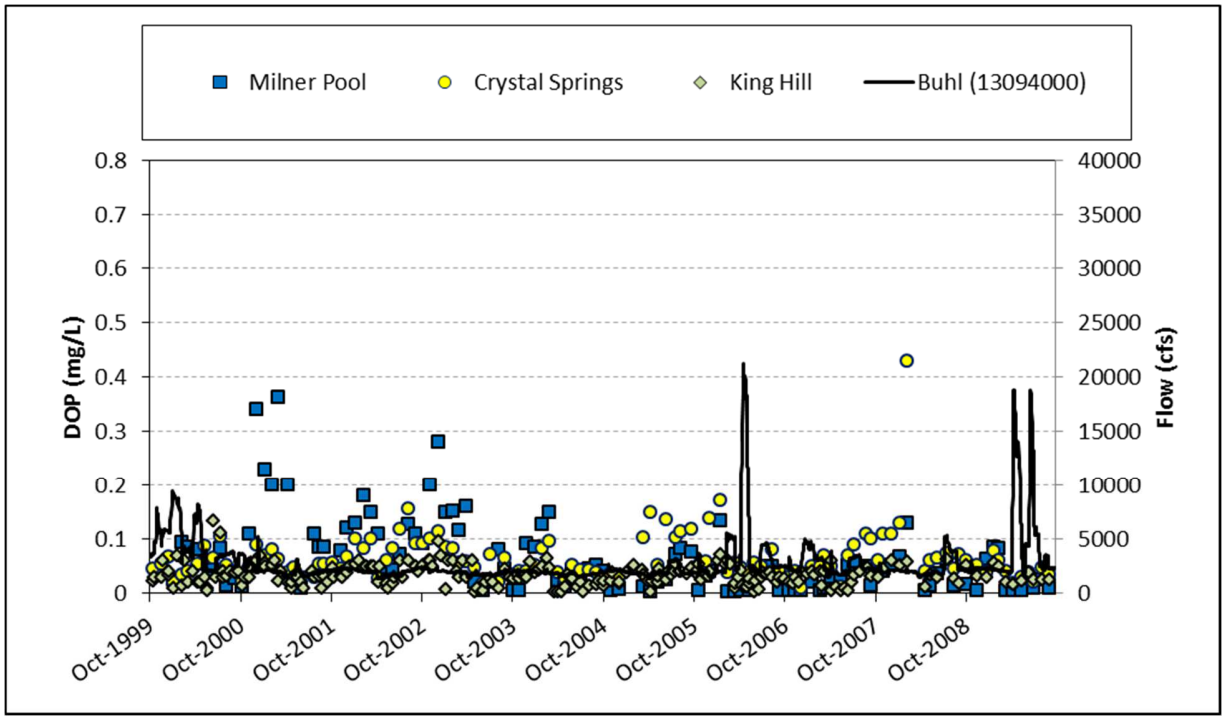


Figure 32. DOP from water years 2000 to 2009 for DEQ/USGS monitoring locations.

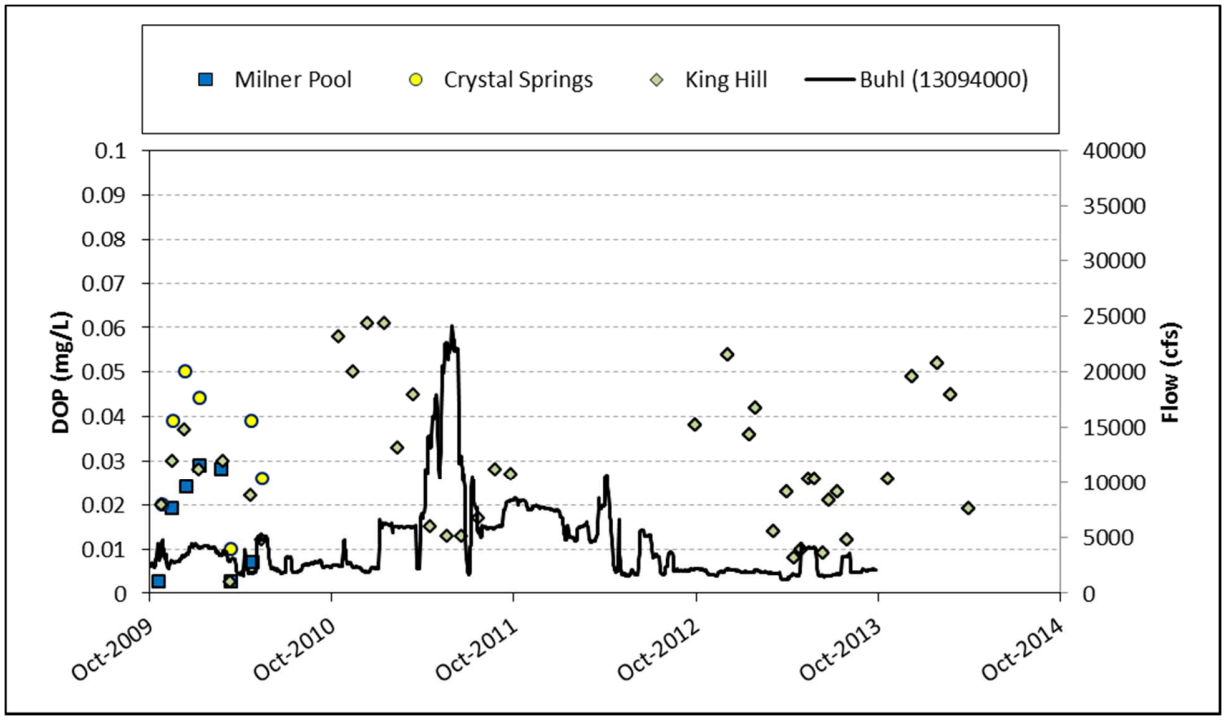


Figure 33. DOP from water years 2010 to present for DEQ/USGS monitoring locations.

Tetra Tech reviewed the DEQ data in more detail and found that the increase in TP concentrations at Crystal Springs relative to the upstream mainstem stations occurs consistently across seasons and decades. However, in the 2000s, TP concentrations remain elevated downstream of Crystal Springs, through Box Canyon, until Gridley Bridge, where a substantial decrease is observed. In contrast, TP concentrations in the 1990s begin to decline below Crystal Springs during all seasons except the winter, when they remain elevated at Box Canyon. These trends can be seen in the box-and-whisker plots (showing 10th, 25th, 50th, 75th, and 90th percentiles generated by season) in Appendix D.

Appendix E provides box-and-whisker plots (showing 10th, 25th, 50th, 75th, and 90th percentiles) comparing TP at each mainstem station across seasons and decades using DEQ data only. When comparing decades during each season, significant decreases in TP concentrations have been observed during the fall (September through November) at a number of stations: Crystal Springs ($p<0.05$), Gridley Bridge ($p<0.002$), Milner Pool ($p<0.001$), and Pillar Falls ($p<0.001$). The most visibly apparent difference in trends across seasons and between decades occurs at Pillar Falls, where TP is relatively constant across seasons in the 1990s but shows a decreasing trend from winter to fall in the 2000s. (Fall concentrations are significantly different from spring and winter concentrations with $p<0.001$.) (See Appendix E, Figure 97.) The effects of diversions and irrigation return flow could be more evident at this location, which would explain the strong seasonal trends.

DEQ calculated daily loads for each mainstem monitoring station, using daily USGS flows to calculate loads for sampling locations with a flow gage (DEQ 2011). For those locations without flow gages, daily flows were interpolated based on river mile distance and linear relationship to the Milner Dam or King Hill gages for each of the five monitoring sites between flow gages.

Table 8 summarizes the daily loads at each mainstem station for the 1990-1999 and 2000-2009 time periods. Daily load appears to have decreased between decades at each station due to a combination of lower concentrations and lower flows. DEQ calculated net loading between Middle Snake River study segments as shown in Figure 34. The net load calculations represent the difference between the upstream and downstream daily load as calculated by DEQ (2011). For both decades, these load calculations show load increases at every study segment except between Box Canyon and Gridley Bridge. This load decrease could be explained by aquatic vegetation uptake and retention, as discussed further in Section 6. More detailed loading estimates are presented in Sections 4.3.6 and 7.

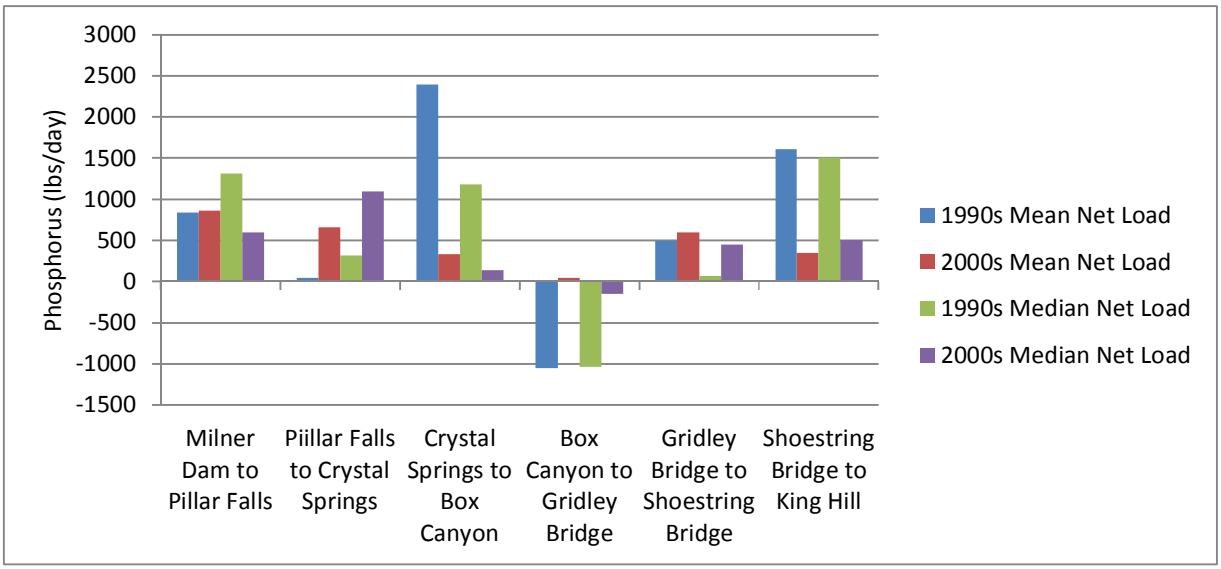


Figure 34. Mean and median net phosphorus loads by Middle Snake River study segment, comparison by decades (DEQ 2011).

Table 8. Daily Total Phosphorus Loads (lb/day), Descriptive Statistics (DEQ 2011)

Site	Decade	Count	Minimum	Median	Mean	Maximum
Milner Pool	1990-1999	199	1	1,247	2,818	42,854
	2000-2009	112	0.1	344	555	4,546
Pillar Falls	1990-1999	98	695	2,559	3,659	20,499
	2000-2009	116	43	943	1,417	14,679
Crystal Springs	1990-1999	221	957	2,879	3,706	19,922
	2000-2009	115	0	2,040	2,077	8,099
Box Canyon	1990-1999	92	558	4,058	6,102	31,019
	2000-2009	114	586	2,177	2,411	8,084
Gridley Bridge	1990-1999	125	1333	3,025	5,053	37,251
	2000-2009	115	787	2,027	2,456	28,607
Shoestring Bridge	1990-1999	155	1722	3,095	5,551	51,341
	2000-2009	114	977	2,481	3,051	22,138
King Hill	1990-1999	77	0	4,602	7,157	57,164
	2000-2009	114	366	2,985	3,402	16,428

Appendix F compares summary statistics for each decade across all mainstem stations and relevant constituents analyzed for WYs 1990-2010. Statistics are reported together for USGS and DEQ data and separately for Idaho Power and canal company data. Mean TP concentrations have remained relatively constant or decreased slightly in the 2000s compared to the 1990s for any mainstem station. A comparison of the most recent King Hill TP data to past decades (Table 9) indicates a consistent decrease in average and median TP concentrations.

Table 9. Summary statistics for DEQ/USGS data at King Hill (WY 1990-2013)

	WY 1990-1999	WY 2000-2009	WY 2010-2013
Count	181	224	39
Min	0.02	0.01	0.04
Mean	0.09	0.08	0.07
Max	0.34	0.41	0.11
Median	0.08	0.07	0.06

For mean dissolved ortho-phosphorus (Appendix F), some stations have experienced minimal change (Milner Pool and Gridley Bridge), increases (Pillar Falls, Box Canyon, Shoestring Bridge), and decreases (Crystal Falls and King Hill). Dissolved oxygen, pH, and stream temperature appear to have remained constant, on average, between the 1990s and 2000s. TSS has decreased at all stations in the 2000s compared to the 1990s except at the Idaho Power monitoring station. Turbidity appears to have either decreased or remained at similar concentrations across all stations (either mean or median turbidity decreased at all stations between the time periods). At Gridley Bridge and all upstream stations, a minor observation was that turbidity maxima are much greater in the 2000s compared to the 1990s, but these values reflect only a few outliers occurring in 2008 and 2009.

Increases in total nitrogen and all analyzed nitrogen species have occurred at all mainstem stations between the 1990s and the 2000s. Chlorophyll *a* appears to have remained constant or increased slightly at most stations except for Shoestring Bridge (SR 03) and the Idaho Power monitoring station, where chlorophyll *a* appears to have increased in the 2000s. (The small sample size in the 1990s may not have captured sufficient variability.) No change in pheophytin is apparent. Data are available for filtered TP and unfiltered ortho-P, but these data are limited. No change in filtered TP is apparent for the King Hill Bridge station (SR01).

4.3.2 Tributary Monitoring

Considering the large number of natural tributaries, springs, and irrigation drains, TP data are limited throughout the subbasin. However, significant datasets are available for several of the major tributaries, and extensive data have recently been collected for the irrigation drains within the subbasin.

Table 10 compares the average TP concentrations for tributaries with at least 10 observations collected by either DEQ or USGS after WY 2000. Two additional stations were included because they provided samples along the same stream but at a different location. The DEQ data were available for only the 2000s, but USGS data are compared between the 1990s and 2000s. Appendix F provides a companion table including all tributaries with DEQ or USGS data, regardless of sample size.

In the few tributaries with data for both decades, small increases and decreases are evident, but it is unlikely that these changes have a substantial effect on subbasin-wide loading. Because most tributaries do not have data for comparison across decades, it is unknown whether significant changes in tributary concentrations have occurred over time.

As noted in the TMDL Five-Year Review, TP observations are not meeting the TMDL water quality target in the following streams: Blind Canyon Creek, Cedar Draw, Clear Springs, Cottonwood Creek, Deep Creek, Dry Creek, McMullen Creek, Mud Creek, Pioneer Reservoir, Rock Creek (RC town to mouth), and Clover Creek (DEQ 2010). The USGS data also indicate that the target is not met in Blind Canyon Spring and North Cottonwood Creek.

Table 10. Comparison of Total Phosphorus Concentrations across Decades for Select DEQ and USGS Tributary Monitoring Stations

Stream or Spring	Agency	WY 1990–1999		WY 2000–2012	
		Mean	Count	Mean	Count
Blue Lakes Spring Bel Pump Plant near Twin Falls, ID (13090999)	USGS	0.03	6	0.01	17
Box Canyon Creek: headwaters to mouth	DEQ	-	-	0.02	5
Box Canyon Springs near Wendell, ID	USGS	0.01	35	0.015	18
Rock Creek: headwaters to Rock Creek Town	DEQ	-	-	0.03	45
Rock Creek: Rock Creek Town to mouth	DEQ	-	-	0.08	161
Rock Creek at Highway 30/93 crossing at Twin Falls, ID	USGS	0.09	86	0.10	111
Rock Creek at USFS Footbridge near Rock Creek, ID	USGS	-	-	0.03	2

Note: "-" indicates no data.

Figure 35 and Figure 36 display the average TP concentrations at each irrigation drain monitoring station for the North Side Canal Co. and Twin Falls Canal Co./USDA-ARS Kimberly, respectively. Figure 37 compares average daily TP loads at the Twin Falls Canal Co. sites. Instantaneous flow data were readily available for the Twin Falls Canal Co. locations and were used in the load calculations. Load estimates can also be calculated for at least some of the other irrigation drain locations, but more extensive manipulation of available flow data would be required and was out of scope for this assessment.

The highest average concentrations in the North Side Canal Co. dataset occur at Y9, which drains into Clover Creek (confluence with Middle Snake River downstream of mainstem subbasin outlet). Average TP concentrations are above the tributary standard of 0.1 mg/L. The remaining North Side Canal locations average below the standard. The majority of the Twin Falls Canal Co./USDA-ARS Kimberly monitoring locations average above the 0.1 mg/L standard, and the greatest density of high concentrations occurs between the Pillar Falls and Crystal Springs gages and along Salmon Falls Creek.

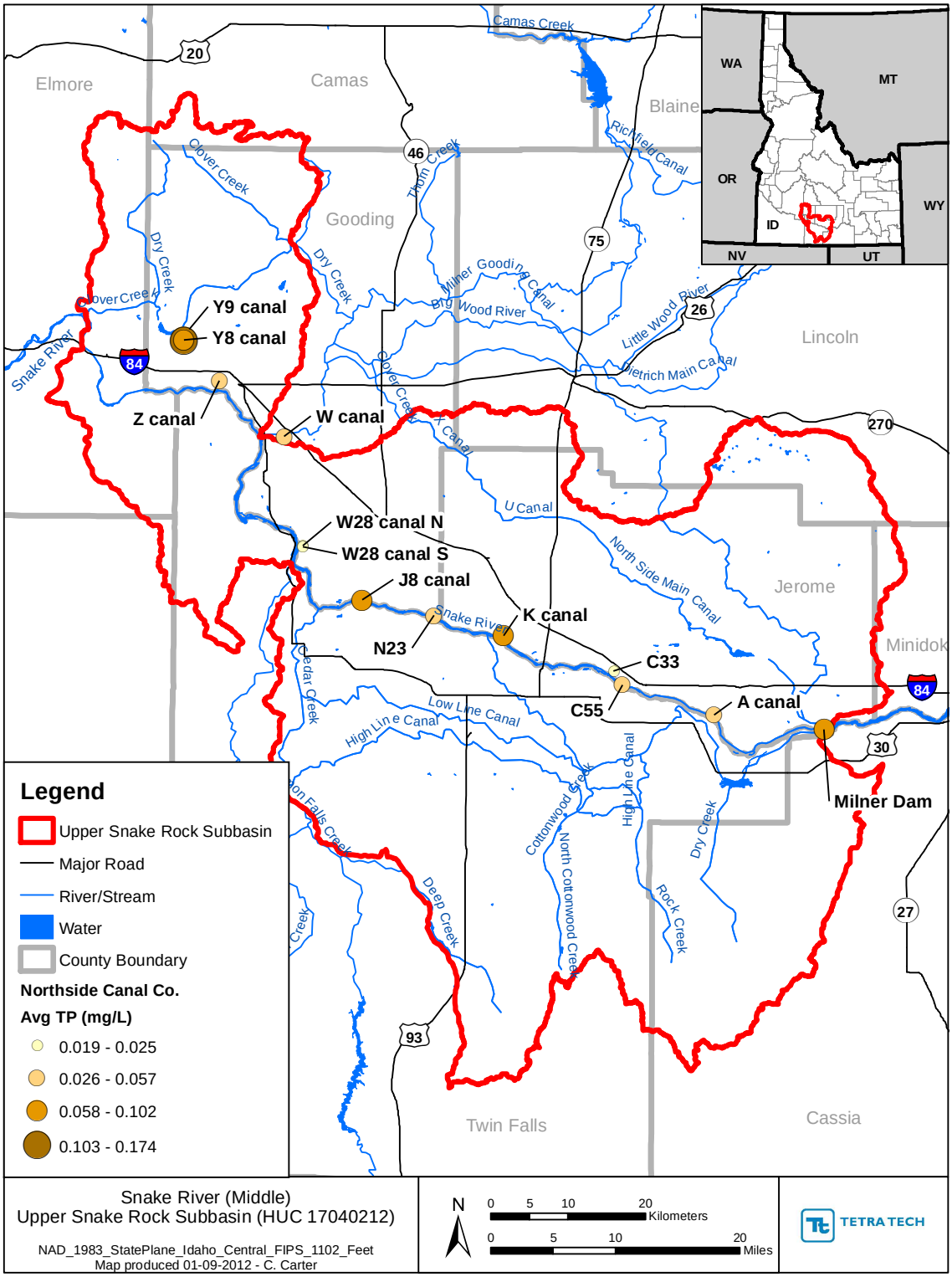


Figure 35. North Side Canal Co. average TP concentrations (2002–2011).

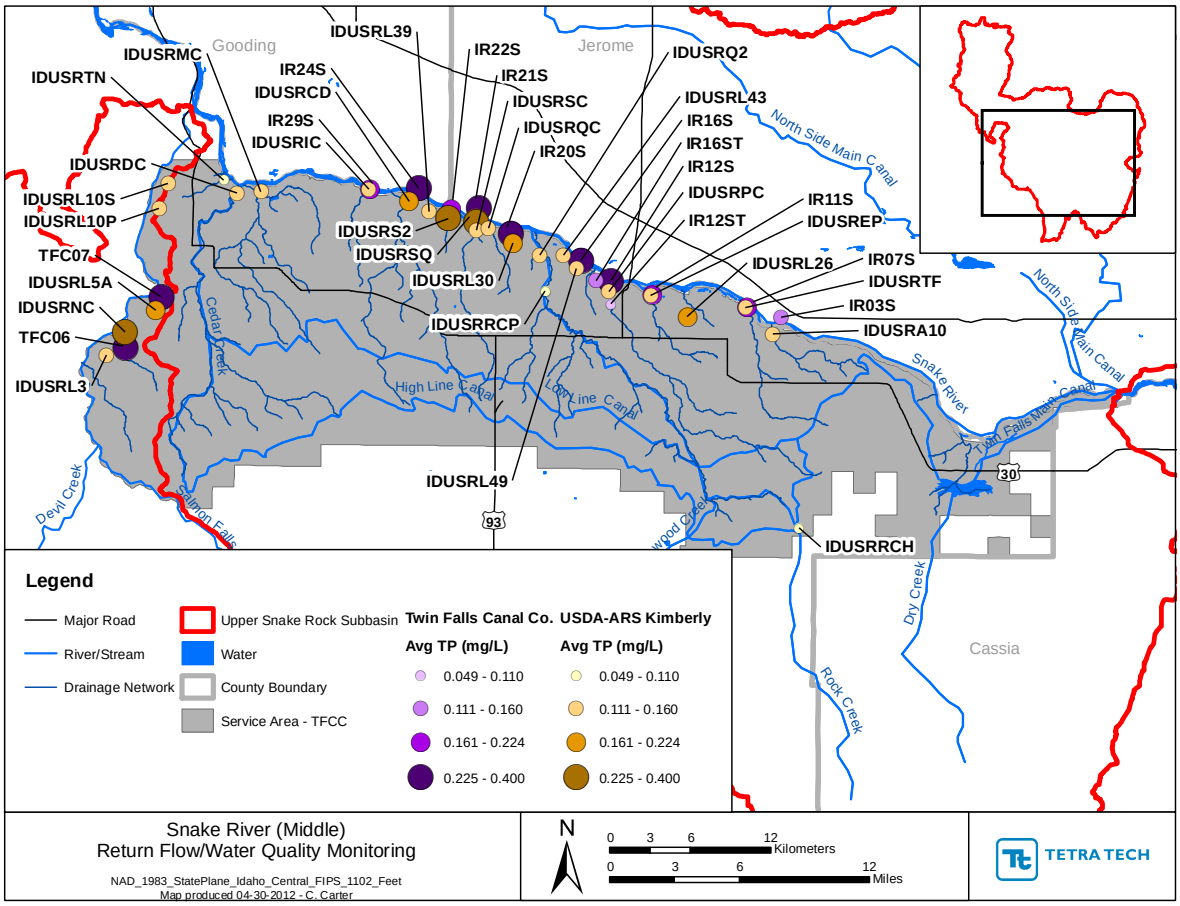


Figure 36. Twin Falls Canal Co. (2000–2012) and USDA-ARS Kimberly (2005–2008) average TP concentrations.

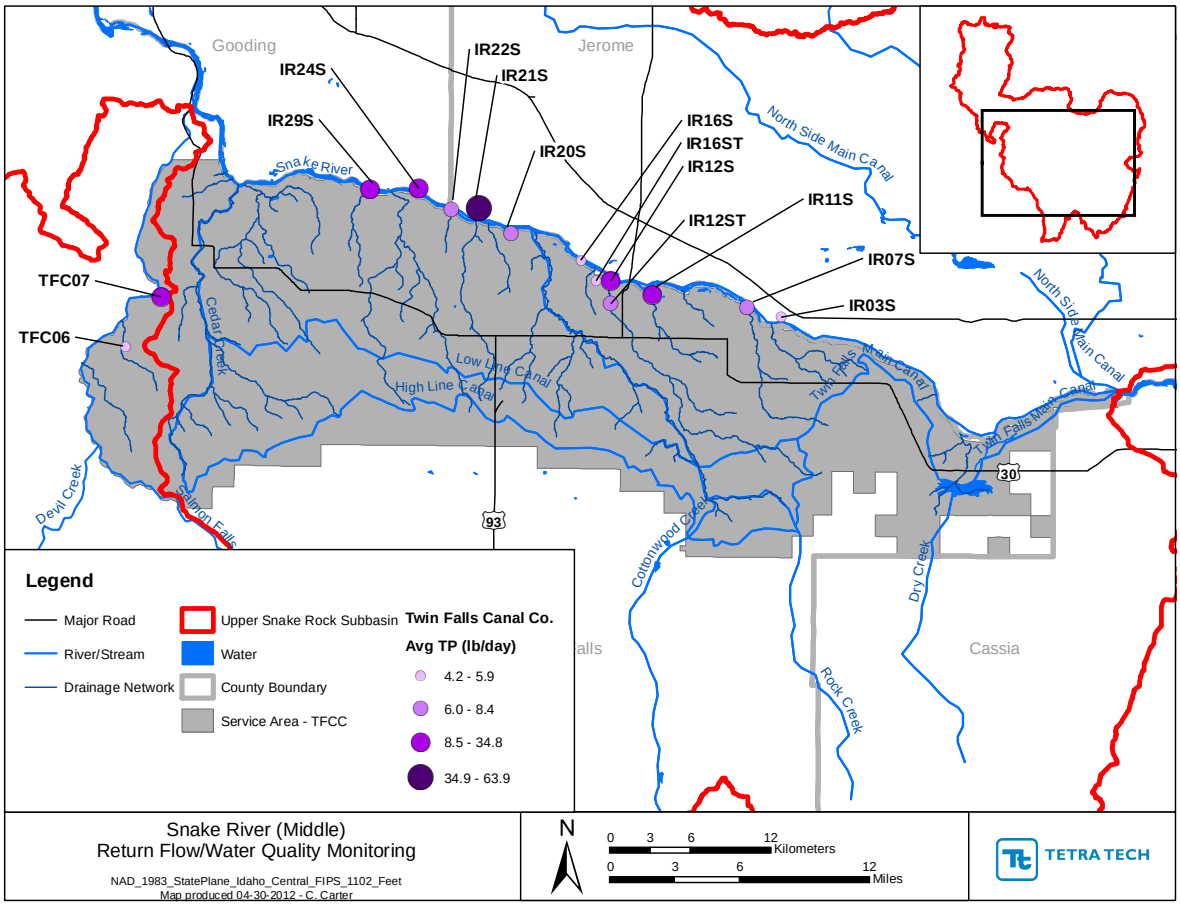


Figure 37. Twin Falls Canal Co. (2000–2012) average daily TP loads.

4.3.3 Point Source Discharge Monitoring

In May 2012, point source DMR data were retrieved for all point source dischargers in Gooding, Jerome, and Twin Falls counties within the Upper Snake-Rock Subbasin. The DMR data retrieval included the monitoring period from 2001 to 2012. A total of 84 point source dischargers were found to be located within the Upper Snake-Rock Subbasin. Of the 84 point source dischargers, 78 facilities were found to have TP load records recorded in pounds per day (lb/day); the other six dischargers without TP load records were removed from further analysis but are listed in Table 11. In May 2013, updated information on these dischargers was obtained from DEQ and is included in Table 11. Aquaculture facilities are identified by general aquaculture permit numbers (IDGs), while POTWs are identified by NPDES numbers (IDs).

Table 11. Facilities from DMR Dataset That Did Not Have DMR Values for TP Load

Information Obtained May 2012			Updated Information From DEQ May 2013			
NPDES ID	**Permit Name**	**Facility Name**	**Name on File**	**Operating**	**Submitted NOI for new GAP**	**Last Submitted DMR**
IDG130080	BUHL TROUT REARING FACILITY	BUHL TROUT REARING FACILITY	Buhl Trout Rearing Facility - Fullmer Ponds	no	no	No data since 3/1/2002
IDG130091	COATS ENTERPRISES	DEADMAN GULCH FISH FARM	Correct	no	yes	not determined/ no data in current office file
IDG130097	C AND M FISH FARM	C AND M FISH FARM	Correct	no	yes	not determined/no data in current office file
IDG130102	SNYDER BLUE ROCK FARMS LLC	SNYDER BLUE ROCK FARMS LLC	Snyder Ponds	yes	no	10/1/2005 thru 4/1/2006
IDG130107[1]	RANGEN INC	WOODS FARMS PARTNERSHIP	Woods Farm Ponds	no	no	3/1/2002 thru 2/1/2003
ID0000230	AMALGAMATED SUGAR CO LLC	AMALGAMATED SUGAR COMPANY LLC	AMALGAMATED SUGAR LLC[2]	yes	N/A[3]	1/12/12

[1] IDG130107 had a single average value of 0.01 lb/day reported for permitted feature CPH at monitoring location 2 on 10/31/2003.
[2]This facility discharges primarily noncontact cooling water and did not receive a total phosphorus wasteload allocation in any of the Middle Snake River or Upper Snake Rock TMDL documentation.
[3]Not applicable because this is not an aquaculture facility.

Of the remaining 78 facilities, only 71 facilities were found to have TP loads reported with a monitoring location code (MLC) of 1 or 2, representing an effluent gross or net value, respectively, from the following discharge points: SUM, CRB, 001. The seven facilities that did not have TP loads reported as either an effluent gross or net value and did not have records for discharge points of either SUM, CRB, or 001 are listed in Table 12. TP load data from these facilities that were recorded at discharge points other than SUM, CRB, or 001 and monitoring locations other than 1 or 2 were not analyzed. Tetra Tech was informed by EPA (Leigh Woodruff, EPA, personal communication to Catherine Carter, Tetra Tech, Inc., May 25, 2012) that data from discharge locations other than SUM, CRB, or 001 should be ignored because these other locations do not represent total effluent discharge and data from monitoring locations other than 1 or 2 should be ignored because these other monitoring locations were established for special studies and might not represent effluent discharge.

Table 12. Facilities from DMR Dataset That Had TP Load Data but Did Not Have Records for Monitoring Locations 1 or 2 or for Permitted Features SUM, 001, or CRB

NPDES ID	Permit Name	Facility Name
IDG130048	AQUARIUS AQUACULTURE	AQUARIUS AQUACULTURE - HIDDEN SPRINGS FARM PONDS
IDG130050	ARK FISHERIES INC	LEE PONDS
IDG130084	HOLLARD, LARRY	DAYDREAM RANCH
IDG130088	CLEAR SPRINGS FOODS INC	CLEAR SPRINGS FOODS INC/BRIGGS EAST
IDG130100	ARK FISHERIES INC	WRIGHT FARM PONDS
IDG130106	WOODS FARMS PARTNERSHIP	WOODS FARMS PARTNERSHIP
IDG130130	ARK FISHERIES INC	JOHNSON FARM PONDS

Of the remaining 71 facilities, monthly average TP load records were used to calculate an average TP load for each monitoring period of record for each facility. Average yearly values were then used to calculate annual average TP load (in pounds per day) across the monitoring period for each facility. Annual average TP loads, as well as yearly minimum and maximum TP load values, are listed for each facility in Appendix G. Existing annual average TP loads were compared to WLAs provided in the Upper Snake-Rock TMDL Modification documents (DEQ 2004, 2005). The following four facilities were found to have annual average TP loads that exceeded their annual average WLA: ID0020664 City of Buhl WWTP, IDG130112 Lively Farm Pond, IDG130131 Tupper Ponds, and ID0027600 Jerome Cheese. In addition, 16 facilities have maximum annual average daily loads above their WLAs, and four facilities have both average and maximum annual average daily loads above their WLAs (the same four noted above). Negative existing load values indicate that the load discharged is less than the load entering the facility through the source water intake.

WLAs were not listed in the Upper Snake-Rock TMDL Modification documents (DEQ 2004, 2005) for four of the 71 facilities; for these four facilities, current permit limit values for TP load (lb/day) are listed in Appendix G in place of WLAs.

During the analysis of DMR data, one record was deleted because it was thought to be an outlier. The TP load for this record was 1,448,159 lb TP/day; it was recorded for facility IDG130001 on 3/31/2005 at discharge point CRB at the net effluent monitoring location.

Several facilities with WLAs listed in the Upper Snake-Rock TMDL Modification documents (DEQ 2004, 2005) either did not have data in the DMR dataset (i.e., records were blank) or were not included in the DMR dataset download. The status of these facilities is unknown, but it is plausible that since the publication of the TMDL Modification documents in 2004 and 2005, these facilities have been shut down, have been sold, or have undergone a permit transfer, in which case the GAP ID could be associated with a different facility. These facilities are listed in Table 13. In May 2013, updated information on these dischargers was obtained from DEQ and is included Table 13.

Table 13. Facilities for Which There is a WLA but No DMR Data were Available in 2012

Information Obtained May 2012			Updated Information From DEQ May 2013			
GAP	**Facility Name**	**WLA: TP (lb/day)**	**Name on File**	**Operating**	**Submitted NOI for new GAP**	**Last Submitted DMR**
17	FDC	32.7	Correct	yes	yes	current
130	Johnson	0.7	Babington Ponds	yes	yes	current
50	Lee	1.0	Correct	yes	yes	current
48	Hidden	3.2	Hidden Springs Farm Ponds	yes	no	12/1/2012
132	EV-Ranch	0.9	Billingsley Cr. State Park Fish Ponds	no	no	not determined/no data in current office file
19	Cedar Draw Hatchery	5.7	Correct	no	no	1/1/2007
27	Green's Trout Farm	3	Correct	no	no	12/1/2003
47	Peter's Farm Pond	2	Kaufman Ponds	no	no	not determined/no data in current office file
79	Blau Farm Pond	1.3	Correct	no	no	not determined/no data in current office file
80	Buhl Trout Rearing Facility	3.5	Buhl Trout Rearing Facility - Fullmer Ponds	no	no	not determined/no data in current office file
84	Daydream Ranch Facility	4.2	Correct	no	yes	1/1/2004
88	Briggs Creek Fisheries	11.6	Briggs Cr. Fish Hatchery - Briggs Cr. East	yes	yes	current
91	Deadman Hatchery	2.2	Correct	no	yes	4/1/2012 (only one on file)
97	C & M Fish Farm	3.3	Correct	no	yes	4/1/2012
100	Gary Wright Farm Ponds	3.4	Wright Ponds	no	no	not determined/ no data in current office file
102	Rocky Ridge Ranch	0.8	Snyder Ponds	yes	no	12/1/2012
105	Mike Flemming	1.3	Flemming Farm Ponds	no	no	5/1/2001
106	Rangen Inc./Woods	3.5	Woods Farm Ponds	no	no	7/1/2001
107	Rangen Inc./Decker Springs	2.5	Decker Springs Farm Ponds	no	no	not determined/no data in current office file
115	Leo Martins	2.2	Correct	no	no	7/1/2001
117	Standal Ponds	1.7	White Water Falls	no	no	not determined/no data in current office file

4.3.4 Twin Falls POTW Discharge Assessment

Among the point sources identified, the City of Twin Falls Wastewater Treatment Plant (WWTP) discharges the highest daily loads measured for any single source. Given that this facility is the most significant point source discharger in the reach, recent monitoring data was used to assess the magnitude of TP concentration and load from the Twin Falls WWTP relative to the receiving water, the Middle Snake River. Two years of monitoring data spanning 2012-2013 were used. Data were available as part of the plant's monitoring requirements and included a set of daily measurements collected on a quarterly basis. The data used for this evaluation included effluent flow and effluent TP concentration, as well as upstream flow and TP concentration in the Middle Snake River. The values are shown in Table 14. The analysis was also conducted using the plant's permit limits in place of the monitoring data. The current permit does not include a limitation on outflow but does list a weekly average TP load limit of 990 lbs/day and a monthly average TP load limit of 710 lbs/day (EPA 2010).

Table 14. Twin Falls POTW Monitoring Data

Quarter	Date	TP, Middle Snake River Upstream of Discharge (mg/L)	TP, Effluent (mg/L)	Flow, Snake River (MGD)	Flow, Discharge (MGD)
2012, Q1	2/8/2012	0.052	11.18	2307	6.86
2012, Q2	5/2/2012	0.183	4.92	8337	6.25
2012, Q3	8/8/2012	0.058	6.43	711	5.44
2012, Q4	11/28/2012	0.13	4.2	475	8.4
2013, Q1	3/6/2013	0.324	5.9	544.8	8.1
2013, Q2	5/29/2013	0.171	5.54	1803	7.6
2013, Q3	8/14/2013	0.142	3.74	361	11.79
2013, Q4	11/6/2013	0.065	10.8	589	7.1

Using the monitoring data, flow-weighted concentrations were calculated to show the expected concentration of TP in the Middle Snake River assuming the effluent is fully mixed with 100 percent of upstream flow. The calculation was performed for three conditions:

1. Using effluent concentrations from the monitoring data (referred to as "effluent" concentration).
2. Using an estimated concentration corresponding to the permit limit weekly average TP load 990 lbs/day (referred to as "weekly permitted" concentration). Flow was assumed to be equal to plant flow on the quarterly monitoring date.
3. Using an estimated concentration corresponding to the permit monthly average TP load of 710 lbs/day TP (referred to as "monthly permitted" concentration). Flow was assumed to be equal to plant flow on the quarterly monitoring date.

Results are shown in Figure 38, Figure 39, and Figure 40 for each of the three conditions and compared to the upstream concentration. As seen in Figure 38, on dates when high flows were measured in the Middle Snake River (2012, Q1; 2012, Q2; 2013, Q2), mixing of effluent had little effect on TP concentration. On the dates when lower flows were observed, effluent TP had a noticeable effect on downstream concentration. Figure 38 also compares the instream concentrations to the TMDL instream target of 0.075

mg/L TP. The upstream concentrations exceed the target during four of the seven events. Across all events, the mixed "effluent" concentration exceeded the target. A similar trend exists for the estimated "weekly permitted" and "monthly permitted" concentrations (Figure 39 and Figure 40, respectively), though the concentrations are considerably higher. This comparison indicates that effluent concentrations may contribute to target exceedance for some of the events, and exacerbate exceedances in other events, but upstream flows and concentrations are likely to be a significant factor as well.

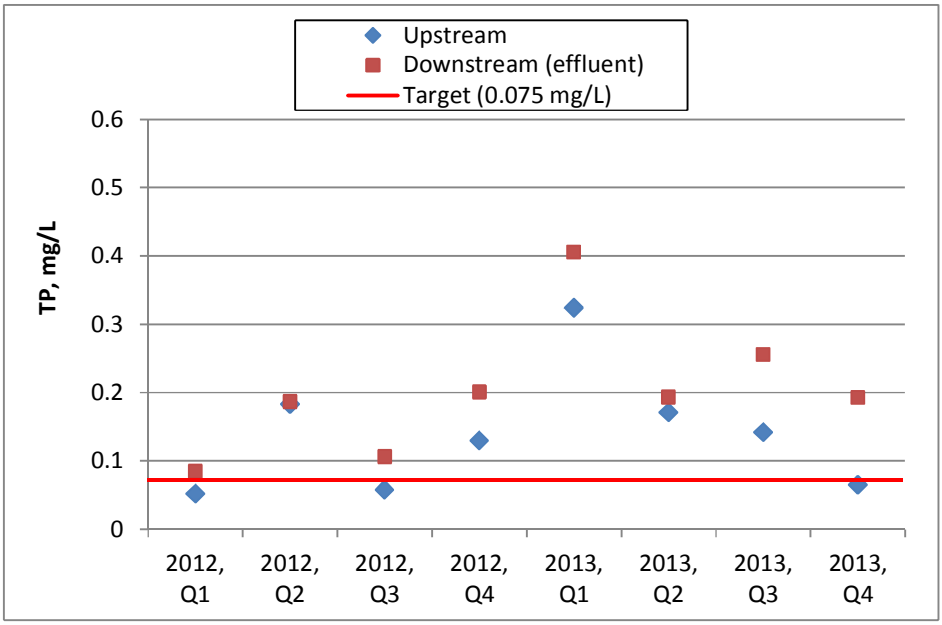


Figure 38. Comparison of TP Concentrations Upstream and Downstream of Twin Falls WWTP Using Measured Effluent Concentrations.

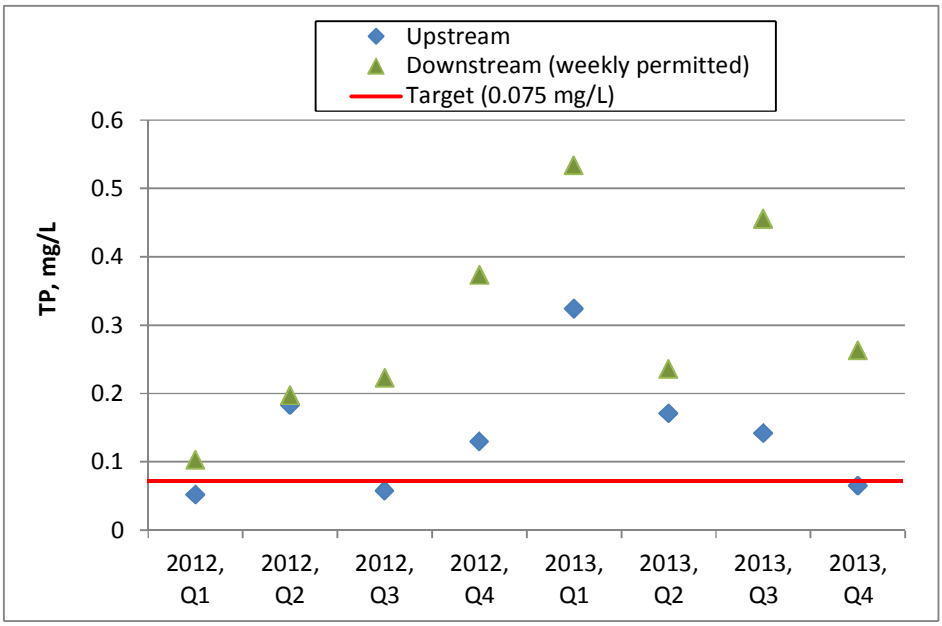


Figure 39. Comparison of TP Concentrations Upstream and Downstream of Twin Falls WWTP Using Weekly Permitted Limit.

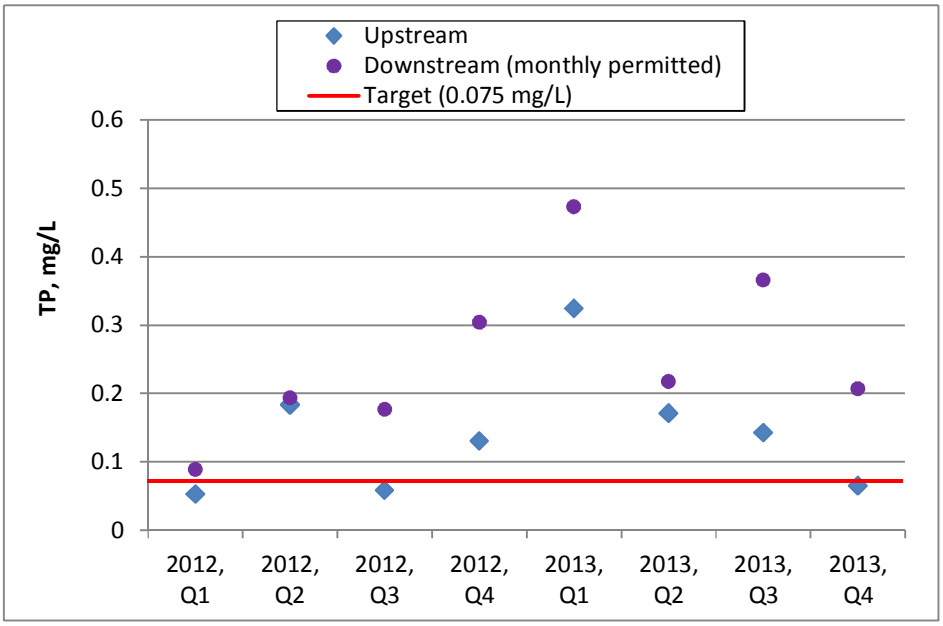


Figure 40. Comparison of TP Concentrations Upstream and Downstream of Twin Falls WWTP Using Monthly Permitted Limit.

TP loads were also calculated from the monitoring data, representing both upstream conditions and load from the WWTP (Figure 41). With one exception (2013 Q4), background loads in the Middle Snake River are higher than the WWTP loads. If the weekly average TP load permit limit was evaluated, then the value of 990 lbs/day would simply substitute for the WWTP loads, as shown in Figure 42. Likewise, the monthly permitted load of 710 lbs/day is shown in Figure 43.

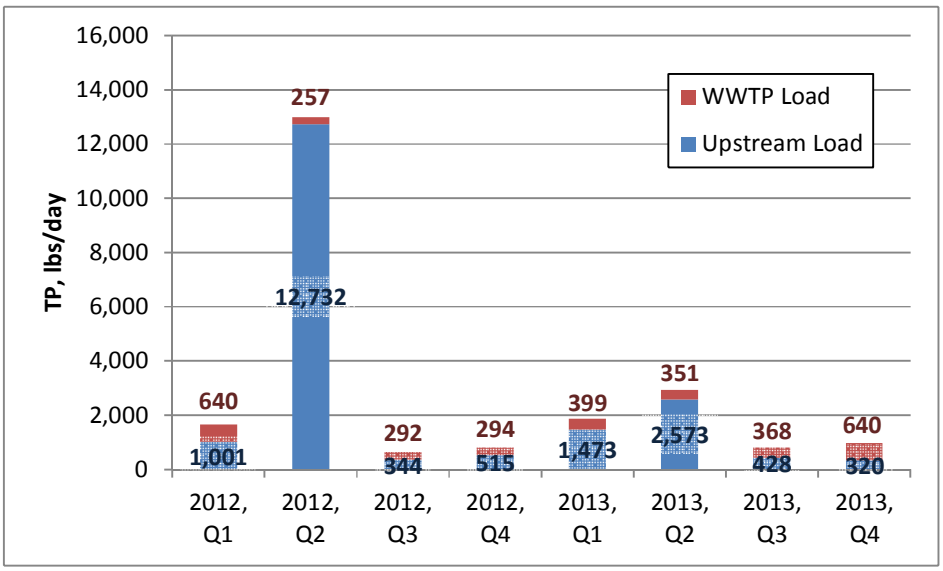


Figure 41. TP Loads from the Middle Snake River and Twin Falls WWTP.

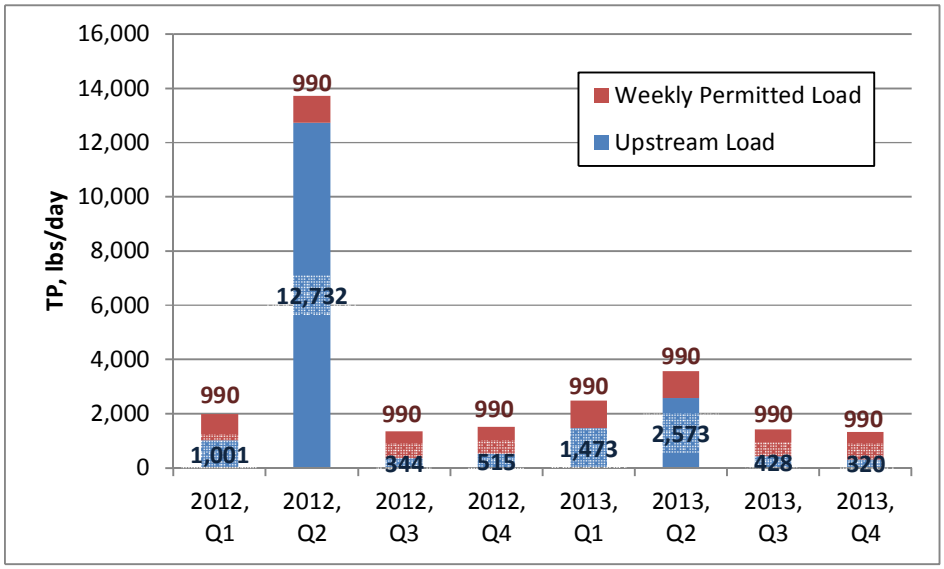


Figure 42. TP Loads from the Middle Snake River compared to Twin Falls WWTP weekly permitted load.

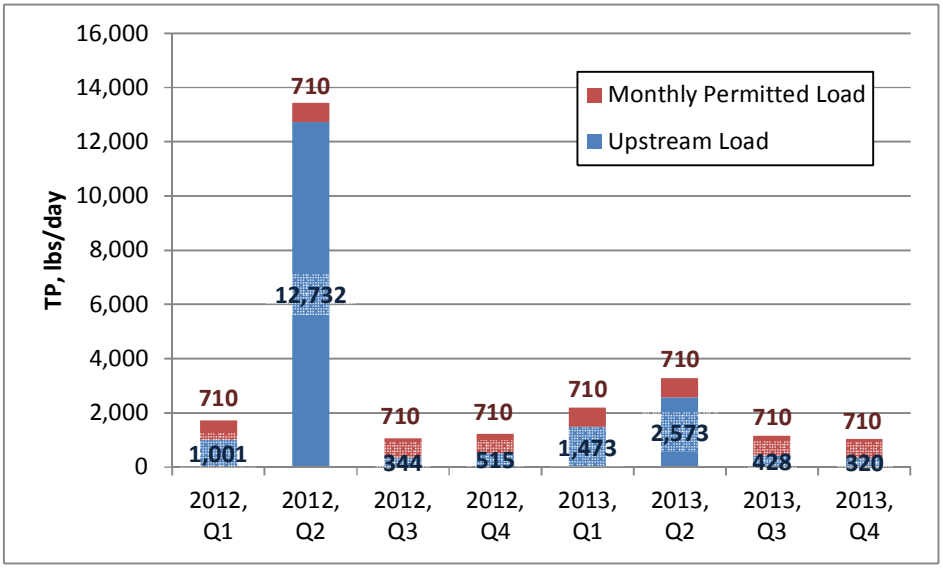


Figure 43. TP Loads from the Middle Snake River compared to Twin Falls WWTP monthly.

4.3.5 Trend Analysis

Advanced statistical analyses were performed to determine if total phosphorus concentrations exhibit significant trends over time in the Middle Snake River mainstem. This section summarizes the methods and results. Detailed methods are provided in Appendix I.

Four locations on the mainstem were analyzed: Milner, Pillar Falls, Buhl, and King Hill. These locations were selected because they provided the most recent and most complete data in terms of representing seasonal and annual variability. Data collected by different entities were analyzed separately. University of Idaho data at the TFCC diversion forebay (IS0AS) was used as a surrogate for Milner Pool because

these data were more complete and represented TP concentrations from the same inflow source as Milner Pool.

The nearest USGS gage to Pillar Falls (near Twin Falls 13090500) had discharge data only from 7/15/2009. Discharge data from 10/1/2000 to 7/14/2009 were estimated at this location using maintenance of variance extension regression model (MOVE.1 LOC) and daily discharge data from an upstream gage at Kimberly (13090000). The USGS SREF 1.0 program was used to produce daily discharge estimates at Twin Falls using Kimberly data and the MOVE.1 LOC method.

Available trend tests were performed for Buhl to test whether variability in test result would affect the overall conclusions. First, the use of either Mann-Kendall or Seasonal Kendall was considered. Then, each of these tests were performed with or without removal of variation due to flow. LOWESS, which stands for locally weighted scatterplot smoothing, was used to remove variation due to flow (Cleveland 1979). While the test results varied, all four test combinations resulted in a trend of statistical significance when using a critical probability value of $p \leq 0.05$.

The Seasonal Kendall test with LOWESS was used at Milner, Pillar Falls, and Buhl. For the Seasonal Kendall test, the trend slope represents the median of a series of slopes between values from the same season, based on Sen's nonparametric slope estimator (Sen 1968). The Mann-Kendall test with LOWESS was used for the King Hill IPC data because very little seasonality was observed in the IPC data.

Results are shown in Table 15 for all four sites. Using a critical value of $p \leq 0.05$, significant trends are present at Milner, Pillar Falls, and Buhl, with relatively high magnitudes of decreasing trend in TP concentration. A downward trend is predicted at all sites, indicating that TP has been declining over the monitoring period at a cross section of mainstem locations. The trend is strongest at Pillar Falls and is also strong at Milner and Buhl. The trend is weaker at King Hill.

It is important to note that trend tests are not a prediction of the future. Each test is valid for the time period it covers, but that does not necessarily mean the trend will continue. If a trend is present, it is possible that whatever process has caused the trend will not behave in the same manner going forward.

Table 15. Trend Test Results for All Locations

Location	Test	p-value[1]	Trend (mg/L/yr)
Milner	Seasonal Kendall with LOWESS	0.0174	-0.0028
Pillar Falls	Seasonal Kendall with LOWESS	0.0082	-0.0055
Buhl	Seasonal Kendall with LOWESS	0.0195	-0.0031
King Hill (IPC data)	Mann-Kendall with LOWESS	0.0001	-0.0010
King Hill (USGS data)	Seasonal Kendall with LOWESS	0.1640	-0.0008

[1]Seasonal Kendall tests show p-value adjusted for autocorrelation

4.3.6 LOADEST Modeling

LOAD ESTimator (LOADEST) is a FORTRAN program developed by USGS for estimating constituent loads in streams and rivers (Runkel et al. 2004). LOADEST was executed at the same four locations applied to the trend analysis in Section 4.3.5: Milner, Pillar Falls, Buhl, and King Hill. Daily loads were estimated from 10/1/2008 to 9/30/2013. LOADEST calibrations were performed using observed discharge and paired TP data from 10/1/2000 to 9/30/2013. The same TP and discharge datasets used in

the trend analysis were also applied to the LOADEST calibration. LOADEST was run using a model number of zero, which enables the program to choose the best model from 9 in-built regression models.

Table 16 shows the annual TP loads and flow-weighted concentrations at Milner, Pillar Falls, Buhl and King Hill. Figure 44 and Figure 45 show the LOADEST estimated daily and annual TP loads. Figure 46 and Figure 47 show the annual flow-weighted TP concentrations at Milner, Pillar Falls, Buhl and King Hill, respectively. The LOADEST analysis shows a downward trend at all sites with time. The trend is strongest at Milner and Pillar Falls. The flow weighted TP concentrations are consistent with the Seasonal Kendall and Mann Kendall trend analysis findings. It is important to note that these analyses were conducted to study the trend, and the selected time period is not necessarily appropriate to evaluate target compliance for regulatory purposes.

Table 16. LOADEST estimated annual loads and flow-weighted concentrations (on a water year basis)

Water Year	Milner		Pillar Falls		Buhl		King Hill IPC		King Hill USGS	
	Load (tons)	FWC (mg/L)	Load (tons)	FWC (mg/L)	Load (tons)	FWC (mg/L)	Load (tons)	FWC (mg/L)	Load (tons)	FWC (mg/L)
2009	175	0.070	210	0.076	435	0.103	830	0.093	737	0.083
2010	111	0.082	148	0.085	289	0.096	643	0.083	554	0.071
2011	343	0.061	414	0.069	638	0.086	1126	0.092	1080	0.088
2012	233	0.070	292	0.079	387	0.077	786	0.079	745	0.075
2013	30	0.064	51	0.056	164	0.078	444	0.065	387	0.057

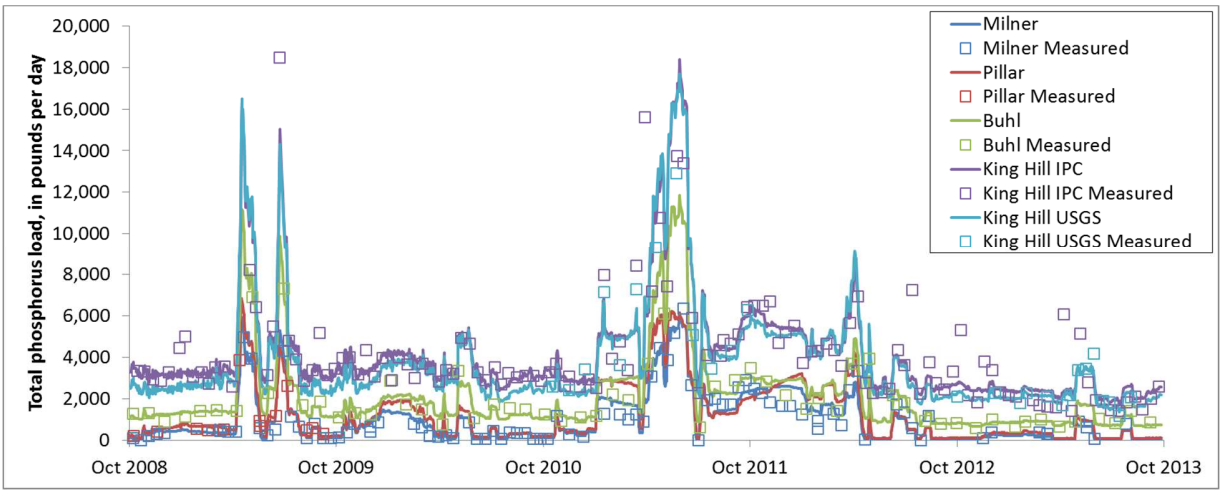


Figure 44. Daily estimated and measured TP loads.

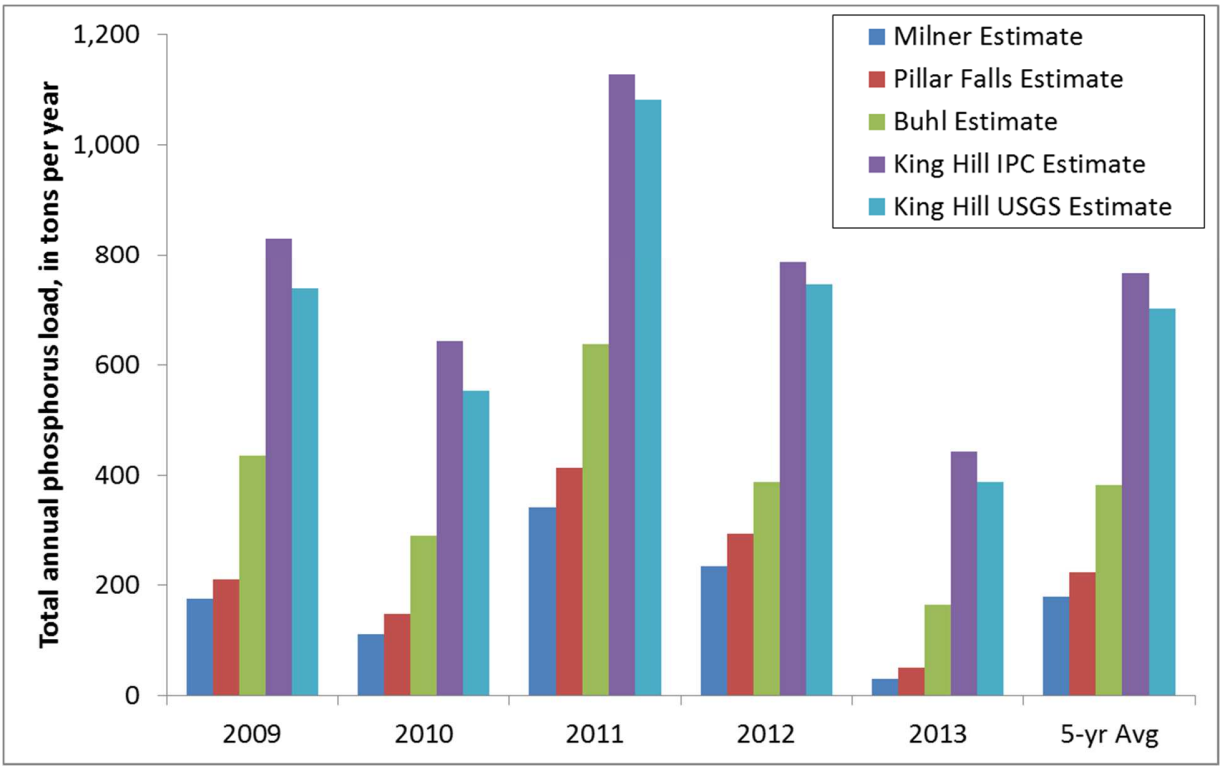


Figure 45. Annual estimated TP loads (on a water year basis).

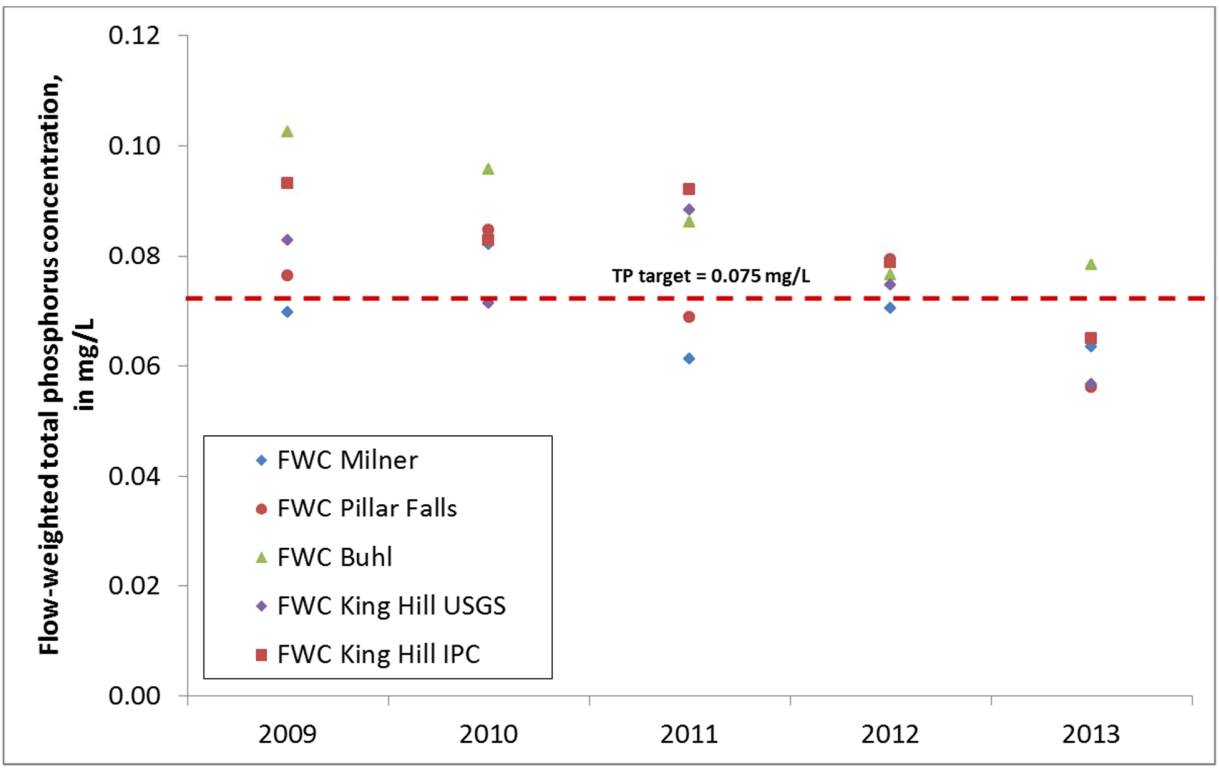


Figure 46. Flow weighted TP concentrations (on a water year basis).

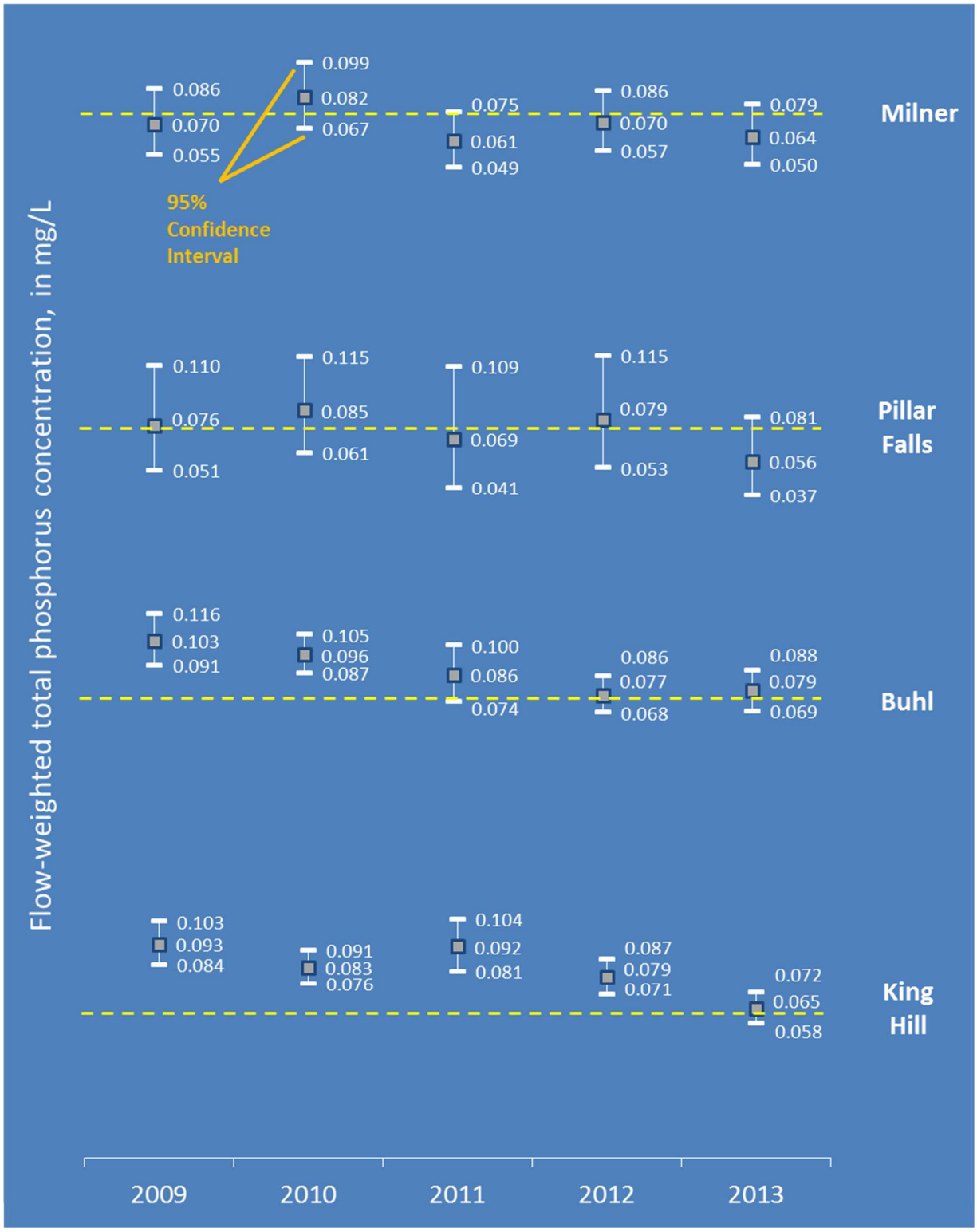


Figure 47. Flow weighted TP concentrations (on a water year basis).

4.4 MACROPHYTE HARVESTING

Harvesting of macrophytes constitutes a loss mechanism for phosphorus in the Middle Snake River. Idaho Power is currently tracking macrophytes removed from the Snake River for hydroelectric project maintenance at four locations: Upper Salmon "B" Dam, Upper Salmon "A" Dam, Lower Salmon Dam, and Bliss Dam. The quantity of macrophytes removed is recorded in truckloads for each location. For each truckload of macrophytes removed, an equivalent amount of TP (in kilograms [kg]) removed was calculated using TP concentrations (in milligrams per kilogram [mg/kg]) measured for both dry and wet aquatic vegetation (Table 17) and the net weight estimated for a truckload of macrophytes. It should be noted that these weights represent all trash and debris collected by trash racks; the data are not limited to macrophytes. Therefore, TP load removal estimates using these data should be used as a comparative index rather than as absolute estimates.

Table 17. Aquatic Vegetation TP Concentrations (Idaho Power 2012)

Date	TP (mg/kg)
17-Jul-02	446
13-Feb-03	355
13-Feb-03	185
13-Feb-03	170
13-May-03	500
13-May-03	620
13-May-03	540
14-Aug-03	340
13-Nov-03	270
13-Nov-03	270
13-Nov-03	325
27-May-04[1]	3,640
27-May-04[1]	3,580
27-May-04[1]	3,720

[1] Samples from 2004 represent dry weight records; samples from 2002 and 2003 represent wet weight records.

Based on the assumptions that each truckload was full and included only wet aquatic vegetation, the average annual TP removal was estimated for each location (Table 18). The equivalent of approximately 1,241 lbs of TP is removed annually from the Upper Salmon "B" Dam; lesser amounts are removed from Upper Salmon "A" Dam (317 lbs), Lower Salmon Dam (106 lbs), and Bliss Dam (207 lbs). These calculations may be overestimating TP removal because the weights could include other, non-macrophyte debris. A direct comparison to mainstem TP loads is of limited value; however, the fact that these annual

loads are within the range of the mainstem daily loads provides some perspective on the magnitude of the TP load currently being removed. For example, the daily load at King Hill in the 2000s was estimated to range from 366 to 16,428 lbs. This implies that the TP load removed annually through macrophytes is less than or equal to the amount of TP that passes through the Middle Snake River mainstem on a daily basis.

Table 18. Estimated Average Annual TP Loss from Removal of Macrophytes

Dam	Avg. Annual TP Removal (lb)	Year Range
Upper Salmon "B"	1,241	1991 - 2011
Upper Salmon "A"	317	2006 - 2011
Lower Salmon	106	2007 - 2011
Bliss	207	2007 - 2011

Calculations of TP equivalency for this analysis are based on the assumption that each truckload of macrophytes removed was full (i.e., the truckloads were of equal weight) and contained only wet aquatic vegetation. Truckload weight was based on one truckload measured in the early 1990s, which was then used to calculate all TP equivalency values based on wet weight aquatic vegetation TP concentrations recorded for the corresponding season. It is possible that the truckloads contained varying quantities of macrophytes and that the macrophytes removed from the dam varied in moisture content. The first truckload measured in the 1990s could also have included sediment, trash, or other debris and may not have included solely macrophytes; quantities of these materials are likely to vary by truckload as well. To improve this assessment in the future, the truckload weight and bulk density could be calculated every year instead of basing these assumptions on one truckload in the early 1990s. Given the current assumptions, these data best represent only an index of macrophyte biomass removal and TP equivalency.

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5. Ground Water Modeling

A number of efforts have been ongoing to estimate spring discharge to the Middle Snake River and accurately predict trends. Among several methodologies developed by Kjelstrom (1995), the "combination" method has been used frequently to estimate spring discharge to the Snake River. This method uses measurements from eight springs, gaging station records for four springs and three sites on the Malad River, and regression equations developed from five of the measured springs.

A more recent study by the USGS and Idaho Power (Hortness and Vidmar 2004) compared data from Kjelstrom (1995) with 2001–2002 data and found that long-term changes in gain/loss estimates likely were related to long-term changes in aquifer levels. In 2008 these methods were used to investigate whether inflow from springs to the Middle Snake River had declined or stabilized. Initial results indicated a decline, but with several corrections to the methods, a linear trend analysis suggested that spring discharge had continued to decline (Blew and Bowling 2009).

The ongoing aquifer modeling for the Eastern Snake Plain Aquifer (ESPA) provides robust data for use in determining aquifer flow trends in the Upper Snake-Rock Subbasin. The Idaho Water Resource Board (WRB) developed the ESPA Comprehensive Aquifer Management Plan in 2009 through a mandate from the Idaho State Legislature.

As an initial step in the planning effort, WRB conducted a series of public meetings with stakeholders and then presented the ESPA Plan Framework (Framework) to the legislature in 2007. The Framework indicated that supply of, and demands for, water are out of balance in the Eastern Snake River Plain and the connected Snake River, and it called for coordinated management of surface waters of the Snake River and the underground waters of the ESPA. The Framework developed overarching goals and objectives for management of the ESPA (WRB 2012).

The Framework identifies opportunities for managing available water supply and demand to address current and future water use needs, including those for irrigated agriculture, aquaculture, industry, hydropower, municipalities, real estate development, and domestic users and to protect environmental values. The long-term objective of the Framework is to incrementally achieve a net ESPA water budget change of 600,000 acre-feet annually. It is projected that this hydrologic goal can be achieved by the year 2030 by implementing a mix of management actions, including the following (WRB 2012):

- Ground water to surface water conversions
- Managed aquifer recharge
- Demand reduction through conservation and efficiency improvements
- A pilot weather modification (cloud seeding) program in the Upper Snake.

In general, the actions are intended to stabilize and improve spring flows, aquifer levels, and river flows across the Eastern Snake Plain (WRB 2012).

The Eastern Snake Plain Aquifer Model (ESPAM) was developed to estimate impacts to surface water resources from aquifer use and to support DWR administrative and planning decisions. The most recent version of ESPAM (Version 2.1) was built using previous modeling efforts dating from the early 1970s. Using advanced parameter estimation tools, the model was calibrated to a 28.5-year dataset (spring 1980 through fall 2008) comprising more than 43,000 aquifer water level observations, more than 2,000 estimates of river gain and loss, and more than 2,000 transient spring discharge measurements, which were collected from 14 different spring complexes (DWR 2013). The calibration period includes periods of both drought and above-average precipitation. The model provides simulations based on existing conditions and does not provide future predictions of groundwater trends.

DWR (2013) discusses observed declines in water level within ESPA. The ESPA discharge to the Middle Snake River has been declining since the 1950s. Water levels have declined between 1980 and 2008, and modeling indicated a decrease in aquifer storage during this same period. These trends are occurring both for groundwater discharges to the Middle Snake River as well as for ESPA discharges in general.

6. Attenuation during Transport

As a complex river system with diverse inflow sources, impoundments, and extensive aquatic plant beds, understanding the fate and transport of TP within the Middle Snake River provides an essential link between inflow sources and downstream concentrations. Various processes can reduce the concentration and total load of phosphorus during transport through a river reach. Together these processes are referred to as attenuation. Specific types of attenuation can be further classified as dilution, retention, or removal. As used in this report, these terms are explicitly defined as follows:

- *Dilution*: A reduction in concentration due to the addition of cleaner water, such as ground water inflow with low phosphorus concentrations. It is important to note that dilution does not reflect a reduction in the total phosphorus mass that is transported through the reach.
- *Retention*: A reduction in the mass and concentration of a pollutant traveling through a reach due to *temporary* storage. For example, uptake of phosphorus by macrophytes reduces concentration and mass transport during the growing season. However, the nutrients will be largely released and transported downstream after fall die-off. Because it is temporary storage, retention does not reduce the total mass of phosphorus that is transported downstream. Rather, it changes the timing of delivery of the phosphorus mass and, often, its chemical form (for instance, most of the inorganic phosphorus taken up by macrophytes may be released as organic phosphorus compounds).
- *Removal*: A reduction in the mass and concentration of a pollutant travelling through a reach due to *permanent* or *long-term* storage. This represents a condition in which the phosphorus mass is prevented from further downstream transport, for example through the formation of insoluble precipitates.

In reality there is not a bright line separating retention and removal for phosphorus, primarily because few forms of removal can be considered as truly permanent. Phosphorus does not have a significant gas phase, so emission to the atmosphere is not a significant permanent loss pathway. Insoluble precipitates may resolubilize under the right chemical conditions. Some attenuation mechanisms, such as storage on the floodplain, may or may not represent long-term storage. From a practical point of view, retention can be defined as storage that typically lasts for less than a year, but may persist for multiple years (e.g. during low flow conditions), and most often represents a seasonal delay in transport. Removal then represents storage that is more permanent, and is expected to last for more than a few years.

As noted above, physical and biological processes in river reaches can result in net removal or temporary retention of nutrients. One of the major processes for temporary retention is uptake of nutrients by macrophytes and periphytic algae. Aquatic plants, as well as heterotrophic organisms, require nutrients for growth and remove inorganic nutrients from the water column, converting them to organic biomass. Heterotrophs also remove organic matter as foodstock. This storage, however, is temporary. In addition to normal die-off and grazing, macrophytes and periphyton are subject to scour and transport downstream during high flow events.

Tanner and Anderson (1996) demonstrated that periphyton are very effective in reducing dissolved inorganic nutrients downstream of wastewater treatment plants in the South Umpqua River, Oregon. Similarly, locations in the Bow River in Alberta support dense *Cladophora* and macrophyte growths that are sensitive to nitrogen load and effective in removing inorganic nitrogen from the water column (Sosiak 2002). Such biological uptake is, however, largely temporary in nature, as biomass follows seasonal cycles with release of nutrients as biomass declines in the fall. Decaying periphyton mats may also promote anoxic conditions that can lead to denitrification and loss of nitrogen from the system but may promote dissolved P release from sediment. Dodds (2003) summarized the role of periphyton in removing phosphorus from aquatic systems. Some of this storage is also temporary; however, Dodds points out that

localized increases in pH during photosynthesis can lead to increased precipitation of calcium phosphate, concurrent deposition of carbonate-phosphate complexes, and long-term burial losses of phosphorus.

Temporary retention in river reaches also occurs as a result of settling and storage of particulate matter, including organic detritus. Inorganic ortho-phosphate can also sorb to sediment particles and settle out. These processes largely constitute temporary retention, as the stored particulate matter can be remobilized by scouring flows.

Permanent removal of nutrient mass can occur in several ways. For nitrogen, denitrification and conversion to nitrogen gas results in a loss of nitrogen from the water to the air, but this does not apply to phosphorus. Water lost to deep ground water, agricultural diversions, or riparian wells can remove nutrients, as can the harvest and removal of aquatic plants. Effective removal of phosphorus may also occur due to burial in deposits that are not readily remobilized (e.g., deposition behind a dam that is sufficiently deep that resuspension back into the water column is suppressed), export to the floodplain, or conversion to tightly bound, insoluble mineral forms.

Phosphorus can be removed from the water column by settling or uptake by plants, and harvesting of macrophytes can result in permanent removal of nutrients (Section 4.4). Aside from harvesting, much of the mass removed through plant uptake is not permanently retained, but only delayed, as plants die and release nutrients, deposited sediment can be scoured by high flow events, and dissolved phosphorus may be regenerated from sediment under hypoxic conditions. In general, temporary retention is most important during lower flow periods, which tend to coincide with the growing season. Temporary retention does not, in the end, change the nutrient load that is delivered downstream; however, it can significantly affect both the timing and bioavailability of load delivery.

As discussed in Section 2.6, evidence exists that retention of phosphorus is occurring due to the presence of aquatic vegetation. Falter and Carlson (1994), Falter et al. (1995), and Falter and Burris (1996) provide results from detailed studies of aquatic macrophytes in the Middle Snake River. These studies addressed aquatic macrophyte growth from Twin Falls to Upper Salmon Falls dam, with the greatest focus on Crystal Springs and Box Canyon. These reaches were considered to represent the greatest macrophyte density within the Middle Snake River while being representative of the processes occurring throughout the River. Among the reaches studied, the Crystal Springs reach had the highest biomass density and the least diversity of macrophyte species. Falter and Burris (1996) also found that a significant relationship between biomass and soluble reactive phosphorus (SRP) in the water column existed within the Crystal Springs reach, and this was the only reach for which this relationship was found to be significant. Across all reaches, EPA (2002) indicated that a poor correlation between dissolved nutrients in the water column and macrophyte biomass existed; however, the poor correlation was attributed to the inherent complexity of aquatic systems and the ability of rooted macrophytes to extract nutrients from both the sediment and water column.

The relationship between water column nutrients and biomass was more apparent when considering nonrooted macrophytes or epiphytes, which obtain nutrients exclusively from the water column. As cited in EPA (2002), Howard-Williams (1981) found that the development of epiphytes (*Cladophora*) on *P. pectinatus* communities increased with N and P fertilizer input but did not increase the rooted plant biomass. This effect was consistent with the observations in the Crystal Springs reach, where both epiphytic dominance and nutrient inputs were greatest compared to the other studied reaches, and the relationship between biomass and SRP was significant.

Sediment nutrient content provided further insight into processes occurring in the Middle Snake River. Regarding the relationship between sediment total phosphorus and aquatic plant biomass, Falter et al. (1995) and Falter and Burris (1996) reported the following results:

- Maximal aquatic plant biomass occurred at a total phosphorus level of approximately 1,100 mg/g TP dry weight (consistently measured throughout studied reaches); and

- Aquatic plant biomass generally declined above 1,100 mg/g TP dry weight.

The decline in plant biomass was attributed to high redox potential, low dissolved oxygen, and low pH in sediment coincident with high organic matter content. The high organic matter content is associated with plentiful TP, but low DO can discourage macrophyte root development.

Thomas et al. (1995) studied respiration rates and organic carbon turnover rates in the Middle Snake River. Turnover time for organic carbon is the time required for the average carbon molecule to pass from being fixed into organic form by photosynthesis to being released through decomposition under aerobic conditions. Thomas et al. (1995) found that the Middle Snake River exhibited very high rates of respiration but very low organic carbon turnover rates. The slow rate of turnover suggested that high levels of nutrients, as well as detritus and energy, were being trapped, and that the sediment deposits and aquatic plant beds facilitated this process.

EPA (2002) concluded that this effect ultimately resulted in a reduced flow of nutrients downstream of the aquatic plant beds. This effect was expected to be greatest along the Crystal Springs reach where both upstream nutrient loading and aquatic plant density were greatest. In particular, aquatic plant biomass was measured up to eight times greater in Crystal Springs than in any other studied reach (EPA 2002). During the periods of maximum plant growth in the Crystal Springs Reach, Falter et al. (1995) demonstrated that TP and SRP decrease from upstream to downstream of the aquatic plant beds. While flow inputs from springs within this reach may have contributed, in part, to the decrease in concentration, these findings suggest that nutrient retention may be occurring within the aquatic plant beds in the Middle Snake River.

Based on a review of recent data, TP concentrations in the Middle Snake River exhibit trends similar to conditions described in earlier studies. In Appendix D, Figure 81 through Figure 88 compare TP concentrations across the monitoring locations by decade using box plots. These figures illustrate that average TP concentrations were elevated at Crystal Springs and, at times, remained elevated at Box Canyon, depending on the decade and season. At the next downstream location of Gridley Bridge, average TP concentrations decreased considerably compared to Crystal Springs and Box Canyon.

Since the studies documented in EPA (2002), the recent extent and growth trends of aquatic plant beds has not been measured. However, a review of 2013 aerial photographs indicates that aquatic vegetation remains prevalent in the vicinity of Crystal Springs and Box Canyon. Plant uptake and senescence is likely resulting in temporary retention of phosphorus and nitrogen in aquatic plant bed sediments. The retained nutrient load is likely to be re-suspended and transported downstream during high flow events.

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7. Mass Balance

A mass balance of TP load was performed along the Middle Snake River from Milner Dam to King Hill. The goal of this analysis was to estimate the change in load occurring within each study segment due to inflow within the segment (as opposed to upstream load). The first step in the process was to estimate an average instream loading rate for each monitoring location. Then, the upstream rate was subtracted from the downstream rate to calculate the change in loading that occurs within the segment. Once the total change in load was derived, portions of this load were attributed to sources of inflow, using a flow balance analysis.

The study segments were selected for this analysis because the segment breaks were defined by the location of current DEQ water quality monitoring stations that were near to or coincident with USGS gages. The study segments are shown below in Figure 48 along with the location of DEQ water quality monitoring stations.

The time period for the mass balance analysis was limited by data available for DEQ mainstem monitoring stations. A mass balance for each year was not feasible due to these data limitations. Therefore, the results were reported for two five-year assessment periods, 2000–2004 and 2005–2009.

The mass balance calculations began with daily loading rates, previously calculated by DEQ based on their estimated flow and TP data, for each mainstem monitoring station (DEQ 2011). (Details on the DEQ's calculation method are provided in Section 4.3.) To estimate an average loading rate for each location and time period, the daily loading rates were averaged first by month, then by year, and finally across the five-year assessment period. The loading units remained as daily loads (lbs/day). The upstream average rate was subtracted from the downstream average rate to calculate the total change in TP loads within a study segment and time period.

The total changes in TP loads within each study segment are provided in Table 19. Negative TP loading changes along the mainstem were observed for the Box Canyon to Gridley Bridge study segment for both five-year assessment periods; a negative TP loading change was also observed for the Shoestring Bridge to King Hill Bridge study segment for the WY 2000–2004 assessment period. Decrease in load might result from retention of TP within the study segments, or they could be an artifact of the uncertainty inherent in the load estimation, which was limited by data availability. Retention of phosphorus in aquatic plant beds could explain at least a portion of the negative TP loading changes. This explanation is especially appropriate for the Box Canyon to Gridley Bridge study segment because a high density of aquatic plant beds has been observed within the vicinity of Box Canyon. While the retention of phosphorus in the plant beds is temporary, the delivery of the load to the next study segment is delayed by the temporary retention. Re-suspension of phosphorus in the plant beds would occur during high flows, which may explain why the negative load is less pronounced within Box Canyon to Gridley Bridge during the wetter period of 2005–2009.

The LOADEST modeling, discussed in Section 4.3.6 and fully documented in Appendix I, provides an additional time period for comparison to the mass balance results. Table 20 compares the results across similar segments, using Crystal Springs and Buhl as proximal locations. The increasing load trend upstream to downstream in the 2005-2009 mass balance results is evident in the 2009-2013 LOADEST results.

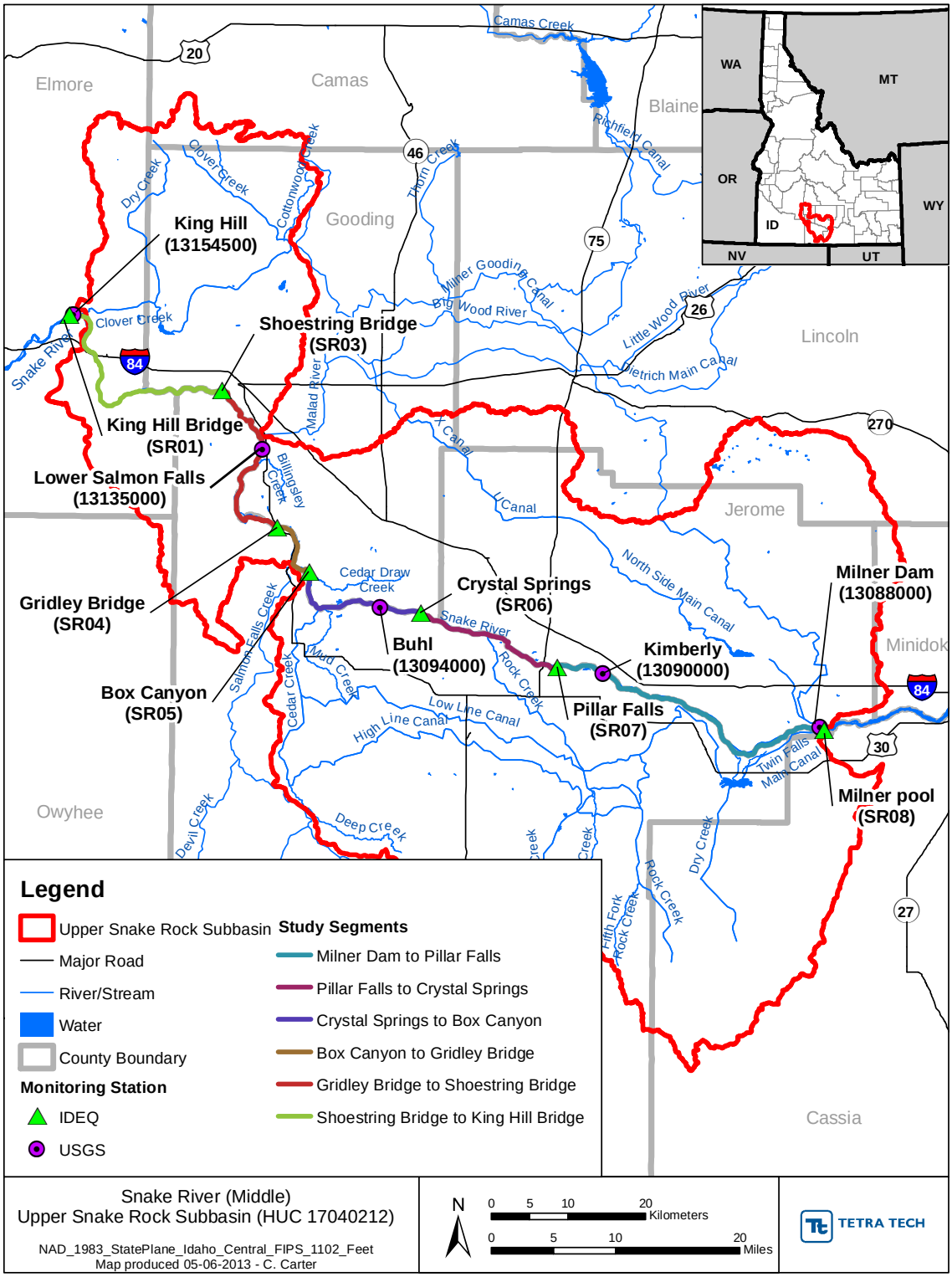

Figure 48. Study segments for mass balance.

Table 19. Total Change in TP Load (lbs/day) within the Study Segments

Study Segment[1]	Change in TP Load, WY 2000–2004 (lbs/day)	Change in TP Load, WY 2005–2009 (lbs/day)
Milner Dam to Pillar Falls	915.0	596.3
Pillar Falls to Crystal Springs	304.7	1,257.3
Crystal Springs to Box Canyon	528.7	43.2
Box Canyon to Gridley Bridge	-94.8	-29.7
Gridley Bridge to Shoestring Bridge	1,059.6	331.0
Shoestring Bridge to King Hill Bridge	-119.1	801.8
Total	2,594.2	2,999.9

[1]As defined in Section 3, the study segments represent the reach just below the starting location through the end location; for example, the second segment includes the Crystal Springs monitoring station but not the Pillar Falls station.

Table 20. Comparison of Mass Balance and LOADEST Results

Study Segment[1]	Change in TP Load, WY 2000–2004 (lbs/day) from Mass Balance	Change in TP Load, WY 2005–2009 (lbs/day) from Mass Balance	Study Segment	Change in TP Load, WY 2009–2013 (lbs/day) from LOADEST
Milner Dam to Pillar Falls	915	596	Milner to Pillar Falls	243
Pillar Falls to Crystal Springs	305	1257	Pillar Falls to Buhl	875
Crystal Springs to King Hill	1374	1146	Buhl to King Hill	2099

A detailed mass balance of TP loading was also performed for each major pollutant source in the watershed. The pollutant sources consisted of loading from tributaries, springs, diffuse ground water, irrigation return drains, and both indirect and direct point source dischargers. A flow balance was conducted to estimate the portion of inflow within a segment that is attributed to a particular source and these results were then used to estimate the pollutant load attributed to each source. The flow balance methods are documented in Appendix H.

For ground water TP loading estimates, baseflow TP loading was considered equal to loading from diffuse ground water. Estimates of baseflow were used along with data on spring flow to calculate loading associated with ground water. Detailed methods for the baseflow calculations are provided in Appendix H. A ground water TP concentration of 0.02 mg/L was assumed, equal to the in-stream target concentration for ground water sources (DEQ 2005), to calculate load from baseflow for each of the study segments. This target concentration was documented in DEQ and the Mid Snake TAC (1999) as the average for springs in the Upper Snake-Rock Subbasin based on a review of USGS and DEQ data that indicated 95 percent of the TP data were at or near (but below) 0.02 mg/L.

Tributaries and springs with available USGS flow data were the only tributaries and springs for which loading was directly estimated in the detailed mass balance analysis. The tributaries included were Rock Creek (13092747), Cedar Draw (13093478), Clover Creek (13154400), and Salmon Falls Creek (13108150). The springs included were Devil's Washbowl (13089500), Devil's Corral (13090100), Blue Lakes (13090999), Briggs (13095175), Blind Canyon (13095400), and Box Canyon (13095500). Instantaneous discharge records for gaged tributaries and springs were sparse and were not available for

all years included in this analysis. Water quality data for these sites were also sparse. The TP concentrations presented in Appendix F (Table 26) were used to estimate loads for these tributary and spring stations.

Tributaries and springs without available flow and concentration data were grouped into a category called "unaccounted waters." The TP loading for unaccounted waters was calculated as the difference between the total change in TP loading for each study segment (Table 19) and the sum of TP loading from all accounted-for pollutant sources contributing to the study segment. This represents an estimate of the net of additional loads and loss processes.

Much of the measured flow data used for ESPAM2.1 are consistent with data used in the flow balance analysis. Data collection efforts for ESPAM2.1 acquired additional spring flow data from water users. Upon review, these data demonstrated that a great portion of the unaccounted-for flow along the study segments of the Middle Snake River is derived from spring flow. On average, from 2000 to 2009, spring flow was found to contribute greater than 50 percent of flow to the mainstem for all study segments except the farthest upstream study segment (Milner Dam to Pillar Falls) and the farthest downstream study segment (Shoestring Bridge to King Hill Bridge) where spring flow contributions were less than 10 percent each. Although these data were helpful in discovering potential contributions to unaccounted-for flow, they were not directly included in flow balance calculations because of the nature of their collection. These data were collected by various spring water users, and rely on measurements reported by the water users. In some cases, total flow includes estimates of unmeasured spring discharge and its use in the analysis would have introduced additional uncertainty (Jennifer Sukow, DWR, personal communication to Catherine Carter, Tetra Tech, Inc., April 23, 2013).

Paired flow and TP concentration data available for irrigation return drains from the Twin Falls Canal Co. and USDA-ARS-Kimberly were used to estimate an annual average TP loading rate for each drain for the five-year assessment periods. Annual average TP loading from both indirect and direct point sources was estimated from monthly average TP loading reported in the DMR data for each point source. Indirect point source dischargers are all point sources that discharge directly to a tributary or spring of the mainstem Middle Snake River. Direct point source dischargers are all point sources that discharge directly to the mainstem of the Middle Snake River.

The results of the detailed mass balance are presented in Table 21. The first column of values reports the total change in TP loading from upstream to downstream that occurs within the segment. Then this load is broken down into portions from each source. Finally, the load from unaccounted waters is presented, which represents the difference between the total change in load and the sum of the known source inputs.

Negative TP loading from unaccounted waters occurs when the sum of the multiple source estimates are greater than the total change in load calculated from the monitoring stations, which is the case for several of the study segments. When interpreting these results, it is important to note that the mass balance is based on gross averages of loading rates and not from loads occurring instantaneously at the various locations. Data uncertainty is the most likely explanation for the negative loading results calculated for unaccounted waters. However, TP retention or removal may explain a decrease in average TP load from load contributed within a segment.

Based on the first column totals in Table 21, total TP loading from just below Milner Dam through King Hill Bridge, increased from approximately 2,600 lb/day to 3,000 lb/day between the two five-year assessment periods. This increase in TP loading along the mainstem is reflective of an increased total TP loading from gaged tributaries, irrigation return drains, and both indirect and direct point source dischargers between the two assessment periods. It is important to note the increase in TP loading for irrigation return drains between the two assessment periods is strongly reflective of more data being available for the second assessment period than for the first. For instance, no data from USDA-ARS-Kimberly drains were available for WY 2000–2004.

Table 21. Detailed Mass Balance for Five-Year Assessment Periods

WYs	Study Segment	Change in TP Load Between Mainstem DEQ Stations (lb/day)	Base-flow TP Load (lb/day)	Gaged Tributary TP Load (lb/day)	Gaged Springs TP Load (lb/day)	Irrigation Return Drain TP Load[1] (lb/day)	Indirect PS TP Load[2] (lb/day)	Direct PS TP Load[2] (lb/day)	Un-accounted Waters TP Load (lb/day)
WY 2000–2004	Milner Dam to Pillar Falls	915	7	0	4	3	0	0	900
	Pillar Falls to Crystal Springs	305	23	44	8	90	2	671	-534
	Crystal Springs to Box Canyon	529	41	0	27	14	203	284	-40
	Box Canyon to Gridley Bridge	-95	22	63	0	0	21	31	-232
	Gridley Bridge to Shoestring Bridge	1,060	50	0	0	0	22	33	954
	Shoestring Bridge to King Hill Bridge	-119	31	0	0	0	0	0	-150
	Total	2,594	174	107	39	107	248	1,020	899
WY 2005–2009	Milner Dam to Pillar Falls	596	7	0	4	226	0	2	357
	Pillar Falls to Crystal Springs	1,257	23	47	8	1,273	2	578	-675
	Crystal Springs to Box Canyon	43	39	2	19	766	211	466	-1,460
	Box Canyon to Gridley Bridge	-30	21	60	0	176	25	25	-337
	Gridley Bridge to Shoestring Bridge	331	49	0	0	0	28	30	224
	Shoestring Bridge to King Hill Bridge	802	32	0	0	0	0	0	769
	Total	3,000	172	110	32	2,441	266	1,101	-1,122

[1] Irrigation return drain loads were calculated from data received by Twin Falls Canal Co. and USDA-ARS-Kimberly drains.
[2] PS = point source. Indirect PS are all point sources that discharge to a tributary of the Snake River; direct PS discharge directly to the Snake River.

Flow balance results on a yearly basis from 2000 to 2009 are provided in Table 22. Detailed methods for these calculations are provided in Appendix H and an example calculation is provided in Figure 49.

In Table 22, "Total Inflow within Reach" represents the gage-to-gage difference in the mainstem Middle Snake River flow calculated from instantaneous discharge recorded at USGS gage locations and adjusted to represent study segment flow based on stream length. The variability observed in reach inflow from year to year and within the 10-year period could be the result of factors not captured by these data, such as cyclic climatic variability. To assess trends in reach inflow, data from a wider assessment period (greater than 10 years total) would need to be analyzed. In addition, the baseflow presented in Table 22 reflects a percentage of the mainstem flow based on the percentages provided in Appendix H. These percentages were captured from an estimate of baseflow averaged over approximately 30 years and they do not reflect a year-to-year evaluation of changes in baseflow. The flow and mass balance results presented here represent a crude analysis of load and flow from the various TP sources throughout the watershed. More extensive methods were beyond the scope of this assessment and would require additional data (for both flow and water quality) for many of the TP sources throughout the watershed.

Table 22. Flow Balance by Study Segment, WY 2000–2009

Study Segment	Flow Category	Flow (cfs)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Upstream Boundary	**Mainstem Flow at Milner**	**2,740**	**441**	**337**	**336**	**285**	**519**	**2,268**	**1,014**	**668**	**2,553**
Milner Dam to Pillar Falls	Baseflow	75	65	66	63	62	60	69	66	64	73
	Gaged Tributaries	0	0	0	0	0	0	0	0	0	0
	Gaged Springs	39	40	36	32	39	35	32	41	34	31
	Irrigation Return Drains	0	8	12	0	3	28	36	66	65	0
	Direct Point Sources	0	0	0	0	0	0	0	0	0	0
	Unaccounted Waters[1]	522	479	441	444	419	380	366	411	378	409
	Total Inflow Within Reach[2]	636	592	554	539	523	503	503	584	542	513
Pillar Falls to Crystal Springs	**Mainstem Flow at Pillar Falls**	**3,376**	**1,033**	**891**	**875**	**808**	**1,022**	**2,771**	**1,598**	**1,210**	**3,066**
	Baseflow	243	210	212	203	198	194	222	213	207	234
	Gaged Tributaries	115	80	77	63	77	86	97	0	78	0
	Gaged Springs	175	171	138	136	163	156	0	0	0	0
	Irrigation Return Drains	0	100	67	101	77	175	187	211	265	17
	Direct Point Sources	0	0	11	11	11	10	10	10	10	10

Study Segment	Flow Category	Flow (cfs)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	Unaccounted Waters[1]	481	315	379	332	301	189	408	453	304	715
	Total Inflow Within Reach[2]	1,014	877	885	847	827	810	925	887	864	977
Crystal Springs to Box Canyon	**Mainstem Flow at Crystal Springs**	**4,390**	**1,910**	**1,776**	**1,722**	**1,635**	**1,832**	**3,695**	**2,485**	**2,074**	**4,043**
	Baseflow	397	388	373	365	363	358	372	357	362	370
	Gaged Tributaries	0	0	0	0	0	0	0	3	0	0
	Gaged Springs	351	352	321	321	318	302	0	21	0	0
	Irrigation Return Drains	0	9	13	13	15	59	65	34	38	16
	Direct Point Sources	0	0	2	2	2	3	3	3	4	4
	Unaccounted Waters[1]	756	719	704	679	676	633	969	932	965	1,015
	Total Inflow Within Reach[2]	1,504	1,467	1,413	1,380	1,375	1,354	1,409	1,351	1,369	1,405
Box Canyon to Gridley Bridge	**Mainstem Flow at Box Canyon**	**5,894**	**3,377**	**3,190**	**3,102**	**3,010**	**3,186**	**5,104**	**3,837**	**3,442**	**5,448**
	Baseflow	211	211	202	198	198	195	199	191	195	196
	Gaged Tributaries	175	171	138	136	163	156	0	0	0	0
	Gaged Springs	0	0	0	0	0	0	0	0	0	0
	Irrigation Return Drains	0	0	0	0	0	0	0	0	0	0
	Direct Point Sources	0	0	0	0	0	0	0	0	0	0
	Unaccounted Waters[1]	399	403	410	401	374	374	541	519	530	533
	Total Inflow Within Reach[2]	785	785	750	735	735	725	740	709	725	729
Gridley Bridge to Shoestring Bridge	**Mainstem Flow at Gridley Bridge**	**6,679**	**4,162**	**3,939**	**3,837**	**3,745**	**3,911**	**5,844**	**4,546**	**4,167**	**6,177**
	Baseflow	495	487	461	446	444	444	491	443	448	447
	Gaged Tributaries	0	0	0	0	0	0	0	0	0	0

Study Segment	Flow Category	Flow (cfs)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	Gaged Springs	0	0	0	0	0	0	0	0	0	0
	Irrigation Return Drains	0	0	0	0	0	0	0	0	0	0
	Direct Point Sources	0	0	0	0	0	0	0	0	0	0
	Unaccounted Waters[1]	1,400	1,373	1,298	1,255	1,248	1,252	1,398	1,250	1,265	1,260
	Total Inflow Within Reach[2]	1,895	1,860	1,759	1,701	1,693	1,697	1,888	1,693	1,714	1,707
Shoestring Bridge to King Hill Bridge	**Mainstem flow at Shoestring Bridge**	**8,574**	**6,022**	**5,698**	**5,537**	**5,438**	**5,607**	**7,732**	**6,239**	**5,881**	**7,884**
	Baseflow	331	305	280	258	252	268	383	285	280	270
	Gaged Tributaries	0	0	0	0	0	0	0	6	0	0
	Gaged Springs	0	0	0	0	0	0	0	0	0	0
	Irrigation Return Drains	0	0	0	0	0	0	0	0	0	0
	Direct Point Sources	0	0	0	0	0	0	0	0	0	0
	Unaccounted Waters[1]	1,063	982	900	830	810	863	1,233	910	900	869
	Total Inflow Within Reach[2]	1,393	1,287	1,180	1,088	1,062	1,131	1,616	1,201	1,180	1,140
	Mainstem flow at King Hill Bridge	**9,967**	**7,309**	**6,878**	**6,626**	**6,500**	**6,738**	**9,349**	**7,440**	**7,060**	**9,024**

[1] Unaccounted-for water flow is the difference between the total inflow within the reach and the sum of flow from all accounted-for sources. Unaccounted-for surface waters included ungaged tributaries, ungaged springs, and discharge from point sources that do not discharge directly to the mainstem.

[2] Total inflow within reach represents the gage-to-gage difference in mainstem Middle Snake River flow calculated from instantaneous discharge recorded at USGS gage locations and adjusted to represent study segment flow based on stream length.

Example Flow Balance Calculations for Study Segment Milner Dam to Pillar Falls (WY 2000)[1]

Inputs

- Flow at USGS Milner Dam gage = 2,739.6 cfs
- Flow at USGS Kimberly gage = 3,061.3 cfs
- Flow at USGS Buhl gage = 4,665.1 cfs
- Percent of total inflow within reach from USGS Milner gage to USGS Kimberly gage as baseflow = 0 (not provided in source information)
- Percent of total inflow within reach from USGS Kimberly to USGS Buhl as baseflow = 24%
- Percent of USGS Segment Milner Dam to Kimberly that is coincident with Study Segment Milner Dam to Pillar Falls = 100%
- Percent of USGS Segment Kimberly to Buhl that is coincident with Study Segment Milner Dam to Pillar Falls = 19.6%
- Gaged spring flow to Study Segment Milner Dam to Pillar Falls (sum of flow from Devils Washbowl and Devils Corral Springs) = **38.6 cfs**
- Flow from gaged tributaries, irrigation return drains, and direct point sources to Study Segment Milner Dam to Pillar Falls = 0 cfs (potentially included in unaccounted waters due to lack of flow data available from these sources for this study segment)

Calculations

Total inflow within USGS Segment Milner Dam to Kimberly
= 3,061.3 cfs - 2,739.6 cfs = 321.7 cfs
Total inflow within USGS Segment Kimberly to Buhl
= 4,665.1 cfs - 3,061.3 cfs = 1,603.8 cfs
Total inflow within Study Segment Milner Dam to Pillar Falls
= (1.00 * 321.7 cfs) + (0.196 * 1,603.8 cfs) = **636.0 cfs**
Baseflow from USGS Segment Milner Dam to Kimberly
= 0 * 321.7 cfs = 0 cfs
Baseflow from USGS Segment Kimberly to Buhl
= 0.24 * 1,603.8 cfs = 384.9 cfs
Baseflow from Study Segment Milner Dam to Pillar Falls
= (1.00 * 0 cfs) + (0.196 * 384.9 cfs) = **75.4 cfs**
Flow from gaged tributaries
= **0 cfs**
Flow from gaged springs
= **38.6 cfs**
Flow from irrigation drains
= **0 cfs**
Flow from direct point sources
= **0 cfs**
Flow from unaccounted waters to Study Segment Milner Dam to Pillar Falls
= 636.0 cfs - (75.4 cfs + 38.6 cfs) = **522.0 cfs**

[1]Bold underline indicates values reported in Table 22.

Figure 49. Example Flow Balance Calculation.

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8. Assessment Discussion

Past assessment of flow trends has indicated decadal-scale declines in flows, particularly ground water inflows (both diffuse and from springs) in the Middle Snake River. A review of the most recent flow data appears to support these trends, without identifying the cause, and demonstrates a disparity between observed flows and the flow assumptions used for the 2005 TMDL.

The most recent water quality data, trend analysis, and LOADEST modeling indicate that TP concentrations have declined in recent years in the Middle Snake River. TP concentrations continue to frequently exceed the TP targets, both in the mainstem and along the tributaries. More extreme TP concentrations tend to occur in dry years, indicating that lower flows can lead to higher TP concentrations within the subbasin when less dilution capacity is available.

The major differences in water quality that have been observed between the 1990s and 2000s are the following:

- The extreme TP concentrations observed at Milner Pool (SR08) and Crystal Springs (SR06) appear to have decreased in magnitude, but not necessarily frequency between decades (and remain above the target).
- In the 2000s, TP remains elevated below Crystal Springs, whereas TP generally began to decline below this station in the 1990s.
- At Pillar Falls, TP in the 1990s was fairly constant across seasons but in the 2000s, showed a significant decreasing trend from winter to fall. Similar, less pronounced trends occur at other stations.
- A review of other water quality constituents indicated an increase in all nitrogen species concentrations, consistent across the mainstem stations.
- An assessment of differences between decades was inconclusive for most tributaries due to a lack of data. Small increases and decreases were evident for the few tributaries with observations in both decades.

Studies of macrophyte growth and response to nutrients in the 1990s and early 2000s indicated that sedimentation encouraged establishment of aquatic plant beds and high nutrient concentrations sustained and perpetuated further growth of aquatic plants. Epiphytes and non-rooted macrophytes have been shown to extract nutrients from the water column and, through senescence, lead to nutrient retention in aquatic plant beds. While the retained load can be resuspended during high flows, this temporary retention can alter the timing of nutrient load delivered downstream and could help explain the decrease in concentrations and load downstream of Box Canyon. The highest densities measured in these studies occurred in the vicinity of the Crystal Springs and Box Canyon monitoring locations. Anecdotal evidence indicates that macrophytes continue to be a problem at Crystal Springs, Box Canyon, and elsewhere in the Middle Snake River during the growing season, suggesting that phosphorus reductions are still necessary to protect designated uses.

Findings from the EPA risk assessment (EPA 2002; Appendix I) provide an important perspective for evaluation of nuisance aquatic plant beds and management strategies. EPA (2002) concluded that the macrophyte beds presented a substantial risk to the Middle Snake River ecosystem. From the Crystal Springs reach to the Boulder Rapids reach, the RBM10 simulation results indicated a high risk of exceedance for the total macrophyte and epiphyte biomass tolerance limits.[1] EPA (2002) stated that the

[1] The biomass tolerance limits were designated as 200 g/m^2 biomass (ash free, dry matter), which represents the threshold above which nuisance levels occur.

likelihood of recovery depended on "the availability of clear, cold water, with high flows capable of scouring out long-deposited sediments." The alcove springs[1] along the Middle Snake River provided a benchmark for recovery due to the cold, clear, and significant flow input of the springs, the relatively low nutrient concentrations, and the resulting high diversity and low density of the aquatic macrophytes downstream of the springs. EPA (2002) generally suggested that efforts to address nuisance macrophyte beds should focus on reducing nutrients and sediment and returning flow patterns to a more natural hydrograph.

Regarding sources of nutrient loading, the review of available loading data indicated (1) that the large majority of point sources are meeting, on average, their wasteload allocations, and (2) that TP loads in the mainstem appear to have experienced a net decrease between the 1990s and 2000s, which may be due to both management and lower flows within the period (Sections 4.3 and 4.3.3, respectively). The LOADEST analysis confirmed a declining trend in load. The mass balance analysis (Section 7) indicated that some increases in TP loads from gaged tributaries, irrigation return drains, and indirect or direct point source dischargers have occurred within the most recent decade (the increase from irrigation return drains was inconclusive due to a disparity in sample size between the time periods).

Declines in ground water inflows (both diffuse and from springs) could be influencing the river's ability to achieve designated uses in the Upper Snake-Rock Subbasin despite point sources meeting wasteload allocations. Table 23 compares the current 2005 TMDL allocations to the average annual inflow from 2000 to 2009 for each reach (all flow to the study segment minus flow from the upstream study segment; based on the flow balance analysis using measured flow from USGS gages) and the load capacity calculated for those flows to meet the 2005 TMDL's target TP concentration (flow multiplied by the target). This comparison indicates that, for all but one study segment, the current allocations for inflow exceed the estimated load capacity based on average annual inflow for 2000-2009.

Table 23. Comparison of Estimated Phosphorus Load Capacity based on 2000–2009 Average Annual Inflows to 2005 TMDL Allocations

Study Segment	Average Annual Inflow, 2000–2009 (cfs)[1]	Estimated Load Capacity (lbs/day) for Inflow Only[2]	Total Current (2005) TMDL Allocations (lbs/day) for Inflow Sources[3]
Milner Dam to Pillar Falls	549	222	410.5
Pillar Falls to Crystal Springs	891	360	2,096.7
Crystal Springs to Box Canyon	1,403	567	1,819.6
Box Canyon to Gridley Bridge	742	300	1,575
Gridley Bridge to Shoestring Bridge	1,761	712	1,352
Shoestring Bridge to King Hill Bridge	1,228	496	210
Total	**6,574**	**2,658**	**7,464**

[1]From Appendix B, Table 25; calculated from flows in Appendix H, Table 34. These flows represent all inflow to the mainstem within the reach, other than the flow from the upstream study segment. This inflow is the result of baseflow, tributaries, springs, irrigation return drains, indirect point sources, direct point sources, and un-accounted waters.
[2]Average annual inflow multiplied by the 0.075 mg/L TP target, with units conversion.
[3]Total current allocations as reported in Table 6 (DEQ 2010).

[1] Alcove springs are springs that discharge from the lower canyon walls along the Snake River banks.

Particular attention to the elevated concentrations at Crystal Springs is warranted, especially considering the high density of nuisance aquatic vegetation at this location. Sources of phosphorus loading to this location include point sources and irrigation drains and declines in ground water inflows (both diffuse and from springs) could be affecting dilution of phosphorus loading, leading to elevated phosphorus concentrations. To more fully understand the causes of these effects, more detailed analysis is required to control for the complexity of the hydrologic system and the interaction of decadal, cyclic, and seasonal trends.

Independent of flow trends over time, consideration of the validity of flow assumptions used in the TMDL development is warranted. As explained in Section 4.2, DEQ (2010) found that even the low flow scenarios referred to in the TMDL development do not appear to represent critical low flow conditions. Mean flow conditions, as applied in the current TMDL allocations, might not be an appropriate scenario to reflect the modified nature of the Middle Snake River system. In a comparison of long-term flow data, Switzer et al. (2010) found that greater than 65 percent of the time flows below the Milner Dam never reached the mean flow observed between 1910 and 2008. With the extensive diversions and impoundments in the system, a low flow scenario could be a more appropriate application for TMDL allocations. As ecological responses to nutrients are chronic and cumulative over time scales on the order of weeks to months, a 30-day average low flow with a 10-year recurrence (30Q10) may be a more appropriate basis for allocations. This review and assessment of available data suggests that further investigation is warranted. While some reductions in TP load have been achieved, the TMDL target concentrations have not been achieved. These conditions, as well as the potential spatial and seasonal effects of ground water decline (as observed in the data), support further investigation of the TMDL assumptions.

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Appendix A. Data Sources

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Table 24. Upper Snake-Rock Subbasin Data Sources

Name	Source	Description	Years	Constituents
Mid Snake Statistics Files	DEQ	Includes raw data from 7 water quality and 4 flow stations on the mainstem and 30 water quality stations on tributaries. In addition, the mainstem data are summarized by various time periods, including calendar years, decades (1990s and 2000s), months, seasons, and water years.	1989–2010 (depends on station; tributary data are for 2007–2008)	Flow, TSS, Lab NTU, TP, DOP, TKN, NH3, NOX, E COLI, F COLI, CHLORO, PHEOP, TEM, Field NTU, pH, SC, TDS, DO, % DO SAT (Not all constituents were sampled at each station location)
Irrigation Return Flow Monitoring	USDA-ARS Kimberly	Water quality and flow volume records for 26 drains for irrigation return flow monitoring	2005–2008	Flow, TKN, TP, Dissolved Aluminum, Dissolved Ca, Dissolved Chloride, Diss. Iron, Diss. Potassium, Diss. Magnesium, Diss. Manganese, Diss. Sodium, Diss. Ammonia, Nitrate, Diss. P, Diss. Sulfur, Diss. Zinc, Specific Conductivity, pH, and Suspended Sediment
Twin Falls Irrigation Drain Monitoring	Twin Falls Canal Co.	Water quality and flow data (for some dates and stations) for Twin Falls Canal Co. irrigation drains.	1990–2011	TSS, TP, air temp, water temp, flow, stage, turbidity, electrical conductivity, dissolved oxygen, pH, Total Nonfilterable Residue, Total Ammonia, TKN, N-dissolved and oxidized, TP, Orthophosphate Dissolved (May not be available for all years or locations)
North Side Canal Irrigation Drain Monitoring	North Side Canal Company	Water quality for North Side Canal Co. irrigation drains.	2002–2011	TP, OP, TSS
Macrophyte	Idaho Power	Aquatic vegetation removal (in number of truckloads) and TP equivalency from Upper Salmon A, Upper Salmon B, Lower Salmon, and Bliss dams	1991–2011	NA

Name	Source	Description	Years	Constituents
Water Quality	Idaho Power	Water quality data collected at river mile 546. Spreadsheet includes raw data, paired data, time series plots, and daily mean flow at King Hill.	1991–2013	Ammonia, Chla, DO, Nitrate, NitrogenTotK, OrgCTot, OrgCTotDis, OrthoPDis, pH, Ptot, SpecCond, SusSolTot, Temperature, Turbidity, VolSusSol
Water Quality	USGS - NWIS	Nutrient and sediment monitoring data throughout the Upper Snake-Rock Subbasin	2003–2013 (depends on station)	TP, TN, Suspended Sediment
Water Quality	Clear Springs Foods	Water quality data collected at the Clear Lakes Grade Road Bridge.	2001-2013	TP (other constituents available)
Water Quality	University of Idaho	Water quality data collected near Milner.	2000-2013	TP (other constituents available)
Irrigation Return Flow	Idaho Department of Water Resources	Gage height records and calculated daily flow (cfs) and flow volume (acre-ft) for return flow drains to the Snake River.	2002–2010 (depends on drain)	Return flow data (not WQ data)
ESPAM	Idaho Department of Water Resources	Estimation of average flow contributions due to springs and underflow (“baseflow”) from 1980 to roughly 2009.	Average of data from 1980 to 2008 or 2009 depending on reach segment	Flow (cfs)

Appendix B. Additional Flow Comparisons

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Table 25. Comparison of TMDL Flow Assumptions (1997,1999, 2000, and 2005) to Flow Summary Statistics (2000–2009)

Study Segment[1]	TMDL Flow Assumptions				Mean Annual Q 2000-2009, cfs[6]	30Q10 POR cfs[7]	7Q10 POR cfs	10th Percentile POR cfs
	1997 TMDL Q, cfs[2]	1999 Draft TMDL Q, cfs[3]	2000 TMDL Q, cfs[4]	2005 TMDL Q, cfs[5]				
MD to PF	NA	425 to 1,302 = 877	3,860 to 4,737 = 877	3,860 to 4,737 = 877	1,116 to 1,665 = 549	2 to 562 = 560	1 to 530 = 529	13 to 710 = 697
PF to CS	NA	1,302 to 2,075 = 773	4,737 to 5,498 = 761	4,737 to 5,498 = 761	1,665 to 2,556 = 891	562 to 1,393 = 831	530 to 1,311 = 781	710 to 1,693 = 983
CS to BC	NA	2,075 to 3,817 = 1,742	5,498 to 7,212 = 1,714	5,498 to 7,212 = 1,714	2,556 to 3,959 = 1,403	1,393 to 2,776 = 1,383	1,311 to 2,678 = 1,367	1,693 to 3,179 = 1,486
BC to GB	NA	3,817 to 5,709 = 1,892	7,212 to 9,113 = 1,901	7,212 to 9,113 = 1,901	3,959 to 4,701 = 742	2,776 to 3,516 = 740	2,678 to 3,417 739	3,179 to 3,958 = 779
GB to SB	NA	5,709 to 7,545 = 1,836	9,113 to 11,108 = 1,995	9,113 to11,108 = 1,995	4,701 to 6,461 = 1,760	3,516 to 5,173 = 1,657	3,417 to 5,043 = 1,626	3,958 to 5,722 = 1,764

Study Segment[1]	TMDL Flow Assumptions				Mean Annual Q 2000-2009, cfs[6]	30Q10 POR cfs[7]	7Q10 POR cfs	10th Percentile POR cfs
	1997 TMDL Q, cfs[2]	1999 Draft TMDL Q, cfs[3]	2000 TMDL Q, cfs[4]	2005 TMDL Q, cfs[5]				
SB to KH	NA	7,545 to 7,966 = 421	11,108 to 11,398 = 290	11,108 to 11,398 = 290	6,461 to 7,689 = 1,228	5,173 to 6,106 = 933	5,043 to 5,892 = 849	5,722 to 6,761 = 1,039

[1]MD = Milner Dam; PF = Pillar Falls; CS = Crystal Springs; BC = Box Canyon; GB = Gridley Bridge; SB = Shoestring Bridge; KH = King Hill; Q = flow; POR = period of record.

[2]NA = Not applicable; The segregation of the TMDL reach segments did not occur until the 2000 TMDL. The 1997 TMDL did not incorporate these six reach segments. However, Table 7 (page 14) of the TMDL indicates flows at the USGS gage stations as: MD = 3,430 cfs; near Kimberly = 3,800 cfs; near Buhl = 5,450 cfs; near Hagerman = 9,280 cfs; and KH = 11,020 cfs.

[3]The values are based on net flow (output – input) as found in the 1999 TMDL (pages 357–363). This is referred to as the "Difference" as net flow for the segment (output – input).

[4]2000 TMDL Executive Summary, TSS TP Allocation Summary for Segments 1–6. This summary was developed by EPA and DEQ and was the basis for the 2000 TMDL based on the 1999 Draft TMDL.

[5]The flows for these reaches were estimated as average (or mean) flows (page 37, Section 10.1, 2005 TMDL) at the compliance points for each of the six segments. Each segment has two compliance points, an input and an output.

[6]Mean annual flow for 2000–2009 for USGS gage stations: MD = 1,116 cfs; near Kimberly = 1,389 cfs; near Buhl = 2,799 cfs; near Hagerman = 6,046 cfs; and KH = 7,712 cfs.

[7]Percent of reach for USGS gages is the following: MD = 5/1/1909 to 9/30/2010; near Kimberly = 10/1/1923 to 9/30/2010; near Buhl = 12/12/1946 to 1/4/2012; near Hagerman = 10/1/1937 to 9/30/2011; and KH = 6/1/1909 to 1/9/2012.

Milner Dam

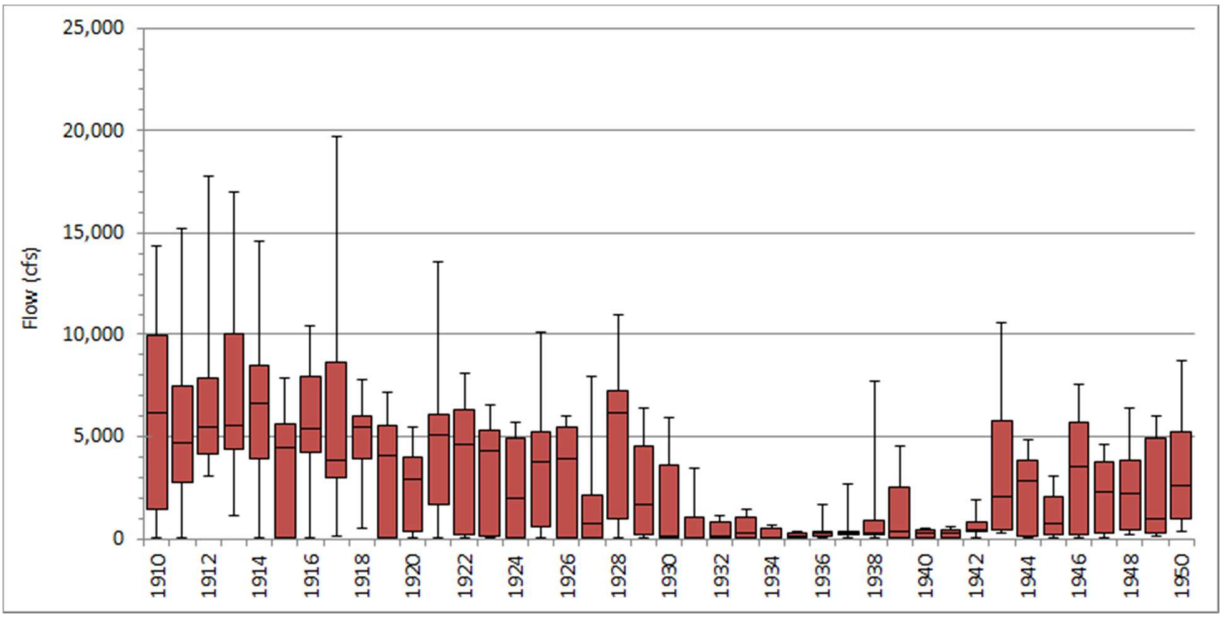

Figure 50. Milner Dam daily flows, 1910–1950.

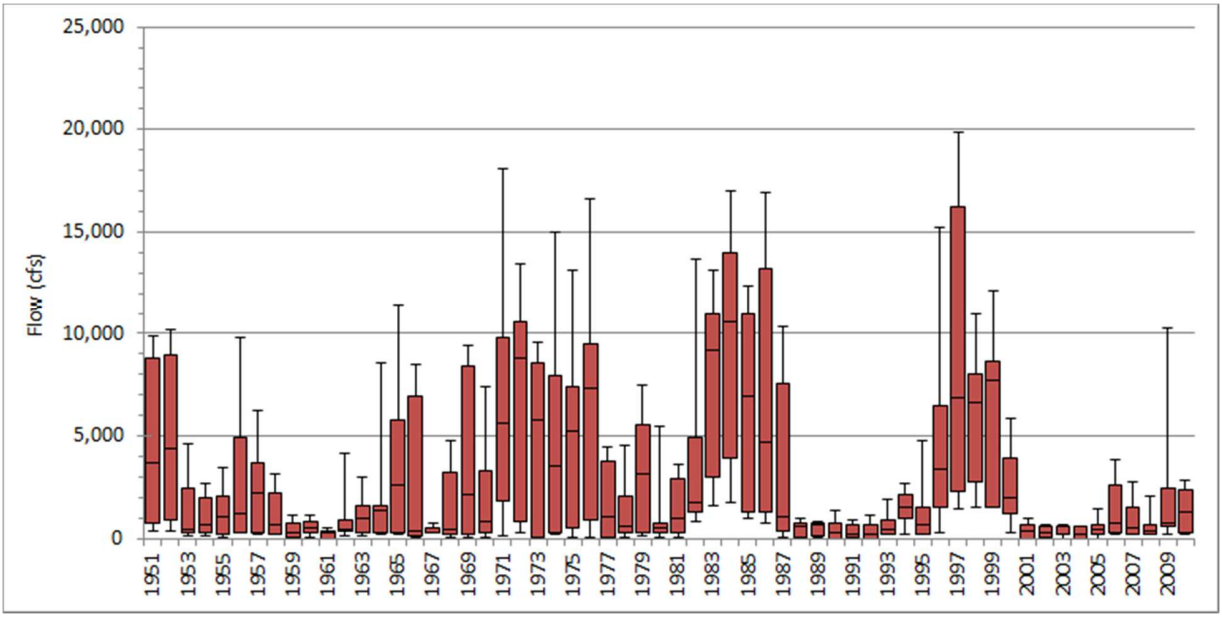

Figure 51. Milner Dam daily flows, 1951–2010.

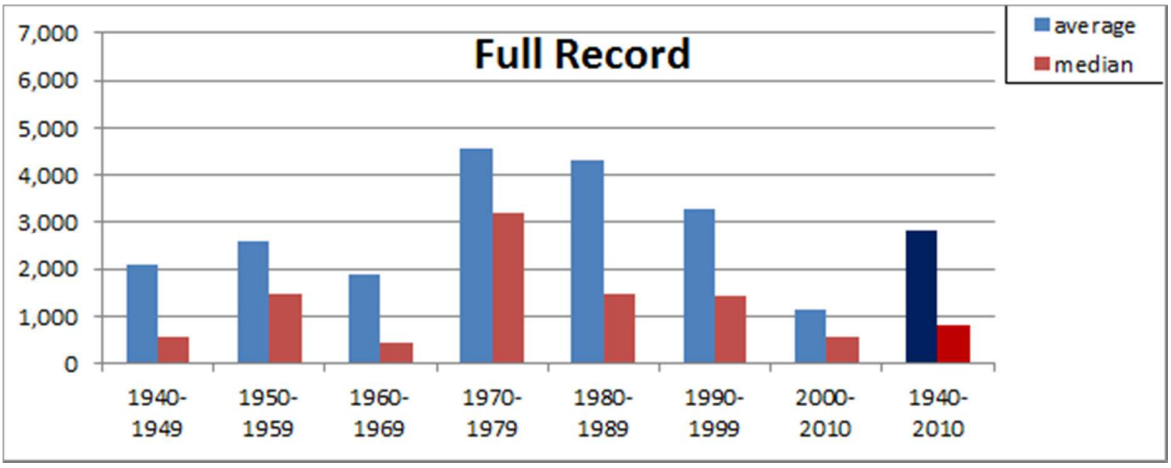

Figure 52. Milner Dam average and median daily flows by decade.

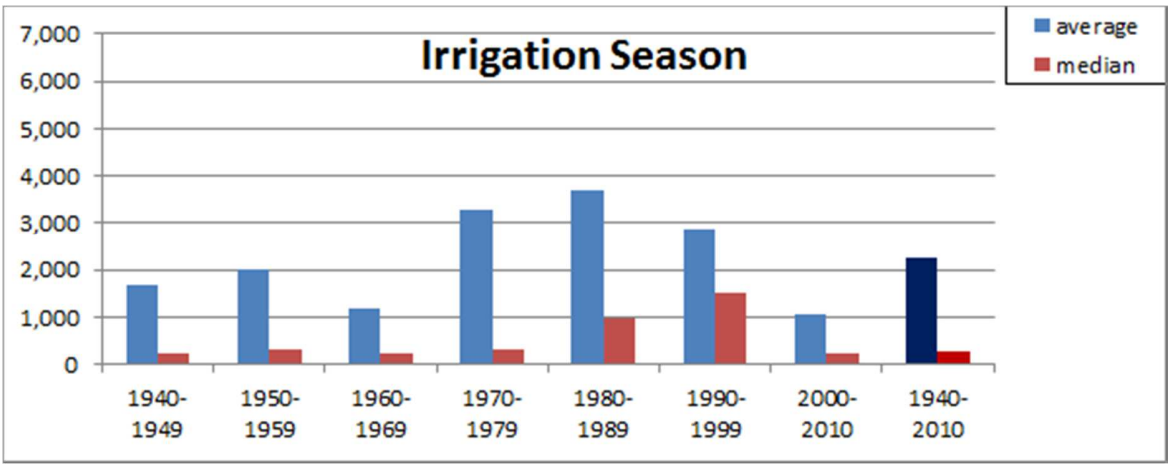

Figure 53. Milner Dam average and median daily flows by decade during the irrigation season.

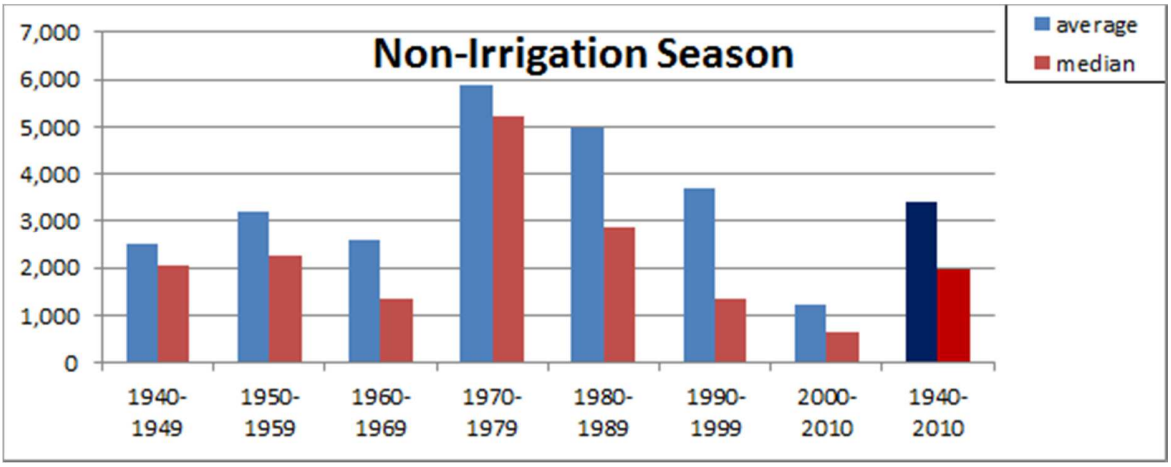

Figure 54. Milner Dam average and median daily flows by decade during the non-irrigation season.

Kimberly

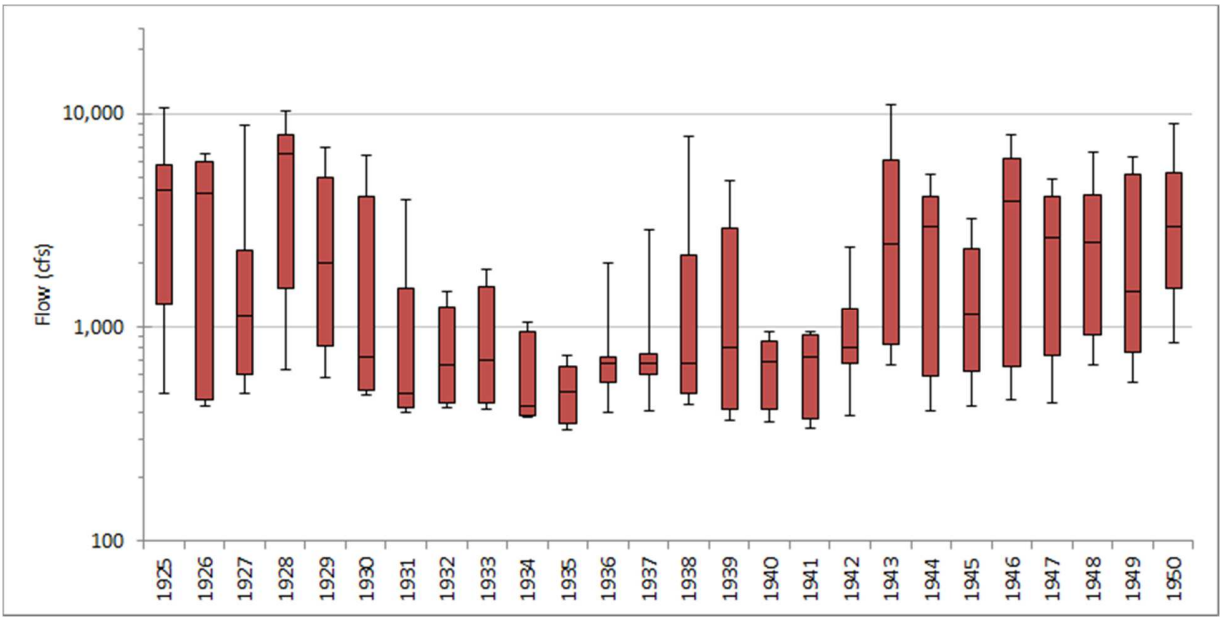

Figure 55. Kimberly daily flows, 1925–1950.

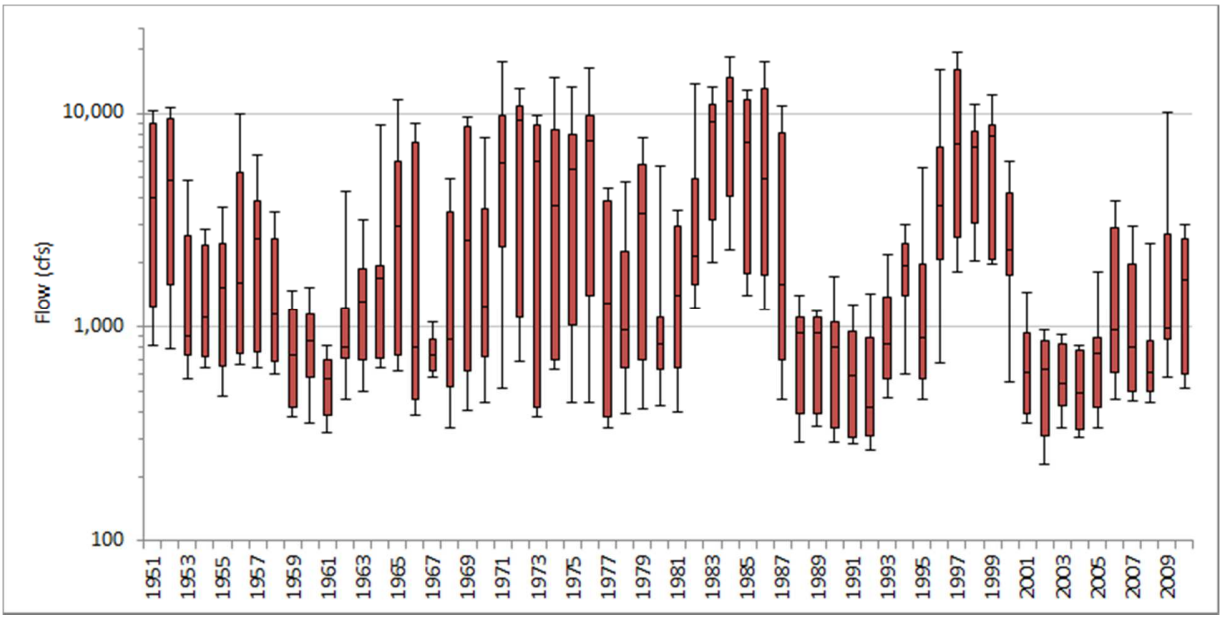

Figure 56. Kimberly daily flows, 1951–2010.

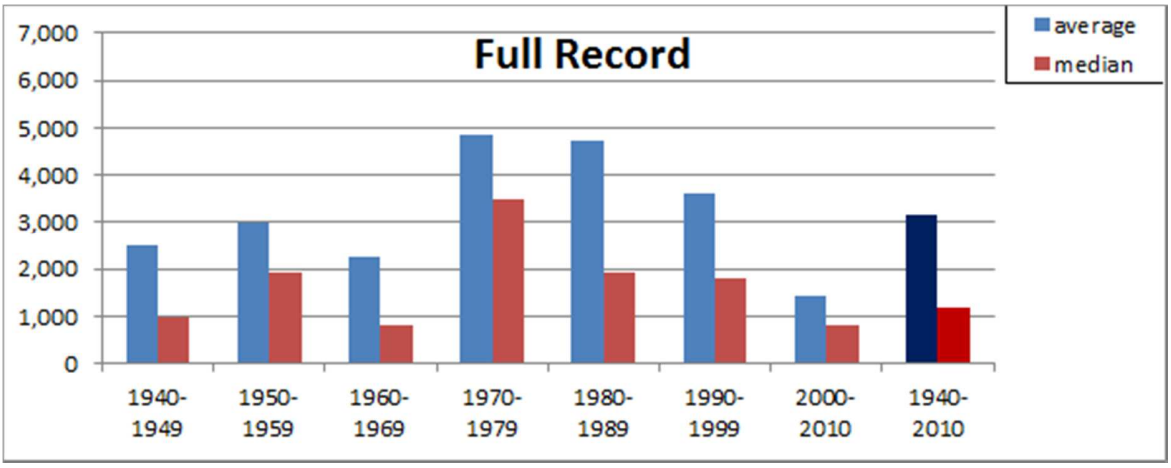

Figure 57. Kimberly average and median daily flows by decade.

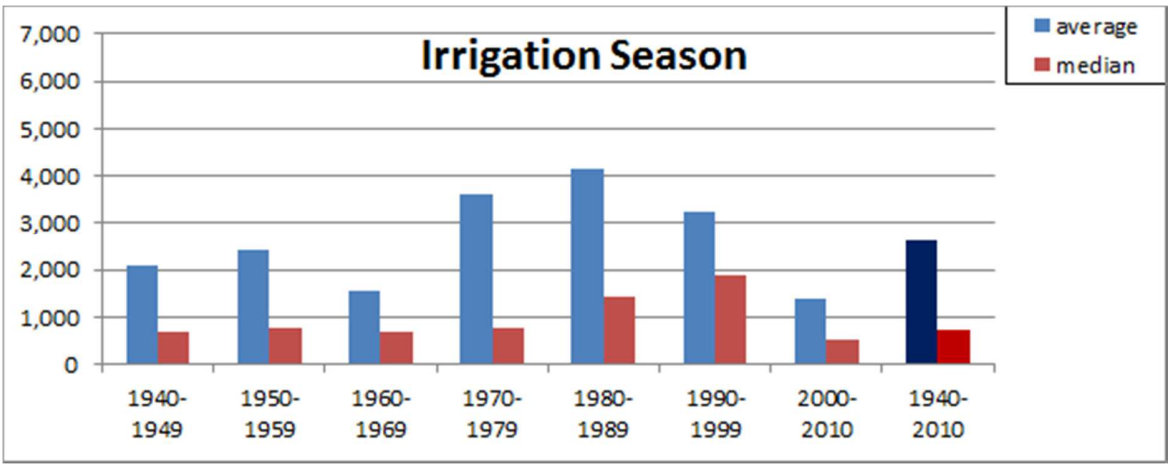

Figure 58. Kimberly average and median daily flows by decade during the irrigation season.

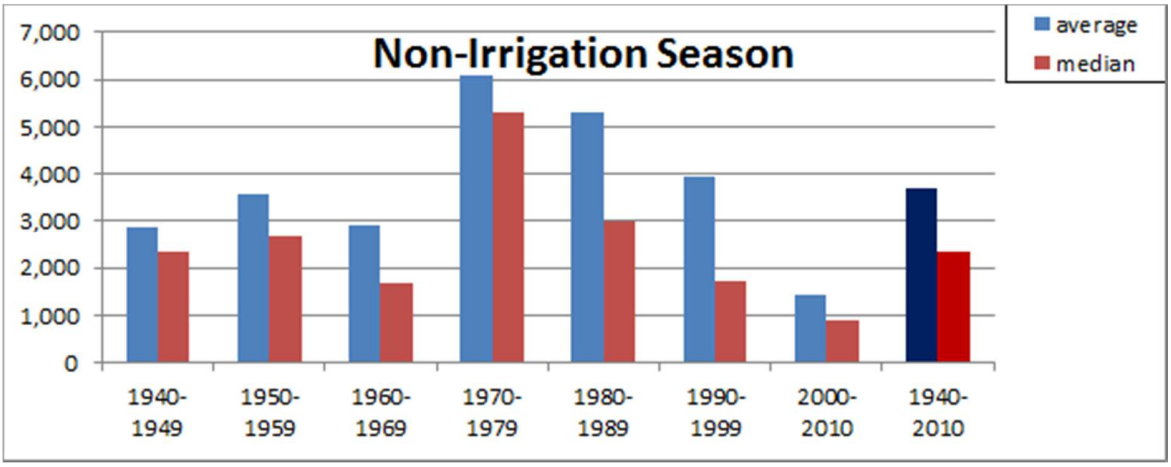

Figure 59. Kimberly average and median daily flows by decade during the non-irrigation season.

Buhl

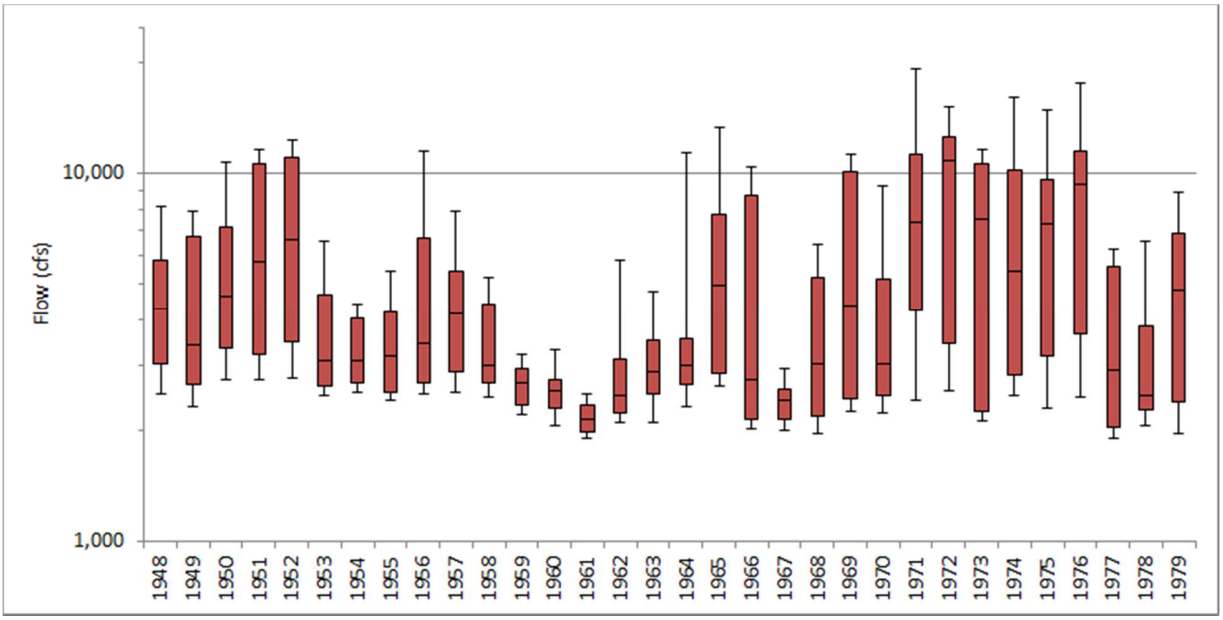

Figure 60. Buhl daily flows, 1948–1979.

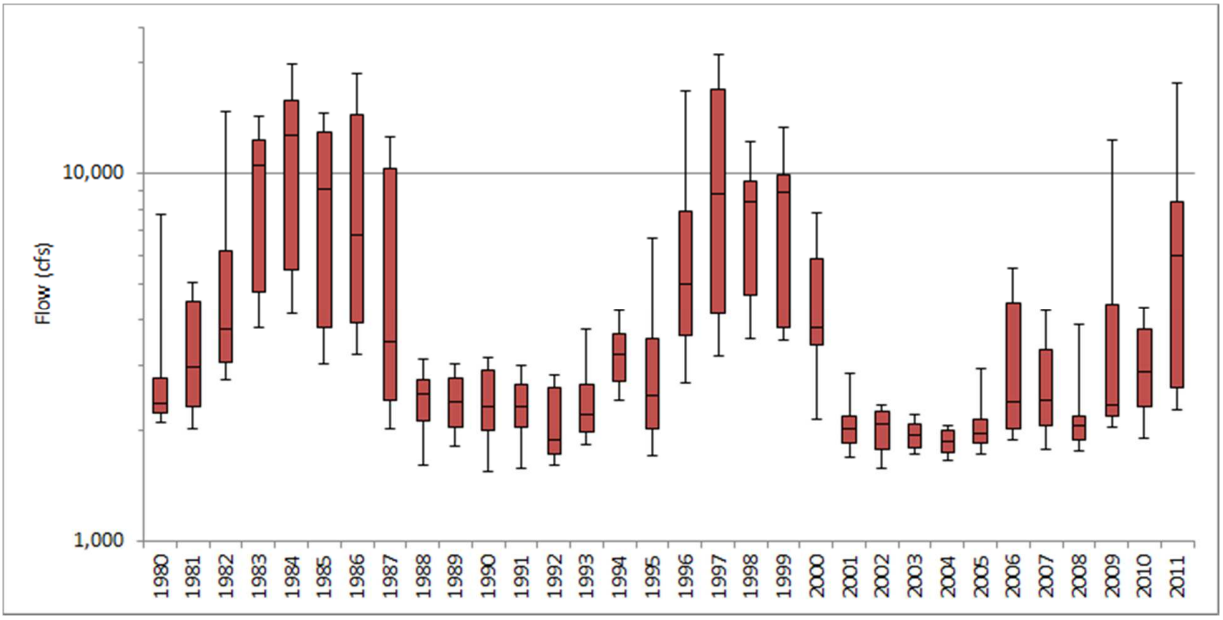

Figure 61. Buhl daily flows, 1980–2011.

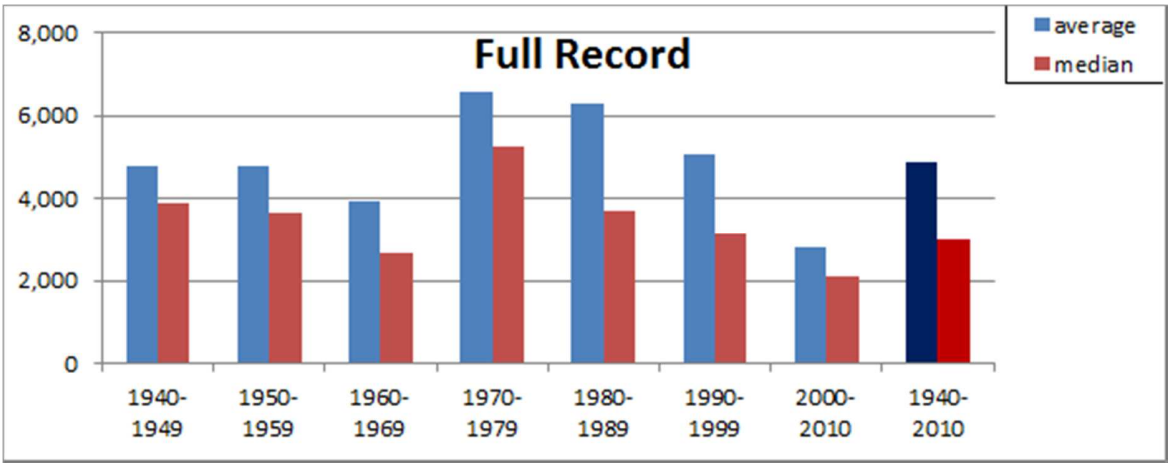

Figure 62. Buhl average and median daily flows by decade.

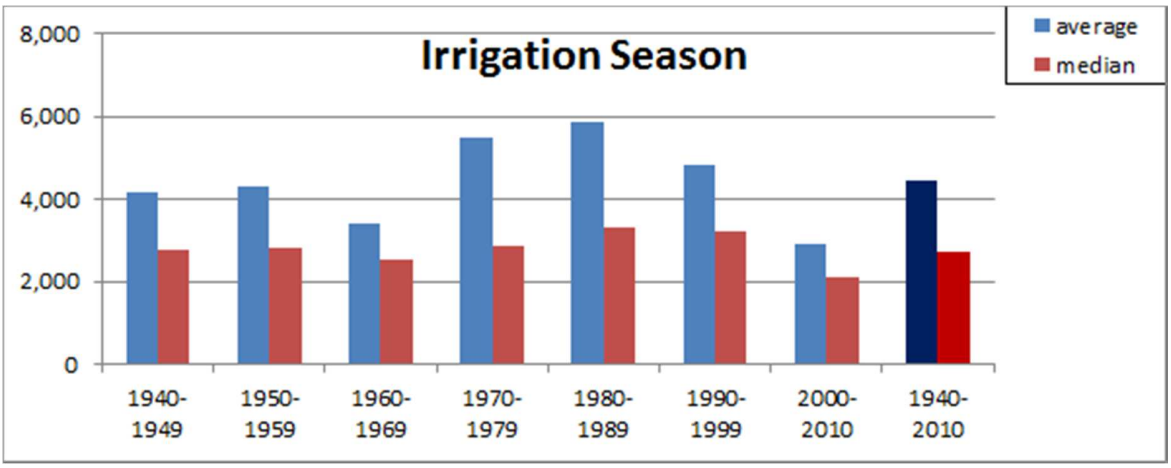

Figure 63. Buhl average and median daily flows by decade during the irrigation season.

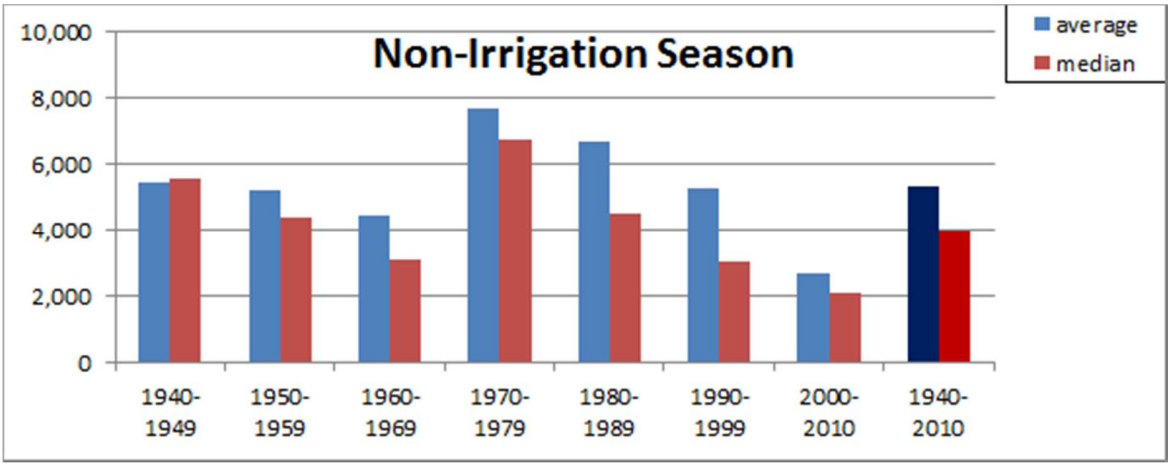

Figure 64. Buhl average and median daily flows by decade during the non-irrigation season.

King Hill

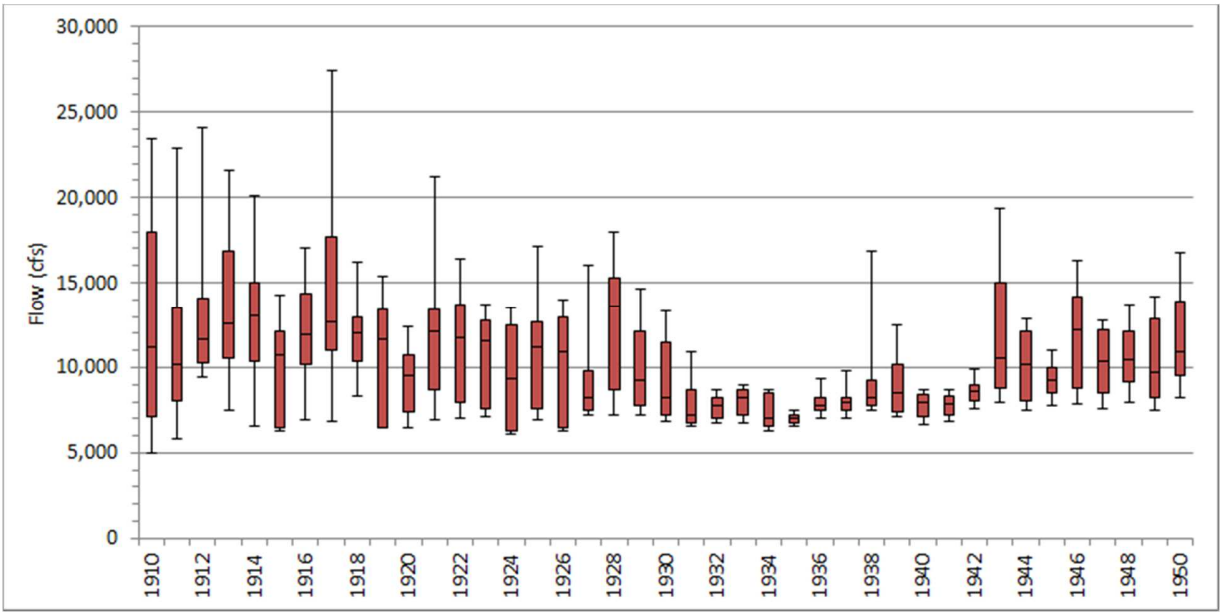

Figure 65. King Hill daily flows, 1910–1950.

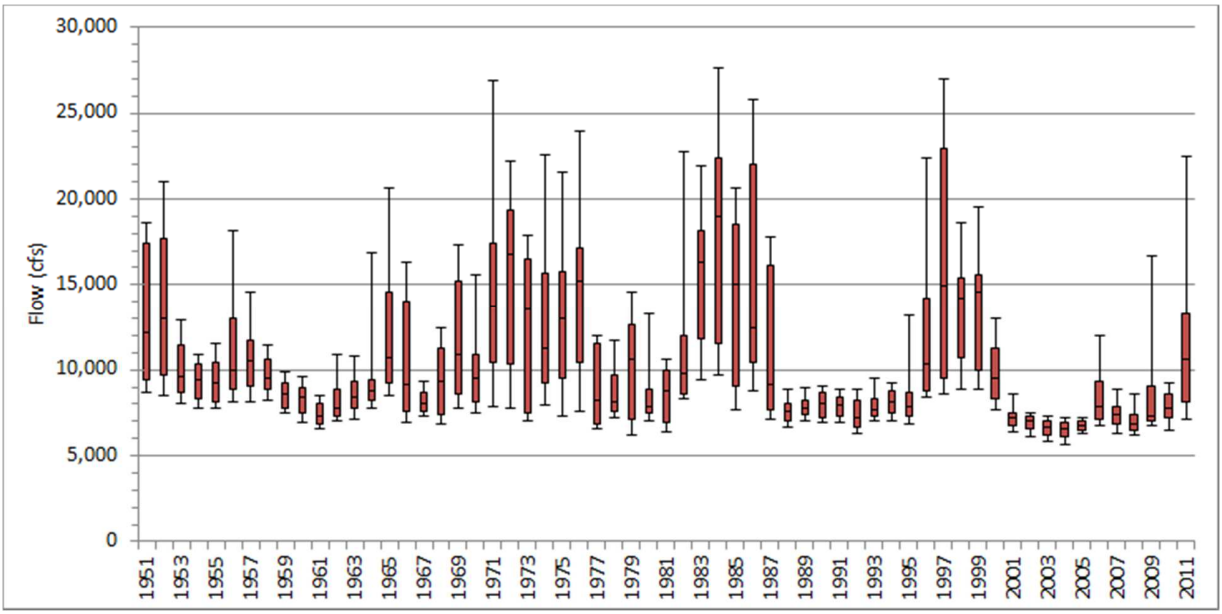

Figure 66. King Hill daily flows, 1951–2011.

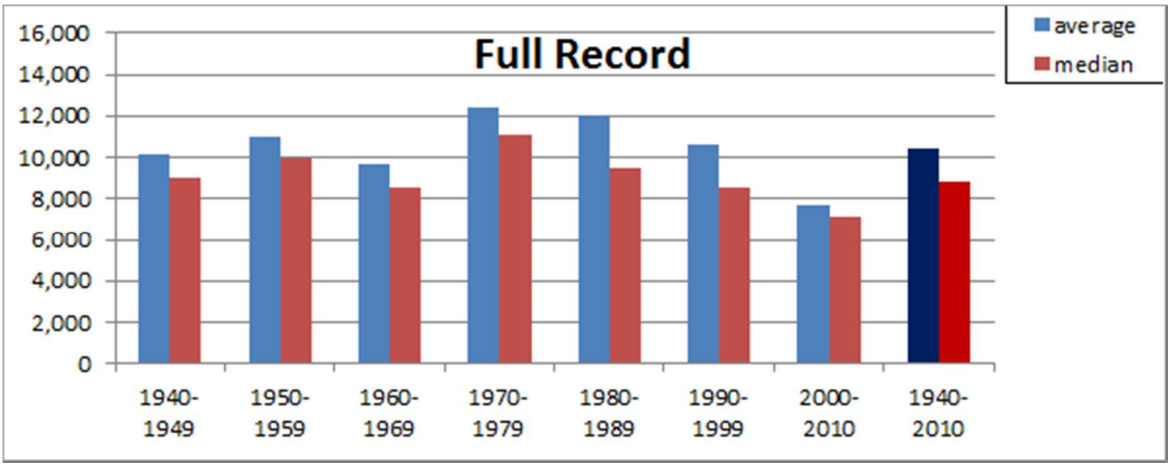

Figure 67. King Hill average and median daily flows by decade.

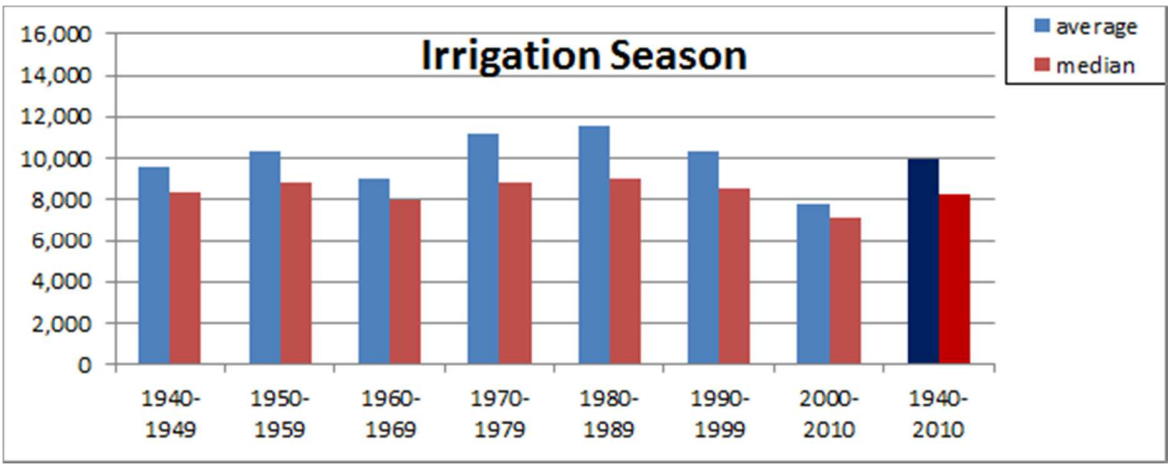

Figure 68. King Hill average and median daily flows by decade during the irrigation season.

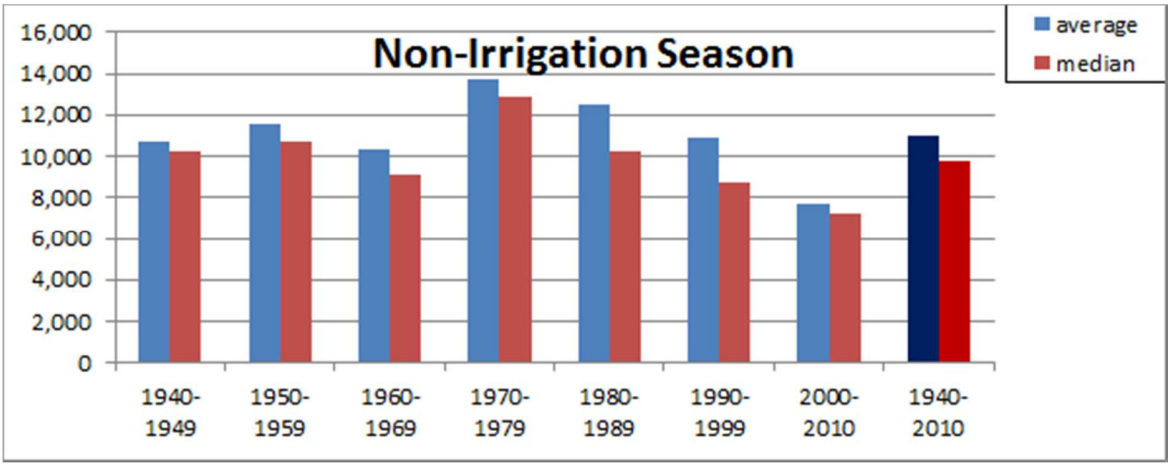

Figure 69. King Hill average and median daily flows by decade during the non-irrigation season.

Appendix C. Water Quality—Time Series

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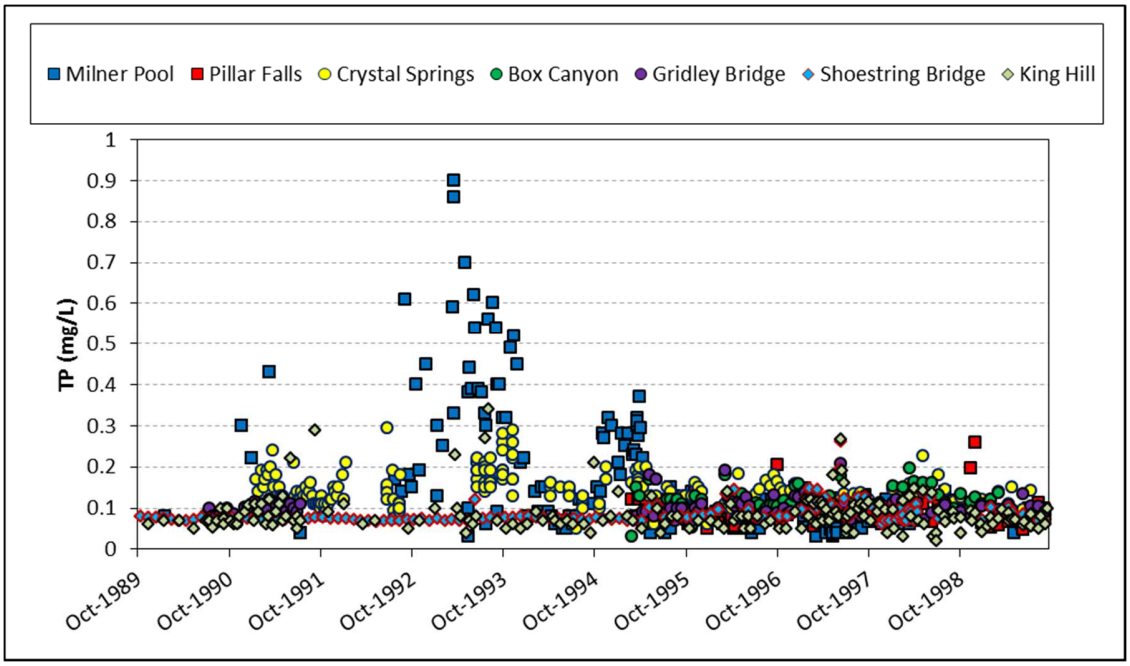

Figure 70. TP from water years 1990 through 1999 for all DEQ mainstem monitoring locations.
(Includes USGS monitoring data at coincident locations.)

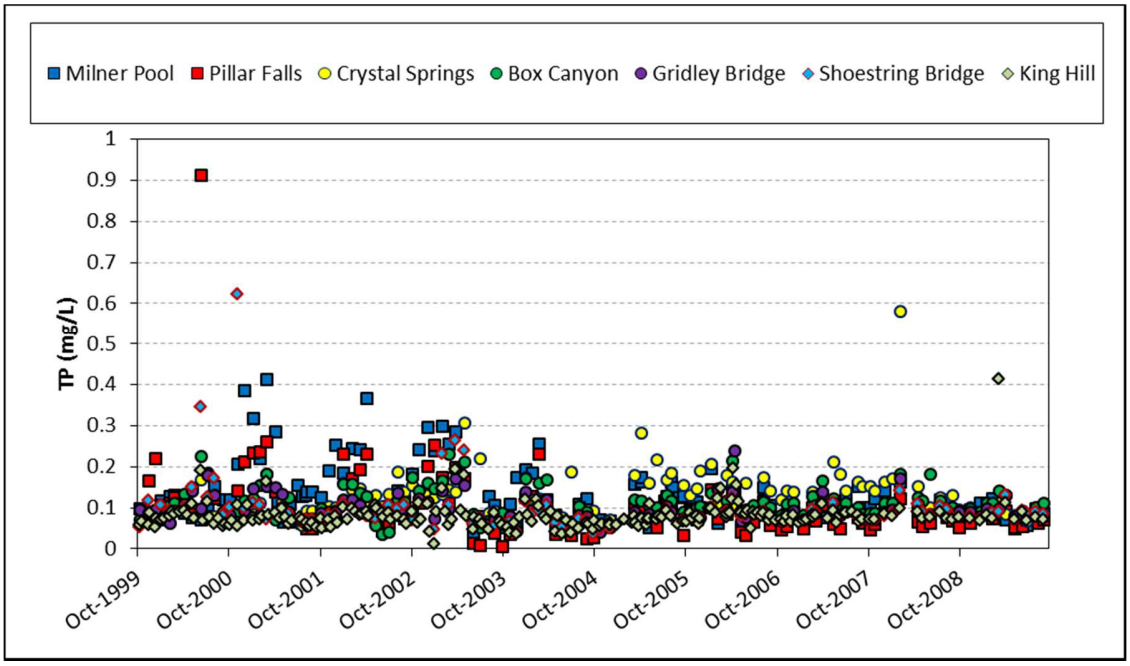

Figure 71. TP from water years 2000 through 2009 for all DEQ mainstem monitoring locations.
(Includes USGS monitoring data at coincident locations.)

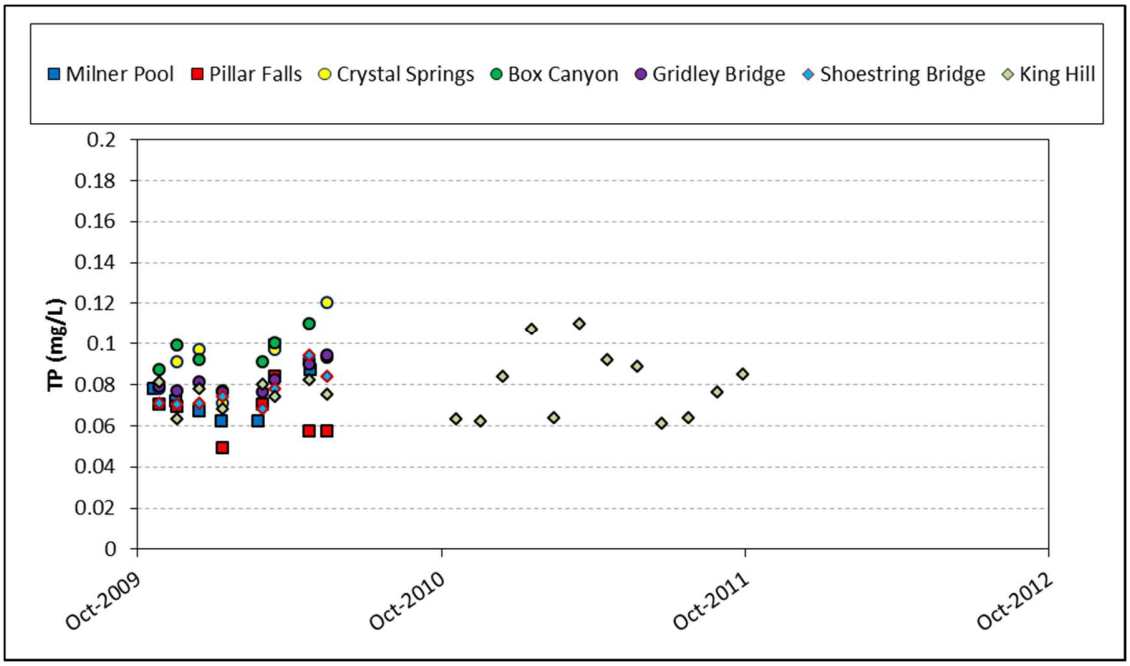

Figure 72. TP from water years 2010 through 2013 for all DEQ mainstem monitoring locations.
(Includes USGS monitoring data at coincident locations.)

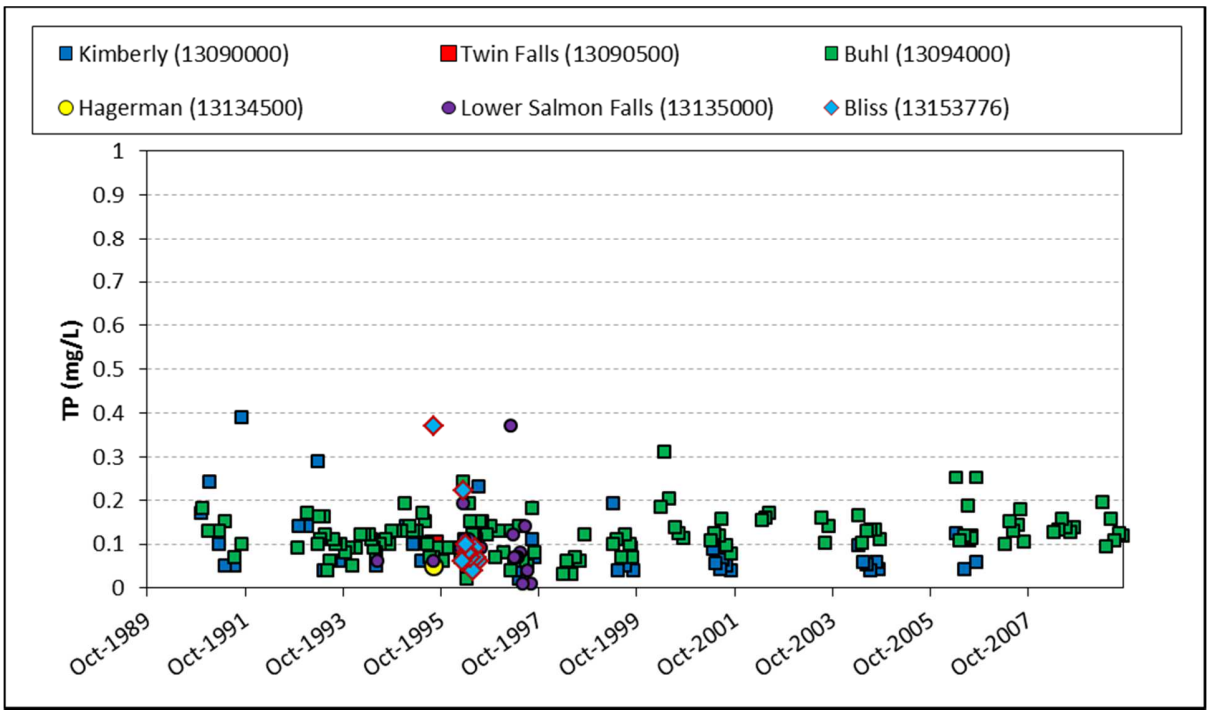

Figure 73. TP from water years 1990 to present for USGS monitoring locations along the Snake River that are not coincident with DEQ monitoring locations.

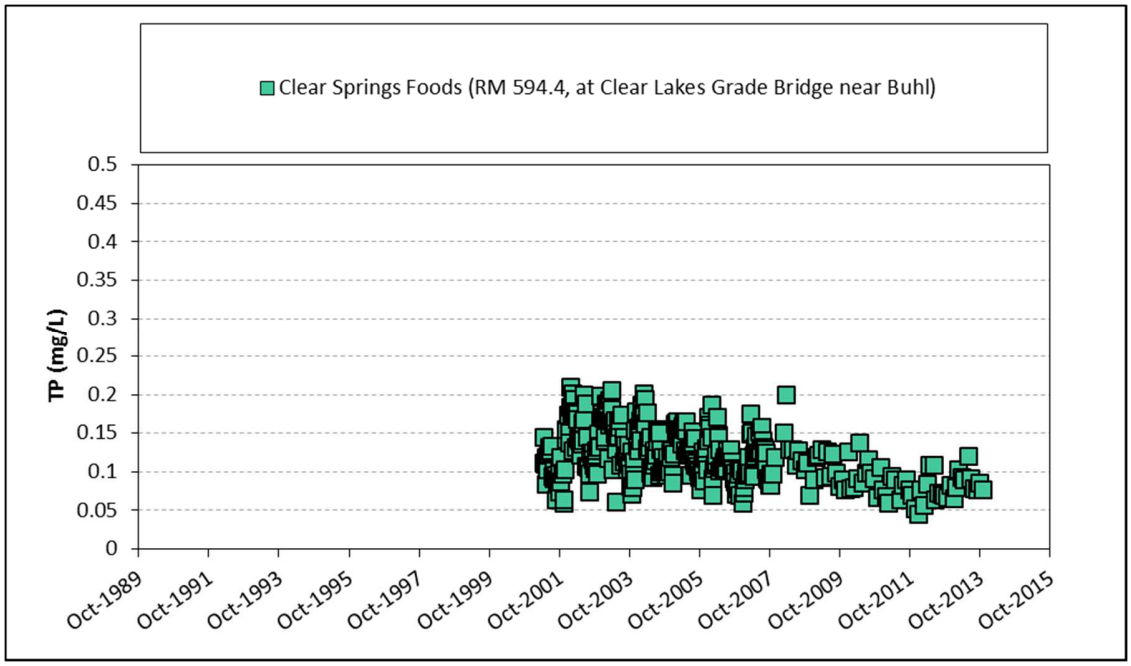

Figure 74. TP from water years 1990 to present for the Clear Springs Foods monitoring location.

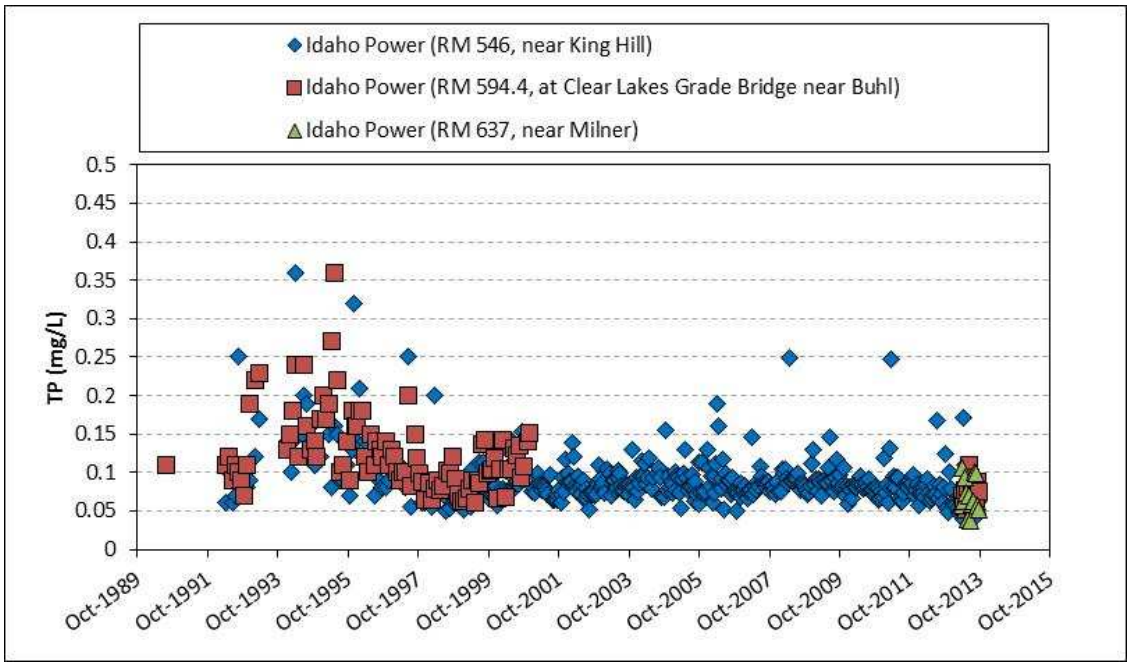

Figure 75. TP from water years 1990 to present for the Idaho Power monitoring locations.

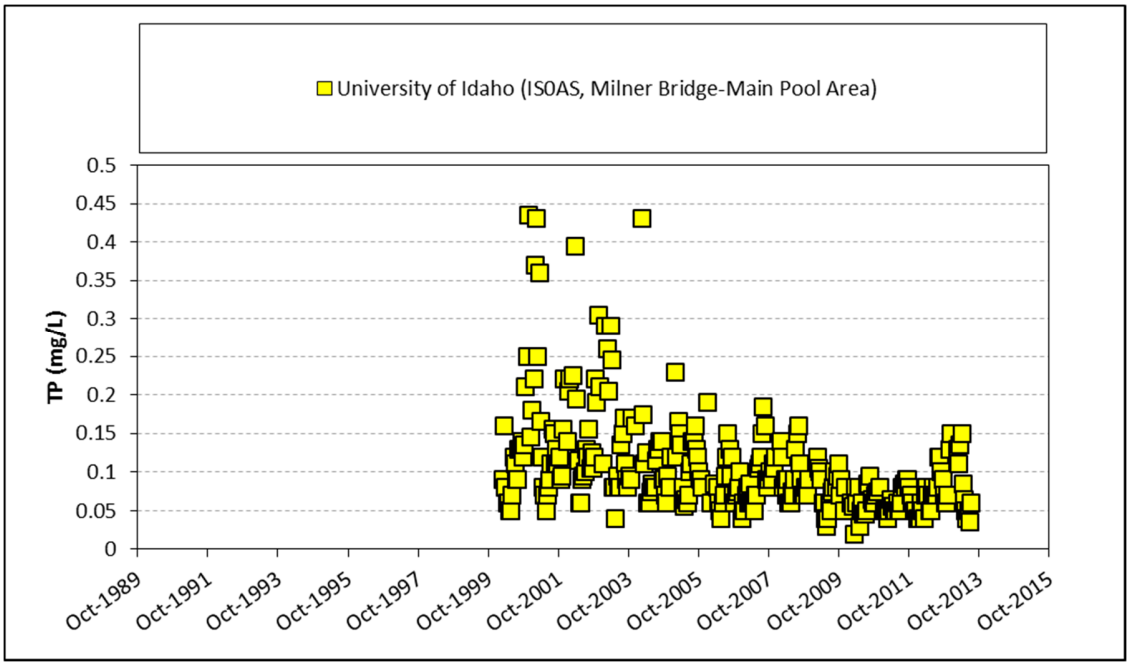

Figure 76. TP from water years 1990 to present for the University of Idaho monitoring location at Milner.

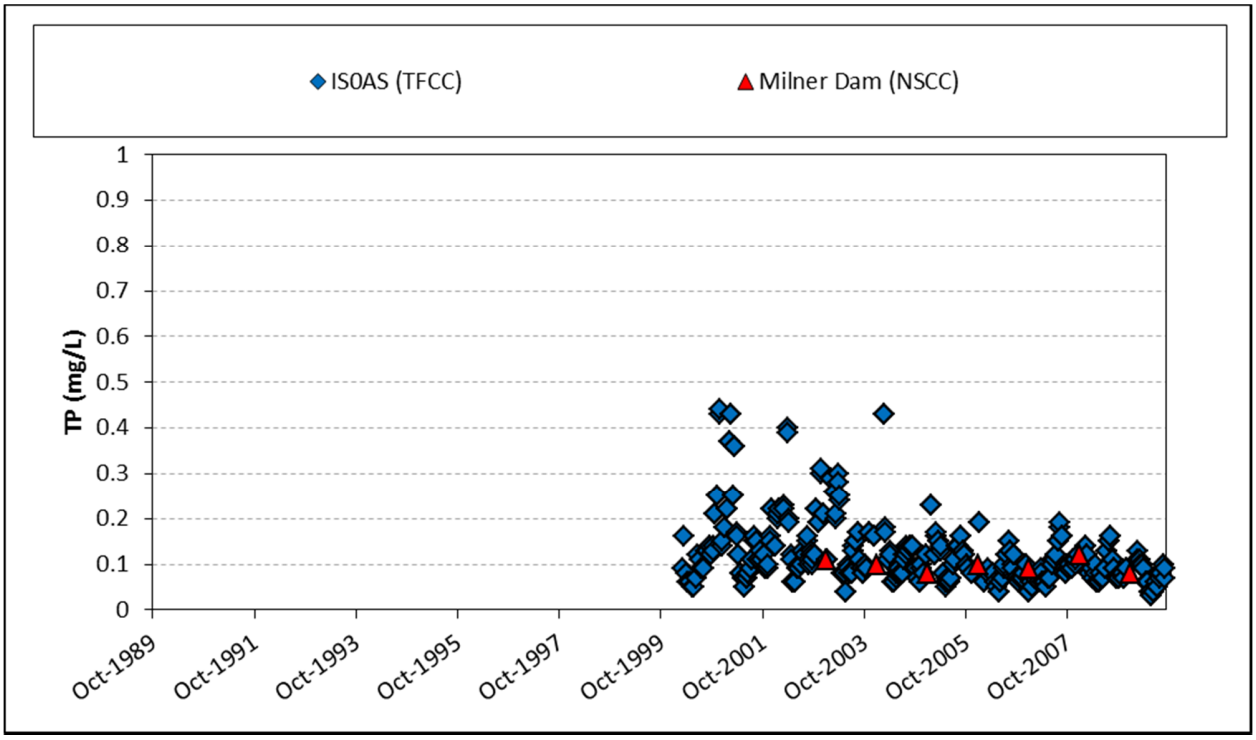

Figure 77. TP from the Twin Falls Canal Co. and North Side Canal Co. monitoring locations at Milner Dam.

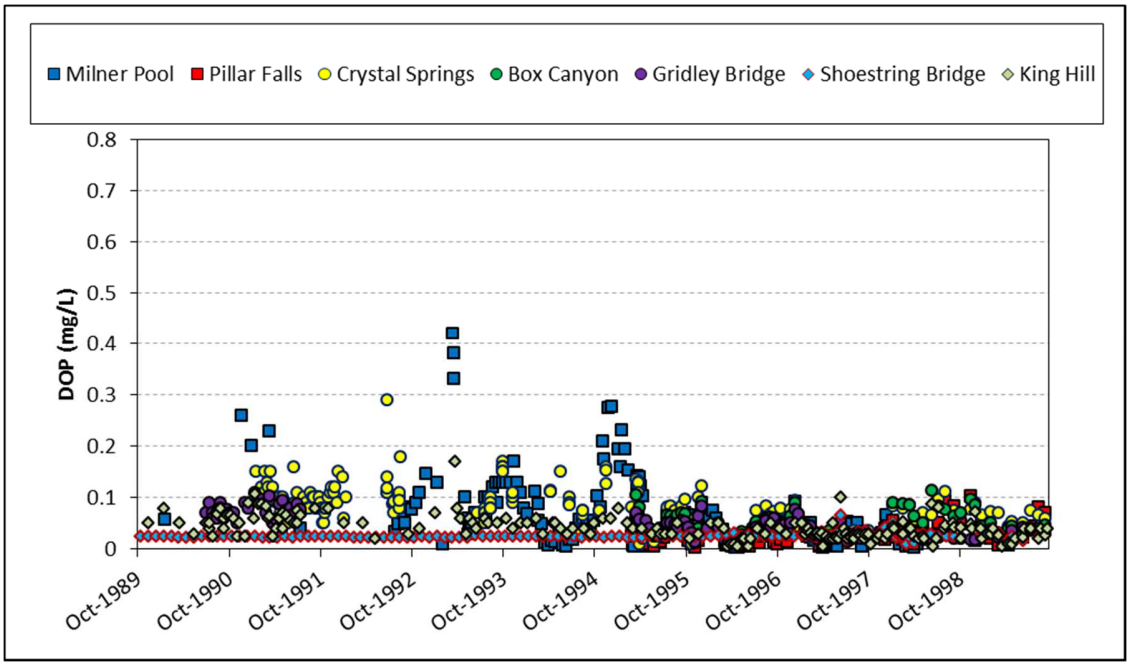

Figure 78. DOP from water years 1990 through 1999 for all DEQ mainstem monitoring locations.
(Includes USGS monitoring data at coincident locations.)

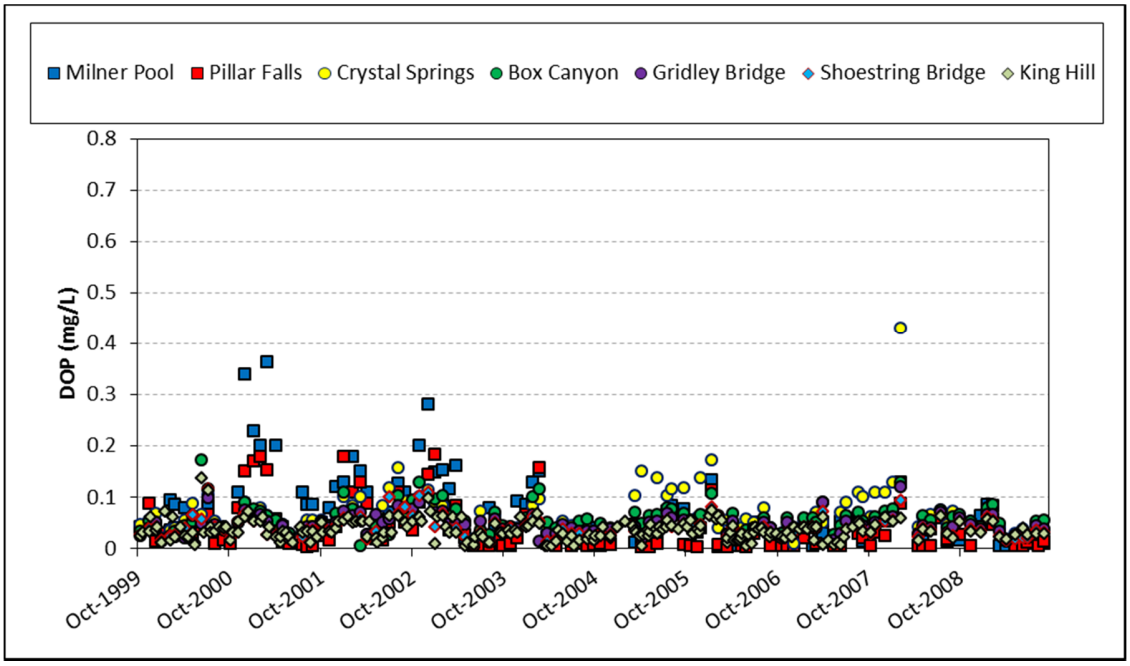

Figure 79. DOP from water years 2000 through 2009 for all DEQ mainstem monitoring locations.
(Includes USGS monitoring data at coincident locations.)

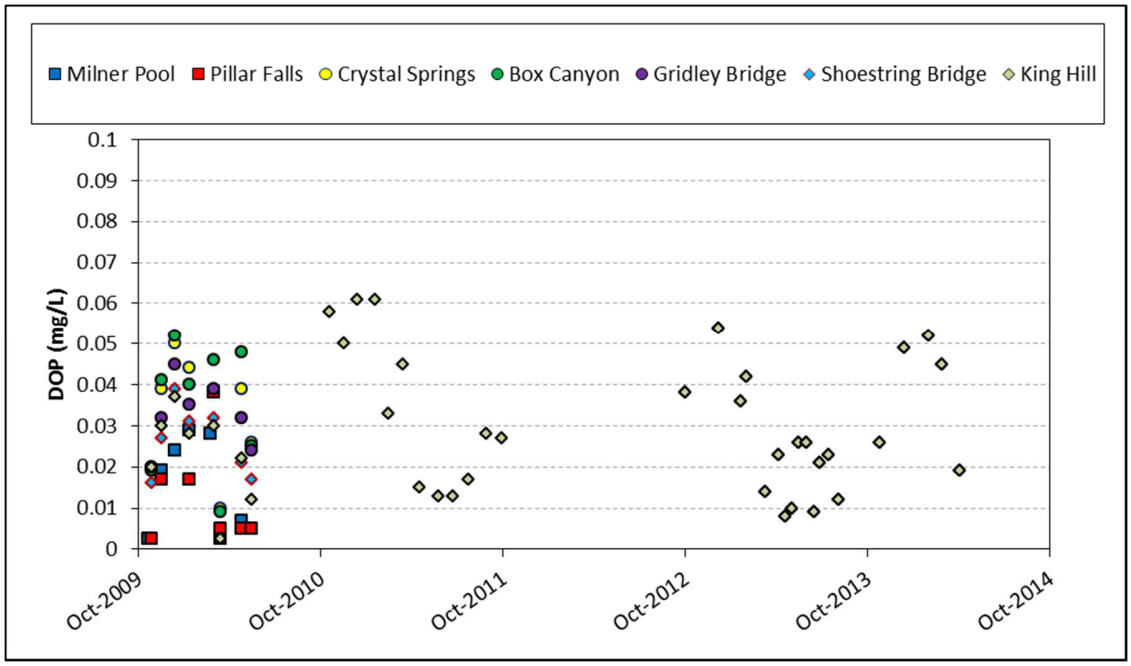

Figure 80. DOP from water years 2010 through 2013 for all DEQ mainstem monitoring locations.
(Includes USGS monitoring data at coincident locations.)

Appendix D. Water Quality—Seasonal Assessment

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Seasonal definitions for Appendix D figures:

- Winter – December 1 to February 28
- Spring – March 1 to May 31
- Summer – June 1 to August 31
- Fall – September 1 to November 30

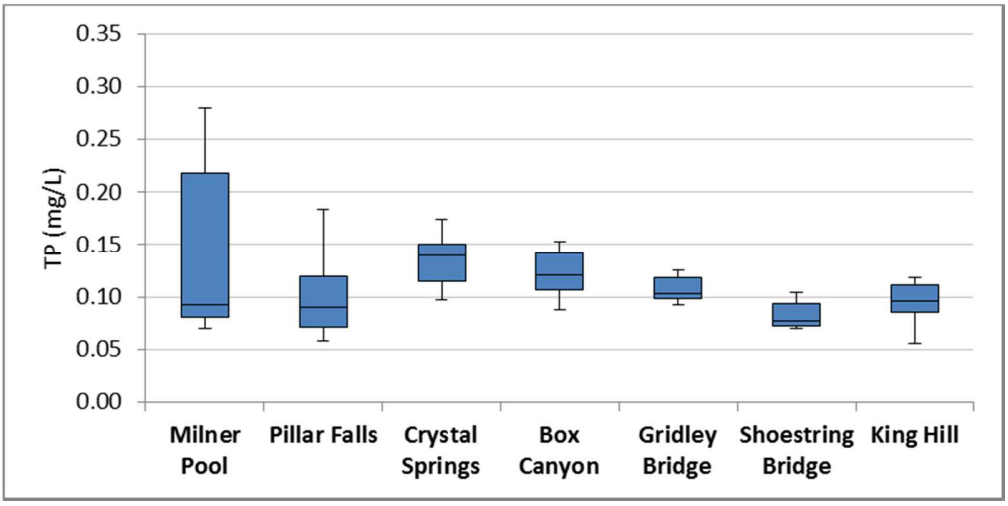

Figure 81. Winter TP concentration along mainstem for water years 1990–1999.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

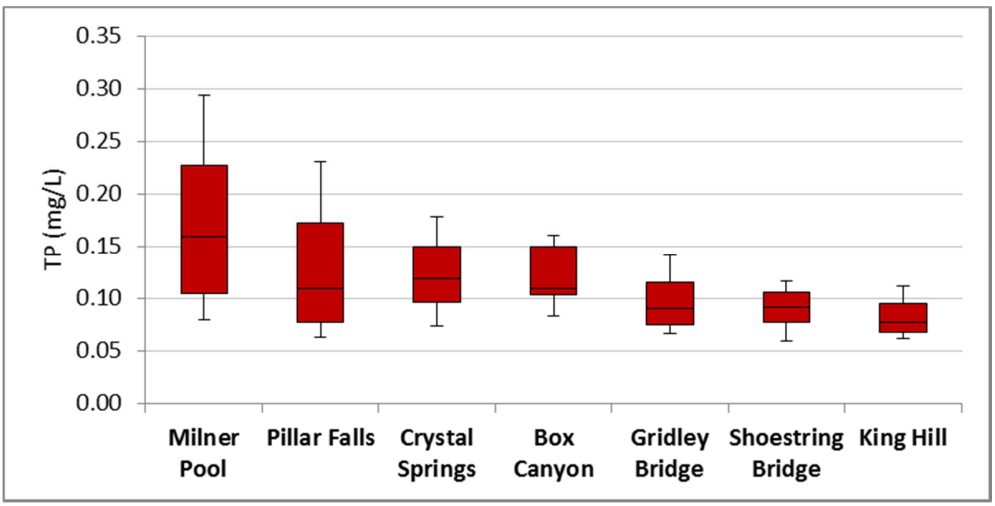

Figure 82. Winter TP concentration along mainstem for water years 2000–2009.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

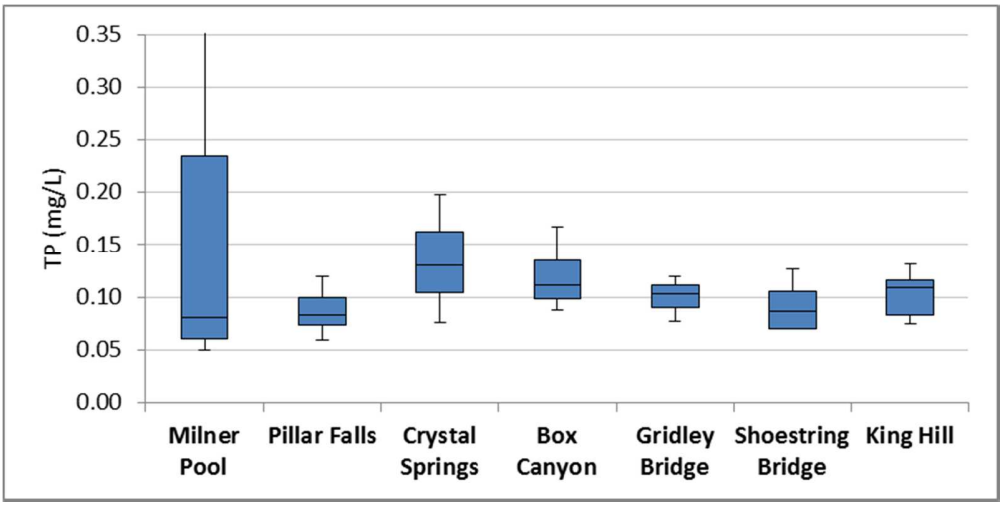

Figure 83. Spring TP concentration along mainstem for water years 1990–1999.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

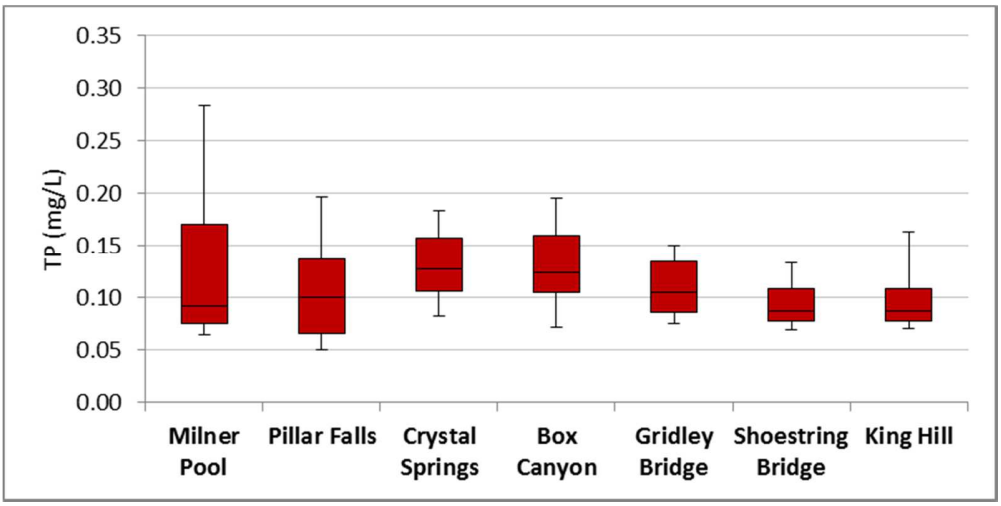

Figure 84. Spring TP concentration along mainstem for water years 2000–2009.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

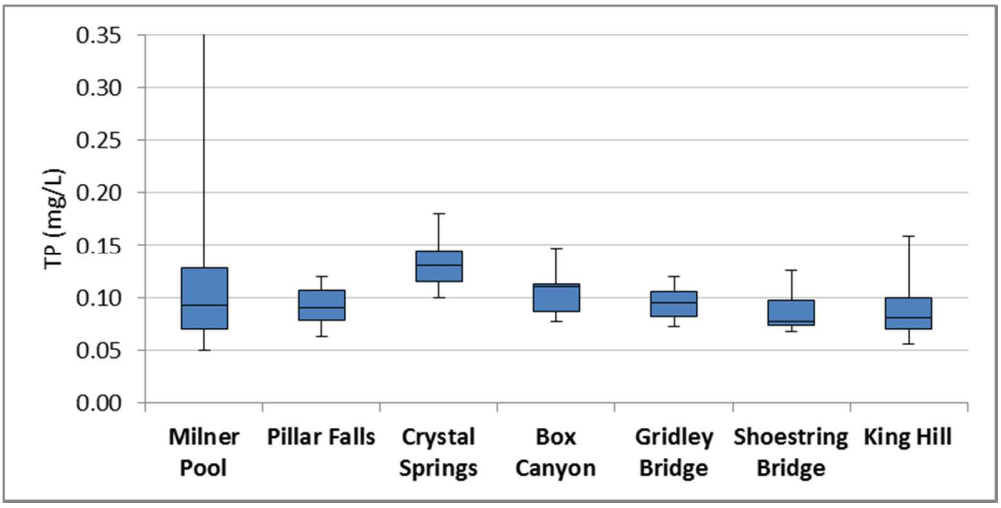

Figure 85. Summer TP concentration along mainstem for water years 1990–1999.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

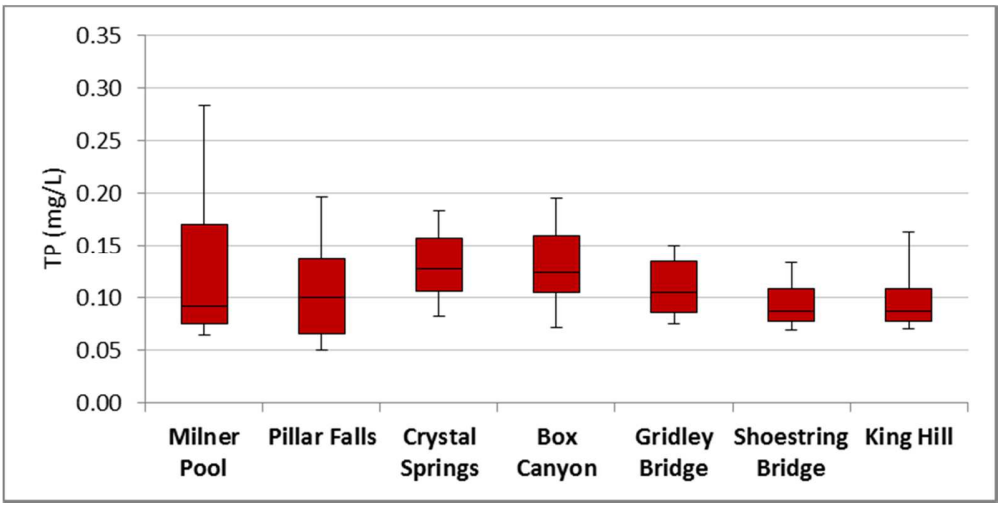

Figure 86. Summer TP concentration along mainstem for water years 2000–2009.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

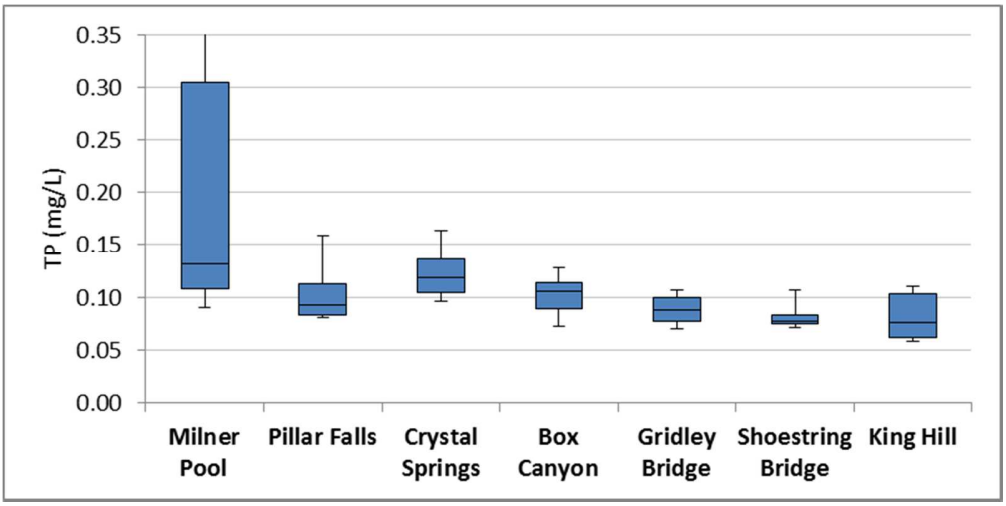

Figure 87. Fall TP concentration along mainstem for water years 1990–1999.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

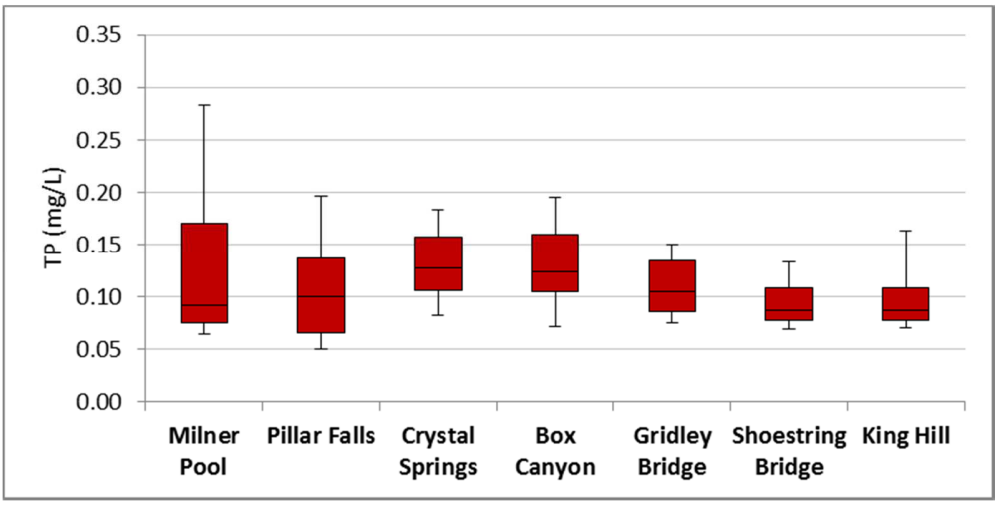

Figure 88. Fall TP concentration along mainstem for water years 2000–2009.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

Appendix E. Water Quality—Seasonal and Decadal Assessment

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Seasonal definitions for Appendix D figures:

- Winter – December 1 to February 28
- Spring – March 1 to May 31
- Summer – June 1 to August 31
- Fall – September 1 to November 30

Decadal definitions for Appendix D figures:

- 1990s – Water years 1990 to 1999
- 2000s – Water years 2000 to 2009

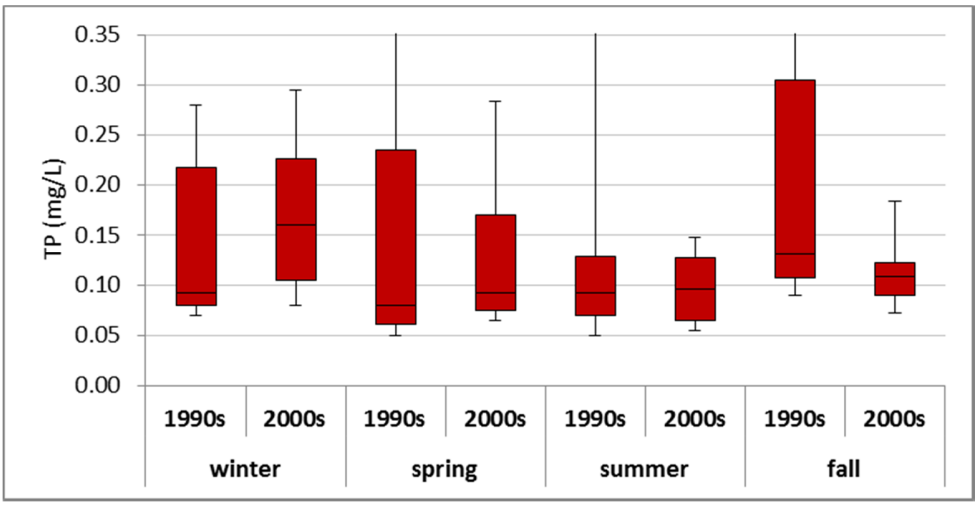

Figure 89. Milner Pool decadal TP concentration comparison between seasons.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

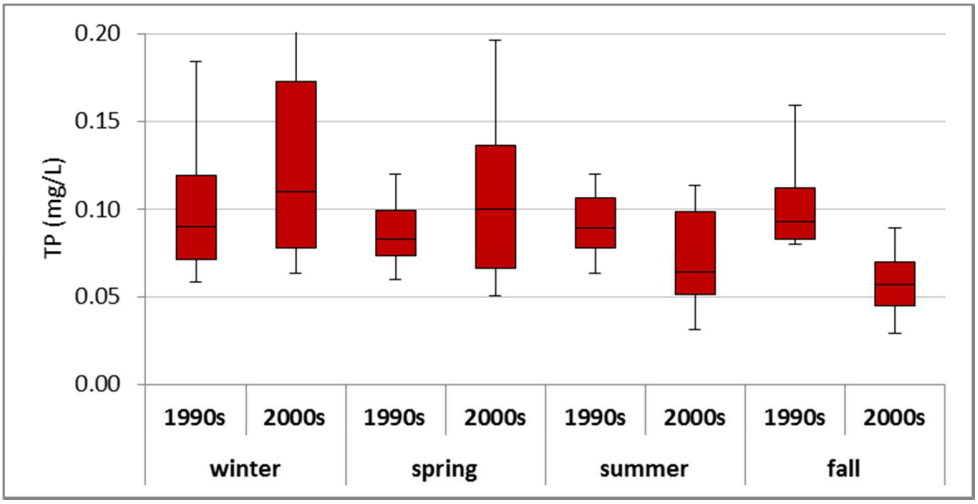

Figure 90. Pillar Falls decadal TP concentration comparison between seasons.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

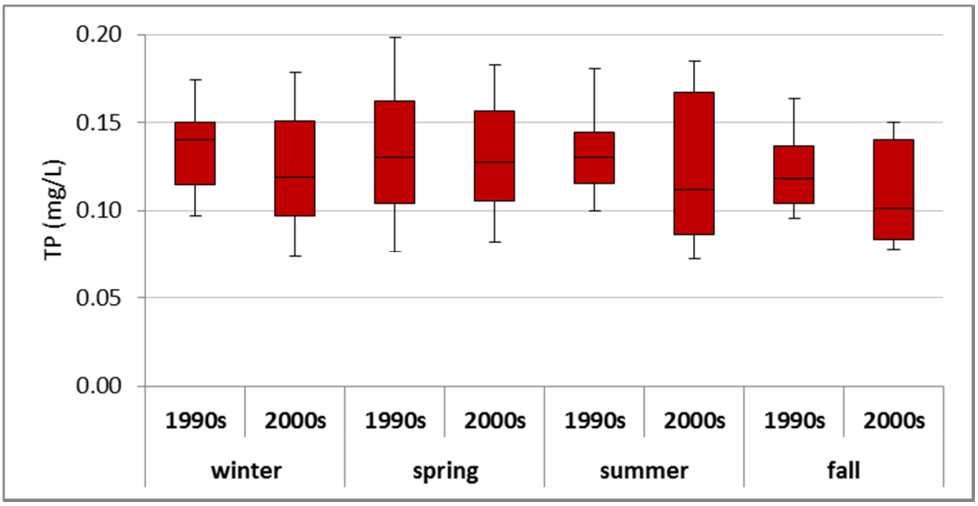

Figure 91. Crystal Springs decadal TP concentration comparison between seasons.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

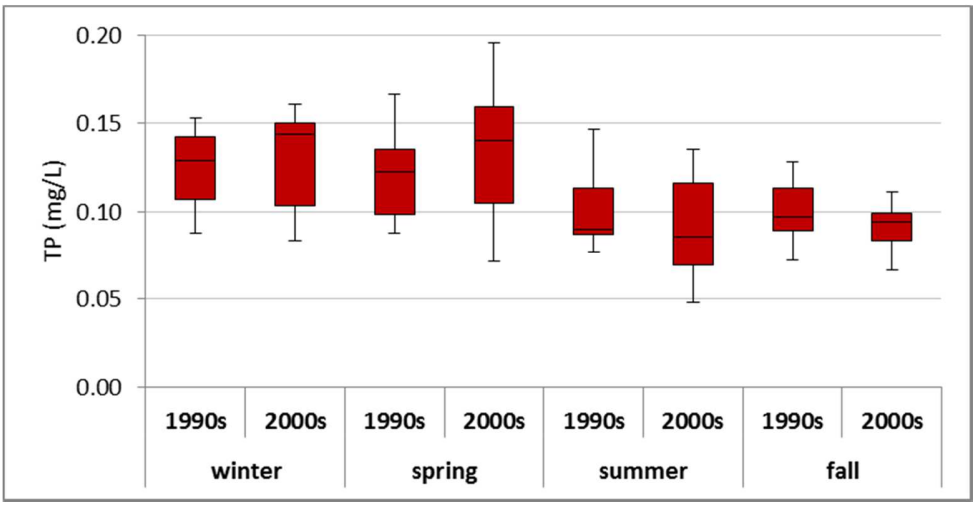

Figure 92. Box Canyon decadal TP concentration comparison between seasons.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

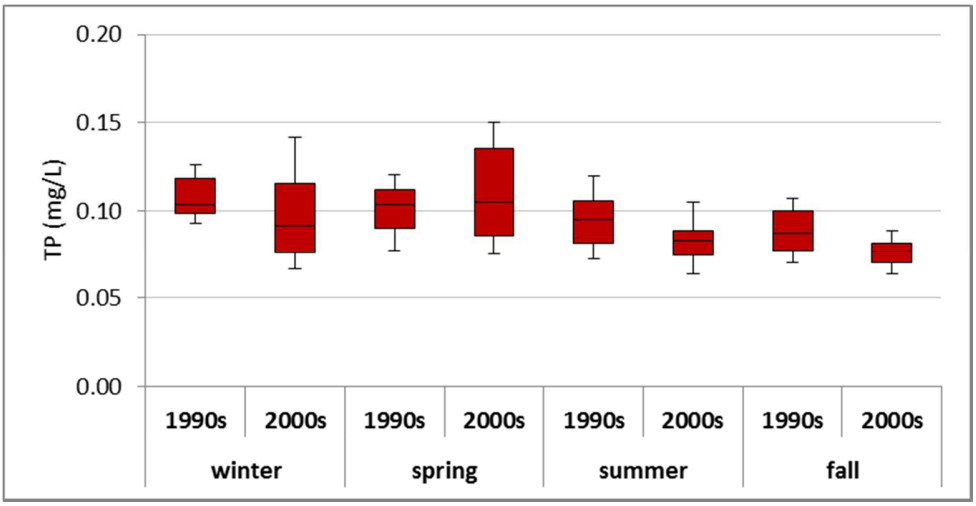

Figure 93. Gridley Bridge decadal TP concentration comparison between seasons.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

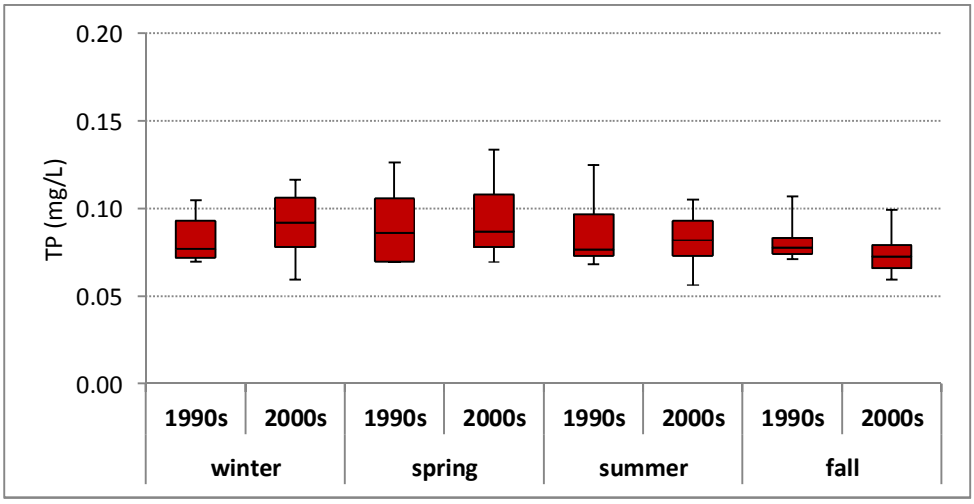

Figure 94. Shoestring Bridge decadal TP concentration comparison between seasons.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

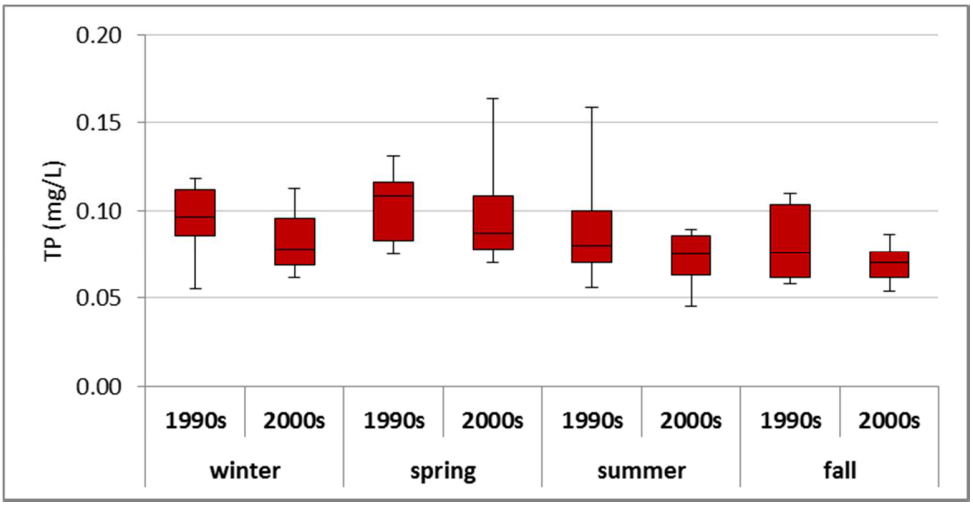

Figure 95. King Hill Bridge decadal TP concentration comparison between seasons.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

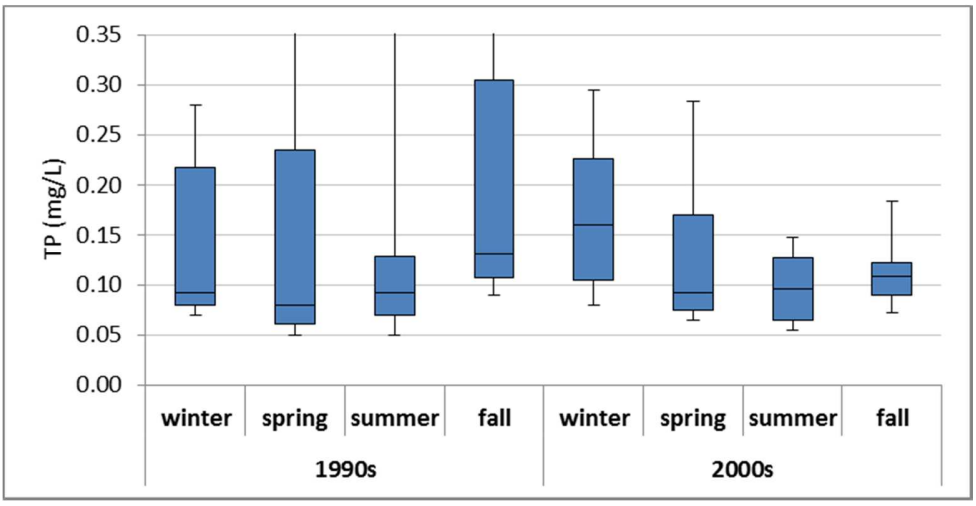

Figure 96. Milner Pool seasonal TP concentration comparison between 1990s and 2000s.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

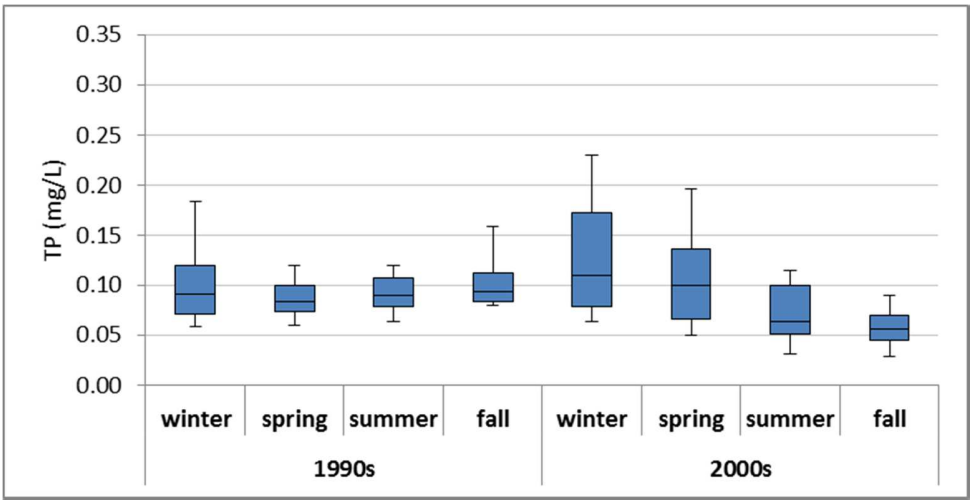

Figure 97. Pillar Falls seasonal TP concentration comparison between 1990s and 2000s.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

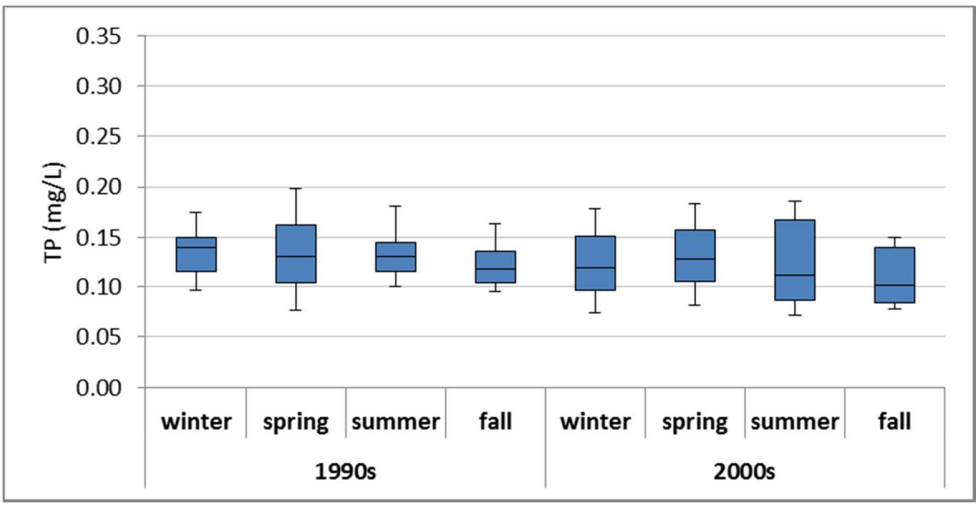

Figure 98. Crystal Springs seasonal TP concentration comparison between 1990s and 2000s.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

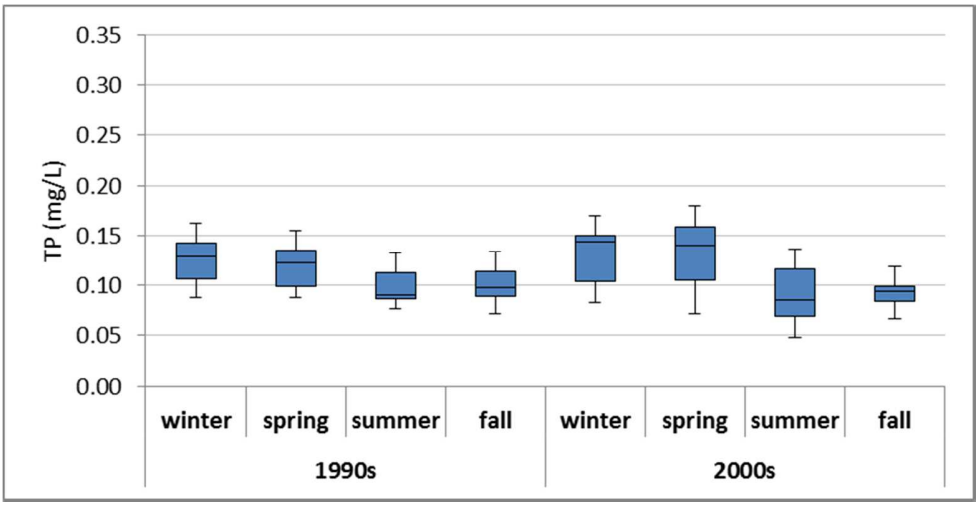

Figure 99. Box Canyon seasonal TP concentration comparison between 1990s and 2000s.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

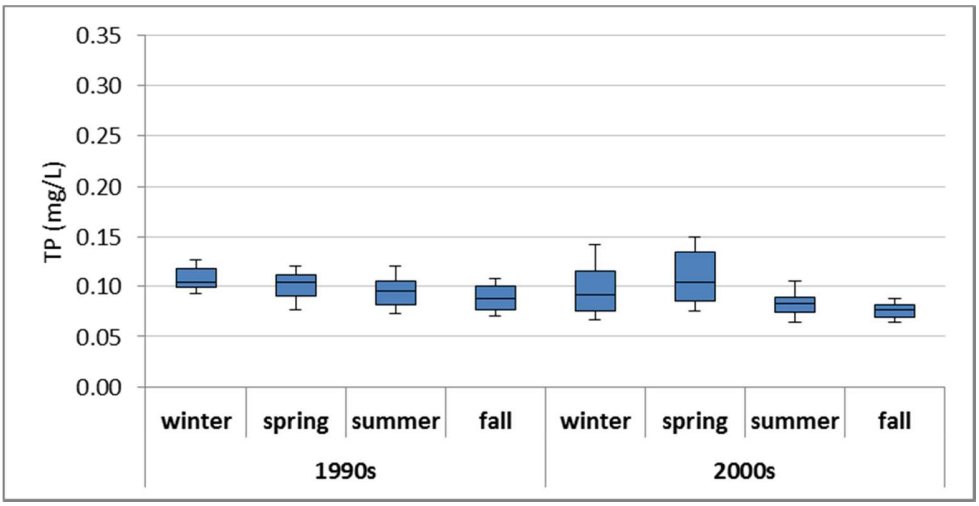

Figure 100. Gridley Bridge seasonal TP concentration comparison between 1990s and 2000s.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

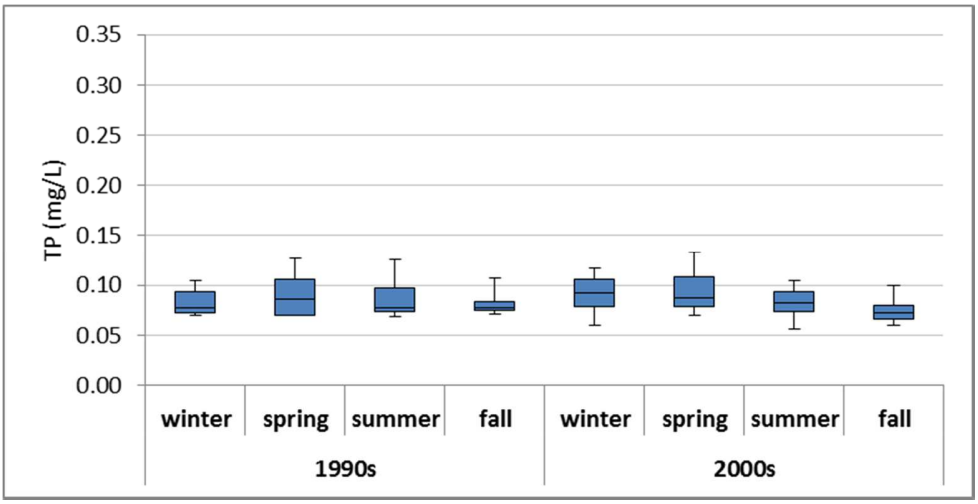

Figure 101. Shoestring Bridge seasonal TP concentration comparison between 1990s and 2000s.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

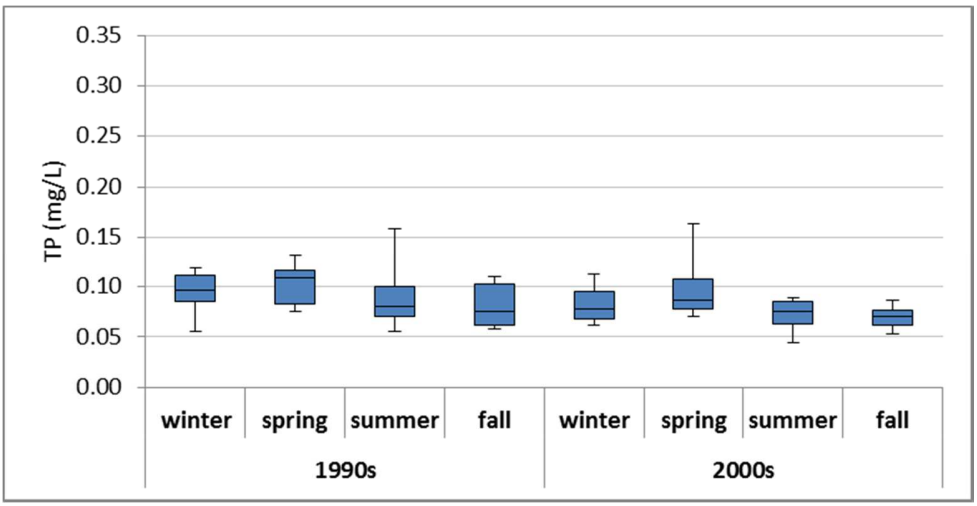

Figure 102. King Hill Bridge seasonal TP concentration comparison between 1990s and 2000s.
(Boxes represent 25th, 50th, and 75th percentiles; whiskers represent 10th and 90th percentiles.)

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Appendix F. Water Quality—Summary Statistics

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Table 26. Water Quality Summary Statistics for the Mainstem of the Middle Snake River (WY 1990-2010)

	DEQ and USGS														Idaho Power		TFCC[4]	NSCC[4]
	Milner Pool		Pillar Falls		Crystal Springs		Box Canyon		Gridley Bridge		Shoestring Bridge		King Hill		King Hill		Milner Dam	Milner Dam
	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	>2000	>2000
TP (mg/L)																		
N	252	131	95	126	218	125	89	125	122	126	152	125	181	244	99	305	517	10
Min	0.03	0.03	0.05	0.01	0.05	0.05	0.03	0.04	0.06	0.04	0.06	0.03	0.02	0.01	0.05	0.05	0.02	0.04
Mean	0.15	0.13	0.10	0.10	0.14	0.12	0.11	0.11	0.10	0.09	0.09	0.09	0.09	0.08	0.10	0.09	0.11	0.08
Max	0.90	0.41	0.26	0.91	0.29	0.58	0.20	0.23	0.21	0.24	0.26	0.62	0.34	0.41	0.36	0.25	0.44	0.12
Median	0.09	0.11	0.09	0.07	0.14	0.11	0.11	0.10	0.10	0.09	0.08	0.08	0.08	0.07	0.09	0.08	0.09	0.09
DOP (mg/L)																		
N	198	119	95	123	218	124	89	125	122	125	152	125	70	125	98	305	518	10
Min	0.003	0.003	0.003	0.003	0.005	0.010	0.007	0.005	0.006	0.003	0.009	0.003	0.008	0.003	0.003	0.003	0.002	0.010
Mean	0.061	0.062	0.032	0.037	0.079	0.065	0.046	0.055	0.044	0.045	0.026	0.037	0.044	0.034	0.041	0.045	0.044	0.039
Max	0.420	0.363	0.103	0.183	0.290	0.430	0.113	0.172	0.110	0.120	0.067	0.113	0.108	0.135	0.160	0.096	0.419	0.070
Median	0.038	0.042	0.024	0.019	0.080	0.054	0.040	0.052	0.038	0.044	0.024	0.034	0.036	0.030	0.040	0.045	0.022	0.035
TSS (mg/L)																		
N	244	131	95	128	218	125	89	125	122	126	152	125	186	246	38	184	518	10
Min	0.50	0.50	0.50	0.50	0.50	0.10	0.50	0.50	0.50	0.50	0.10	0.50	1.00	0.25	0.50	2.30	2.00	6.00
Mean	18.82	10.93	15.52	10.66	25.92	9.83	19.71	7.94	18.91	7.94	19.41	8.49	27.62	11.02	13.16	17.28	15.80	11.50
Max	274.00	35.00	50.00	79.00	442.20	56.00	97.00	54.00	109.00	160.20	156.00	32.00	319.00	73.00	45.00	116.50	68.00	17.00
Median	17.00	10.00	12.00	8.54	13.00	8.00	12.00	6.40	12.45	4.80	10.35	7.80	16.00	8.00	10.83	16.00	15.00	11.00
DO (mg/L)																		
N	251	128	95	123	218	123	89	122	122	123	152	124	184	238	199	299	512	
Min	6.56	3.20	7.44	6.60	6.15	5.80	7.11	3.22	6.37	3.16	6.19	6.80	5.44	5.90	7.90	7.57	7.00	
Mean	10.53	10.01	10.18	9.96	9.79	10.37	9.89	9.57	9.46	9.24	10.33	9.84	10.08	9.80	10.05	10.24	10.23	
Max	17.00	20.00	14.38	13.81	14.75	14.70	12.67	14.35	13.39	12.75	14.81	12.35	13.40	15.70	14.00	13.84	19.70	
Median	10.48	9.74	9.86	9.80	9.70	10.50	9.60	9.59	9.08	9.26	10.49	9.79	10.10	9.77	10.09	10.25	9.80	
pH																		
N	252	128	95	124	218	125	89	125	122	125	152	126	181	241	199	290	519	
Min	6.90	7.20	7.58	7.04	7.30	7.60	7.84	7.14	7.00	7.17	7.80	7.65	6.80	7.20	7.46	5.98	7.30	
Mean	8.57	8.52	8.38	8.47	8.35	8.40	8.27	8.34	8.15	8.25	8.17	8.39	8.30	8.37	8.26	8.23	8.62	
Max	9.40	10.40	8.93	10.38	8.95	10.21	8.81	10.17	8.79	10.27	8.60	10.29	9.10	10.30	9.19	9.73	10.00	
Median	8.60	8.55	8.40	8.41	8.37	8.37	8.28	8.32	8.16	8.22	8.15	8.35	8.30	8.36	8.26	8.27	8.70	
Temp. (℃)																		
N	310	129	95	123	218	124	89	124	122	124	152	124	186	239	202	300	518	
Min	-1.00	-2.14	1.16	-1.20	1.47	1.68	2.88	1.68	1.56	2.05	2.04	1.98	0.90	1.36	3.18	5.73	0.40	
Mean	11.12	11.10	12.01	11.69	13.95	12.53	12.93	12.86	12.81	12.80	12.02	12.83	12.89	12.99	13.66	13.79	12.61	
Max	24.20	24.40	22.02	24.20	23.90	24.00	19.85	21.00	21.00	23.00	20.24	21.00	22.00	22.00	20.53	21.82	28.90	
Median	11.10	10.88	11.27	11.70	14.47	12.10	12.91	12.30	13.17	12.27	10.64	12.55	13.15	12.90	13.63	13.37	12.60	

	DEQ and USGS														Idaho Power		TFCC[4]	NSCC[4]
	Milner Pool		Pillar Falls		Crystal Springs		Box Canyon		Gridley Bridge		Shoestring Bridge		King Hill		King Hill		Milner Dam	Milner Dam
	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	>2000	>2000
Turbidity (NTU)[1]																		
N	119	106	95	115	152	112	89	114	122	116	152	116	103	116	185	238	522	
Min	1.70	1.70	0.10	1.70	0.10	1.17	0.10	0.70	0.10	0.80	1.50	1.40	0.30	1.00	0.90	1.50	2.00	
Mean	10.44	12.90	10.88	10.05	13.42	12.80	13.67	10.56	14.15	13.00	11.21	9.98	10.60	10.03	13.28	7.40	7.94	
Max	40.10	208.90	30.80	76.10	41.20	240.00	69.40	158.30	62.50	454.40	71.20	68.20	88.00	88.30	133.00	58.10	26.00	
Median	9.20	8.29	9.30	7.70	12.00	6.20	10.00	6.36	12.15	5.55	6.60	5.65	4.30	5.60	9.40	6.40	7.00	
TN (mg/L)																		
N	201	119	95	124	218	124	89	125	122	125	152	125	142	152	99	305	518	
Min	0.02	0.22	0.45	0.43	0.51	0.80	0.84	0.98	0.87	1.12	0.88	0.92	0.54	0.90	0.78	1.00	0.36	
Mean	0.80	1.24	1.24	2.10	2.02	2.54	1.92	2.71	1.74	2.31	1.38	2.10	1.48	1.98	1.53	1.84	0.91	
Max	2.40	4.13	3.30	4.74	4.02	4.57	4.88	5.34	3.49	5.41	2.00	5.50	3.62	4.40	2.51	3.14	5.14	
Median	0.70	1.06	1.05	2.03	2.12	2.55	1.69	2.63	1.78	2.23	1.39	2.04	1.41	1.91	1.52	1.85	0.75	
TKN (mg/L)																		
N	201	119	95	124	218	124	89	125	122	125	152	125	142	152	99	305	518	
Min	0.01	0.20	0.23	0.18	0.05	0.10	0.18	0.07	0.20	0.13	0.19	0.05	0.04	0.05	0.05	0.05	0.26	
Mean	0.47	0.71	0.49	0.65	0.43	0.58	0.47	0.53	0.45	0.50	0.39	0.47	0.26	0.40	0.44	0.45	0.58	
Max	1.88	1.91	1.19	1.90	1.34	1.80	1.04	1.60	1.09	2.71	0.75	2.68	1.47	2.28	1.10	1.33	1.44	
Median	0.37	0.60	0.46	0.58	0.41	0.55	0.44	0.47	0.43	0.40	0.36	0.38	0.18	0.35	0.42	0.42	0.54	
NO3 + NO2 (mg/L)[2]																		
N	252	131	95	124	218	124	89	125	122	125	152	125	181	245	99	305	518	
Min	0.01	0.01	0.04	0.05	0.17	0.38	0.35	0.55	0.38	0.58	0.32	0.59	0.44	0.06	0.43	0.51	0.01	
Mean	0.35	0.49	0.74	1.44	1.59	1.97	1.45	2.17	1.29	1.81	0.99	1.64	1.23	1.48	1.09	1.38	0.33	
Max	2.06	3.67	2.55	4.02	3.15	3.89	4.04	5.03	2.82	3.75	1.69	3.38	3.19	3.92	1.85	2.56	4.76	
Median	0.16	0.26	0.64	1.32	1.69	1.97	1.32	2.10	1.29	1.75	1.03	1.60	1.22	1.44	1.18	1.40	0.12	
NH3 (mg/L)																		
N	252	131	95	124	218	124	89	125	122	125	152	125	182	245	99	305	518	
Min	0.0003	0.0025	0.0030	0.0025	0.0060	0.0025	0.0120	0.0190	0.0110	0.0025	0.0100	0.0025	0.0030	0.0025	0.0050	0.0050	0.0050	
Mean	0.0266	0.0833	0.0391	0.0662	0.0875	0.0916	0.0772	0.0968	0.0616	0.0769	0.0299	0.0580	0.0412	0.0375	0.0387	0.0274	0.0383	
Max	0.3000	0.7330	0.2480	0.4650	0.3733	0.5530	0.3695	0.5710	0.2710	0.4650	0.1054	0.4500	0.1590	0.4700	0.1500	0.2400	0.2700	
Median	0.0200	0.0500	0.0222	0.0500	0.0700	0.0655	0.0610	0.0800	0.0510	0.0600	0.0260	0.0500	0.0310	0.0200	0.0250	0.0200	0.0300	
Chlorophyll-*a* (micrograms per liter [µg/L])[3]																		
N	106	117	21	123	21	124	21	124	25	125	9	124	21	124	120	289	471	
Min	2.10	2.20	8.52	1.68	2.13	0.88	3.02	1.25	0.49	0.02	2.14	0.53	2.48	0.91	0.50	1.13	0.50	
Mean	24.84	25.34	19.84	21.91	11.76	13.83	9.90	11.26	13.14	10.32	8.19	13.40	11.39	14.42	10.53	20.33	33.72	
Max	114.00	168.00	60.29	74.00	32.35	70.00	30.94	65.00	38.74	61.00	21.74	98.00	38.25	98.00	133.20	148.88	142.00	
Median	18.35	17.00	14.73	17.00	11.04	10.05	7.50	7.30	10.68	6.60	4.06	8.20	6.93	8.44	6.65	15.20	25.00	
Pheophytin (µg/L)																		
N		115	21	121	21	123	21	123	25	124	9	123	21	123				
Min		0.26	0.41	0.23	1.22	0.02	0.78	0.06	0.12	0.02	0.48	0.02	0.96	0.03				

	DEQ and USGS														Idaho Power		TFCC[4]	NSCC[4]
	Milner Pool		Pillar Falls		Crystal Springs		Box Canyon		Gridley Bridge		Shoestring Bridge		King Hill		King Hill		Milner Dam	Milner Dam
	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	<2000	>2000	>2000	>2000
Mean		7.91	4.00	6.14	4.44	4.15	3.57	3.24	2.16	2.43	2.03	3.09	4.45	4.13				
Max		56.55	9.88	45.90	10.24	30.00	11.83	18.23	5.66	12.00	5.96	19.76	12.35	18.00				
Median		4.40	4.20	3.80	4.13	2.50	2.76	2.47	2.07	1.70	1.31	2.40	4.03	3.15				
TP, filtered (mg/L)																		
N	2												91	27				
Min	0.01												0.01	0.01				
Mean	0.02												0.05	0.04				
Max	0.03												0.59	0.07				
Median	0.02												0.04	0.05				
Ortho-P, unfiltered (mg/L)																		
N	13												12					
Min	0.02												0.03					
Mean	0.16												0.06					
Max	0.31												0.13					
Median	0.12												0.06					

[1] Field turbidity measurements were used for summary.

[2] NO3 + NO2 for Idaho Power is reported as NO3 only.

[3] Chlorophyll *a* data from varying sources may reflect different lab analysis methods.

[4] TFCC = Twin Falls Canal Co.; NSCC = North Side Canal Co.

Note: blank cells indicate no data available.

Table 27. Comparison of Total Phosphorus (Mean and Sample Size) for Each Tributary with Available DEQ or USGS Data

Stream or Spring	Agency	WY 1990–1999		WY 2000–2012	
		Mean	Count	Mean	Count
5th Fork Rock Creek: headwaters to Rock Creek	DEQ	-	-	0.04	4
Alpheus Creek: headwaters to mouth	DEQ	-	-	0.02	3
Bickle Springs: headwaters to mouth	DEQ	-	-	0.02	4
Billingsley Creek: headwaters to mouth	DEQ	-	-	0.07	5
Blind Canyon Creek (Cedar Draw Creek): headwaters to mouth	DEQ	-	-	0.82	3
Blind Canyon Spring near Buhl, ID 08S 14E 28BDD1S (13095400)	USGS	-	-	0.16	3
Blue Lakes Spring Bel Pump Plant near Twin Falls, ID (13090999)	USGS	0.03	6	0.01	17
Box Canyon Creek: headwaters to mouth	DEQ	-	-	0.02	5
Box Canyon Springs near Wendell, ID	USGS	0.01	35.00	0.015	18
Briggs Creek: headwaters to mouth	DEQ	-	-	0.03	5
Briggs Spring at Head near Buhl, ID	USGS	0.01	7.00	0.02	2
Cedar Draw: headwaters to mouth	DEQ	-	-	0.15	9
Cedar Draw at Clover Road (3900 N.) Near Filer, ID	USGS	-	-	0.1355	2
Clear Springs: headwaters to mouth	DEQ	-	-	0.12	6
Clover Creek: headwaters to Pioneer Reservoir	DEQ	-	-	0.08	8
Clover Creek: Pioneer Reservoir to mouth	DEQ	-	-	0.02	2
Clover Creek near King Hill, ID	USGS	-	-	0.01	2
Cottonwood Creek: headwaters to mouth (at Foothill Road)	DEQ	-	-	0.13	1
North Cottonwood Creek near Rogerson, ID	USGS	-	-	0.09	2
Crystal Springs: headwaters to mouth	DEQ	-	-	0.03	6
Devils Washbowl Spring near Kimberly 10S 18E 04AAD1S	USGS	-	-	0.02	2
Deep Creek: headwaters to mouth	DEQ	-	-	0.22	5
Dry Creek: headwaters to Murtaugh Lake	DEQ	-	-	0.14	3
Ellison Creek	DEQ	-	-	0.03	5
Malad River	DEQ	-	-	0.03	4

Stream or Spring	Agency	WY 1990–1999		WY 2000–2012	
		Mean	Count	Mean	Count
McMullen Creek	DEQ	-	-	0.14	3
Mud Creek	DEQ	-	-	0.14	5
Niagara Springs	DEQ	-	-	0.02	6
Pioneer Reservoir	DEQ	-	-	0.16	4
Riley Creek	DEQ	-	-	0.04	5
Riley Lake	DEQ	-	-	0.02	4
Rock Creek: headwaters to Rock Creek Town	DEQ	-	-	0.03	45
Rock Creek: Rock Creek Town to mouth	DEQ	-	-	0.08	161
Rock Creek at Highway 30/93 crossing at Twin Falls, ID	USGS	0.09	86	0.10	111
Rock Creek at USFS Footbridge near Rock Creek, ID	USGS	-	-	0.03	2
Salmon Falls Creek: headwaters to mouth	DEQ	-	-	0.09	5
Sand Springs: headwaters to mouth	DEQ	-	-	0.04	5
Thousand Springs (Ritter Springs): headwaters to mouth	DEQ	-	-	0.02	5
Tool Box Creek: headwaters to 5th Fork Rock Creek	DEQ	-	-	0.05	2
Vinyard Creek: headwaters to mouth	DEQ	-	-	0.03	6

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Appendix G. Point Source Dischargers

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Table 28. Point Source Dischargers' Existing TP Load and Wasteload Allocations (WLA)

NPDES ID	GAP	Facility Name	WLA: Annual Average TP Load (lb/day)	Minimum: Annual Average TP Load (lb/day)[1]	Average: Annual Average TP Load (lb/day)[1]	Maximum: Annual Average TP Load (lb/day)[1]	Count of Records	Year Range
ID0020061		FILER, CITY OF - FILER WWTP	17	3.8	4.7	7.3	26	2003 - 2011
ID0020168		JEROME, CITY OF - JEROME WWTP	205	151.3	190.6	247.6	83	2005 - 2011
ID0020664		BUHL, CITY OF - BUHL WWTP	17.4	6.0	18.1	22.3	116	2001 - 2012
ID0021270		TWIN FALLS, CITY OF - TWIN FALLS WWTP	710	363.0	499.3	627.5	120	2001 - 2012
ID0022446		HANSEN, CITY OF	3.3	1.3	1.6	1.9	51	2007 - 2012
ID0025941		HAGERMAN, CITY OF	5.7	2.5	3.4	4.9	17	2007 - 2011
ID0027600[1]		JEROME CHEESE COMPANY	0.04	0.0	0.8	1.5	101	2003 - 2011
IDG130001	1	IDAHO SPRINGS	36.9	0.7	3.4	6.4	59	2002 - 2007
IDG130002	2	SNAKE RIVER FARM	49	37.4	39.7	42.0	120	2001 - 2011
IDG130003	3	IDAHO DEPARTMENT OF FISH AND GAME - HAGERMAN STATE FISH HATCHERY	17.2	4.9	8.5	11.5	84	2001 - 2011
IDG130004	4	U.S. FISH AND WILDLIFE SERVICE - HAGERMAN NATIONAL FISH HATCHERY	12.2	2.7	5.2	7.1	87	2001 - 2011
IDG130005	5	JONES FISH HATCHERY	18.3	11.0	13.5	16.3	118	2001 - 2011
IDG130006	6	CLEAR SPRINGS FOODS INC - CRYSTAL SPRINGS TROUT FARM	87	66.9	85.1	130.7	120	2001 - 2011
IDG130007	7	CLEAR SPRINGS FOODS INC - CLEAR LAKE FARM	74.5	59.8	63.9	73.3	120	2001 - 2011
IDG130008	8	BLUE LAKES TROUT COMPANY	69.2	14.2	38.3	49.7	118	2001 - 2011
IDG130009	9	SEAPAC OF IDAHO INC - MAGIC SPRINGS HATCHERY	50.1	20.0	27.5	32.7	120	2001 - 2011
IDG130010	10	RIM VIEW TROUT COMPANY - WENDELL HATCHERY	66.3	31.8	40.7	54.6	121	2001 - 2011
IDG130011	11	CLEAR LAKES TROUT FARM	70.9	28.1	42.0	61.4	120	2001 - 2011
IDG130013	13	IDAHO DEPARTMENT OF FISH AND GAME - NIAGARA SPRINGS FISH HATCHERY	14.4	3.0	7.4	10.4	82	2001 - 2011

NPDES ID	GAP	Facility Name	WLA: Annual Average TP Load (lb/day)	Minimum: Annual Average TP Load (lb/day)[1]	Average: Annual Average TP Load (lb/day)[1]	Maximum: Annual Average TP Load (lb/day)[1]	Count of Records	Year Range
IDG130014	14	CLEAR SPRINGS FOODS INC	141	103.5	117.6	128.9	120	2001 - 2011
IDG130015	15	RANGEN INC	7.9	2.4	3.5	8.9	97	2001 - 2011
IDG130016	16	IDAHO DEPARTMENT OF FISH AND GAME - MAGIC VALLEY STEELHEAD HATCHERY	15.2	-26.2	-1.2	6.4	52	2002 - 2011
IDG130018	18	SEAPAC OF IDAHO INC - PRISTINE SPRINGS HATCHERY	26.8	1.8	18.6	50.4	120	2001 - 2011
IDG130020	20	WHITE SPRINGS TROUT FARM - HAGERMAN HATCHERY	13.5	3.5	6.1	9.8	120	2001 - 2011
IDG130026	26	WHITE WATER RANCH	4.3	1.9	2.8	3.3	15	2008 - 2011
IDG130028	28	IDAHO TROUT COMPANY - RAINBOW TROUT FARMS FILER HATCHERY	5.3	0.6	2.0	3.5	35	2002 - 2011
IDG130029	29	RAINBOW TROUT FARMS BUHL HATCHERY	3.8	0.4	1.5	3.3	34	2002 - 2011
IDG130036	36	CANYON TROUT FARM	4.7	-0.3	0.1	0.4	6	2008 - 2010
IDG130040	40	TUNNEL CREEK	3.3	0.6	1.8	3.0	42	2003 - 2011
IDG130041	41	FISH BREEDERS OF IDAHO INC - CATFISH FARM	16.3	7.1	8.5	11.0	45	2008 - 2011
IDG130046	46	SEAPAC OF IDAHO	3.7	-11.3	-2.1	1.9	16	2008 - 2011
IDG130049	49	BELL FISH PONDS	1.2	0.0	0.4	0.8	8	2004 - 2011
IDG130053	53	JACK'S PONDS	6.7	-1.7	1.8	12.3	19	2002 - 2011
IDG130054	54	CLEAR SPRINGS FOODS INC	29.5	6.5	22.8	27.5	94	2003 - 2011
IDG130056	56	FISH BREEDERS OF IDAHO - BIG BEND TROUT FARM	12.1	1.4	4.4	6.8	25	2004 - 2011
IDG130057	57	BOSWELL TROUT FARMS - COX'S PONDS	6.6	-3.1	0.7	2.9	19	2002 - 2011
IDG130059	59	ARK FISHERIES INC - OLSON PONDS	1.2	0.3	0.9	2.9	25	2001 - 2011
IDG130060	60	BLIND CANYON HATCHERY	3.8	-1.1	2.3	4.6	16	2008 - 2011
IDG130061	61	TEN SPRINGS HATCHERY	13.8	6.1	9.0	11.5	106	2002 - 2011
IDG130062	62	ARK FISHERIES INC - BIRCH CREEK	4.3	1.3	1.5	1.7	16	2008 - 2011
IDG130063	63	WHITE'S HATCHERY	1.6	0.2	0.5	0.8	15	2001 - 2011
IDG130064	64	SWEETWATER FARM	4.8	-1.5	0.5	1.8	8	2001 - 2011

NPDES ID	GAP	Facility Name	WLA: Annual Average TP Load (lb/day)	Minimum: Annual Average TP Load (lb/day)[1]	Average: Annual Average TP Load (lb/day)[1]	Maximum: Annual Average TP Load (lb/day)[1]	Count of Records	Year Range
IDG130065	65	ARK FISHERIES INC - BUCKEYE FARMS	7.5	0.0	2.6	14.5	23	2002 - 2011
IDG130066	66	BILLINGSLEY CREEK RANCH	2.3	1.0	1.6	2.2	18	2001 - 2007
IDG130069	69	DOLANA TROUT FARMS INC	1.8	0.7	1.4	2.0	8	2008 - 2011
IDG130070	70	ARK FISHERIES INC - JUKER FARM PONDS	1.3	0.4	0.8	1.3	25	2001 - 2011
IDG130076	76	LEMMON PONDS	1.9	0.3	1.0	1.7	21	2003 - 2011
IDG130077	77	DEEP CREEK PONDS	6.1	-2.0	-1.2	-0.1	7	2008 - 2010
IDG130082	82	BILLINGSLEY BAY FARMS	11	0.2	1.8	3.0	20	2004 - 2011
IDG130083	83	TALBOTT TROUT FARM	2.5	0.1	0.1	0.1	12	2005 - 2005
IDG130087	87	AWALT FAMILY REVOCABLE TRUST	2.9	0.0	0.5	1.4	9	2008 - 2011
IDG130090	90	FISH BREEDERS OF IDAHO - SMITH'S PONDS	7.7	2.9	5.4	14.2	30	2002 - 2011
IDG130096	96	BOYER PONDS	1.6	0.0	0.1	0.1	13	2004 - 2005
IDG130098	98	LYNCLIF FARMS	3.8	0.4	0.6	0.8	7	2008 - 2011
IDG130103	103	STUTZMAN FARM PONDS	0.6	0.2	0.4	0.7	14	2003 - 2011
IDG130104	104	CANYON SPRINGS	12.2	3.0	7.4	10.6	16	2008 - 2011
IDG130109	109	RCP - RICK AND CHERYL EGGLESTON	1.4	0.0	0.2	0.3	6	2007 - 2010
IDG130111	111	FISH BREEDERS OF IDAHO - HENSLEE HATCHERY	2.9	0.2	1.9	8.2	12	2004 - 2011
IDG130112	112	LIVELY, ROBIN AND TERRY - LIVELY FARM POND	1.7	0.7	2.2	4.1	4	2008 - 2011
IDG130116	116	FIRST ASCENT FISH FARM	7.2	2.6	3.5	4.8	17	2007 - 2011
IDG130118	118	WHITE WATER FISHERIES INC - SLANE POND	1.9	0.5	0.5	0.6	14	2008 - 2011
IDG130119	119	WHITE WATER FISHERIES INC	2.7	0.6	0.9	1.3	15	2008 - 2011
IDG130120	120	WHITE WATER FISHERIES INC	2.4	1.4	1.5	1.7	16	2008 - 2011
IDG130124	124	COLLEGE OF SOUTHERN IDAHO (CSI) FISH TECHNOLOGY PROGRAM - CSI FISH HATCHERY	2.2	0.2	1.0	1.7	26	2003 - 2011
IDG130131	131	TUPPER PONDS	0.3	0.2	0.4	0.6	6	2004 - 2007
IDG130133	133	BAKER PLACE	4.6	2.6	2.9	3.2	13	2008 - 2011

NPDES ID	GAP	Facility Name	WLA: Annual Average TP Load (lb/day)	Minimum: Annual Average TP Load (lb/day)[1]	Average: Annual Average TP Load (lb/day)[1]	Maximum: Annual Average TP Load (lb/day)[1]	Count of Records	Year Range
IDG132001[2]		CLEAR LAKES TROUT PROCESSING	3.3	0.4	0.5	0.7	44	2008 - 2011
IDG132002[2]		CLEAR SPRINGS FOODS INC - FISH PROCESSING PLANT	20.2	9.0	10.6	13.1	47	2008 - 2011
IDG132003[2]		RAINBOW TROUT FARMS INC	2.5	0.8	1.1	1.3	48	2007 - 2011
IDG132004[2]		SEAPAC OF IDAHO	4.7	1.2	1.5	2.1	46	2008 - 2011

[1] Negative existing load values indicate that the load discharged is less than the load entering the facility through the source water intake.

[2] Facility WLA was not included in USR TMDL Modification documents (DEQ 2004, 2005). The value reported for WLA in this table is the current permit limit for average TP load (in pounds per day).

Appendix H. Detailed Flow Balance Methods

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A flow balance was developed for the mainstem of the Middle Snake River using continuous discharge data from five USGS gage sites (Figure 48). The five mainstem USGS gages, listed from upstream to downstream, were Milner Dam (13088000), Kimberly (13090000), Buhl (13094000), Lower Salmon Falls near Hagerman (13135000), and King Hill (13154500). Annual average flow along the mainstem was calculated for each gage for WY 2000–2009 (Table 29). Mainstem flow between each of the five USGS gages was then calculated by subtracting the upstream gage annual average flow from the closest downstream gage annual average flow, starting with Milner Dam at the farthest upstream location. The result of this calculation is the "total inflow" for the reach length between each of the five USGS gages (Table 30); from this point forward these reach lengths will be referred to as USGS segments. The calculation used to determine total inflow for each "USGS segment" is provided in Equation 1; *i* and *j* in this equation represent two consecutive USGS gages.

Equation 1:

$$Downstream\ annual\ average\ flow_j - upstream\ annual\ average\ flow_i = USGS\ segment\ total\ inflow_{i\ to\ j}$$

Table 29. Annual Average Flow at USGS Gages, WY 2000–2009

USGS Gage	Annual Average Flow (cfs) at USGS Gage									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Milner Dam (13088000)	2,740	441	337	336	285	519	2,268	1,014	668	2,553
Kimberly (13090000)	3,061	761	617	613	552	771	2,484	1,323	942	2,764
Buhl (13094000)	4,665	2,148	2,016	1,953	1,860	2,053	3,947	2,726	2,308	4,309
Lower Salmon Falls near Hagerman (13135000)	8,101	5,586	5,299	5,169	5,079	5,225	7,186	5,832	5,481	7,498
King Hill (13154500)	9,992	7,332	6,899	6,646	6,520	6,759	9,379	7,462	7,082	9,045

Table 30. Total Inflow for USGS Segments by Water Year

USGS Segment	Total Inflow (cfs) between USGS Gages									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Milner Dam to Kimberly	322	320	280	276	266	252	216	309	274	210
Kimberly to Buhl	1,604	1,387	1,400	1,340	1,309	1,281	1,463	1,404	1,367	1,545
Buhl to Lower Salmon Falls near Hagerman	3,436	3,438	3,282	3,216	3,218	3,172	3,238	3,105	3,173	3,190
Lower Salmon Falls near Hagerman to King Hill	1,891	1,746	1,600	1,477	1,441	1,534	2,193	1,630	1,601	1,546

Average baseflow, defined as stream flow that is primarily from diffuse ground water inflow occurring within the same reach without surface expression as springs, was obtained from the DWR ESPAM efforts (Wylie 2012) and was used to determine baseflow contributions to each USGS segment. ESPAM provided baseflow values as averages from 1980 to 2008 or 2009, depending on the segment, for USGS segments between Kimberly and Buhl, Buhl and Lower Salmon Falls near Hagerman, and Lower Salmon Falls near Hagerman and King Hill USGS gages. Baseflow values were not provided for the USGS segment between Milner Dam and Kimberly USGS gages; therefore, these flows are considered unaccounted waters in the mass balance analysis described below.

Baseflow was incorporated into the flow balance as a percent of the average reach gain estimated for each reach from 1980 to 2008 or 2009, depending on the segment (Wylie 2012) (Table 31). These percentages were applied to the USGS segment total inflows to determine the baseflow contribution for each USGS segment (Table 32). Although a constant percentage was assumed for each USGS segment, the percent of reach gain from baseflow is not expected to be constant because baseflow is believed to occur at a lower elevation than spring discharge and is assumed to be less sensitive to changes in aquifer head. Baseflow is expected to become a slightly larger percentage of the total flow as reach gains decrease.

Table 31. Percent of Reach Gain from Baseflow (Wylie 2012)

USGS Segment	Average Reach Gain from 1980 to 2008(9) (cfs)[1]	Average Reach Baseflow from 1980 to 2008(9) (cfs)[1]	Percent of Reach Gain from Baseflow
Kimberly to Buhl	1,105	265	24.0%
Buhl to Lower Salmon Falls	3,370	907	26.9%
Lower Salmon Falls to King Hill	1,539	365	23.7%

[1] Average reach gain and reach baseflow values displayed here were taken from DWR ESPAM efforts (Wylie 2012).

Table 32. Example Calculations for WY 2000 Baseflow Contributions to USGS Segment Total Inflow

USGS Segment	WY 2000 USGS Segment Total Inflow (cfs)[1]	Percent of Reach Gain from Baseflow[2]	WY 2000 Baseflow Contribution (cfs)
Milner Dam to Kimberly	322	Not Provided	Unaccounted For
Kimberly to Buhl	1,604	24.0%	385
Buhl to Lower Salmon Falls near Hagerman	3,436	26.9%	924
Lower Salmon Falls near Hagerman to King Hill	1,891	23.7%	448

[1] Flow obtained from Table 30.
[2] Percentages from Table 31.

As an intermediate step in the flow balance, total mainstem inflow and baseflow contributions for each USGS segment were proportioned to the six study segments based on the percent of USGS segment length that was coincident with each study segment (Figure 48); Table 33 lists these percentages. An example calculation used to proportion flow from USGS segments to the Milner Dam to Pillar Falls study segment is provided in Equation 2.

Equation 2:

$$
\begin{aligned}
&(\%\ of\ USGS\ segment_{MD\ to\ K} * USGS\ segment\ total\ inflow_{MD\ to\ K}) \\
&\quad + (\%\ of\ USGS\ segment_{K\ to\ B} * USGS\ segment\ total\ inflow_{K\ to\ B}) \\
&\quad + (\%\ of\ USGS\ segment_{B\ to\ L} * USGS\ segment\ total\ inflow_{B\ to\ L}) \\
&\quad + (\%\ of\ USGS\ segment_{L\ to\ H} * USGS\ segment\ total\ inflow_{L\ to\ H}) \\
&\quad = Study\ segment\ total\ inflow_{MD\ to\ PF}
\end{aligned}
$$

where MD = Milner Dam, K = Kimberly, B = Buhl, L = Lower Salmon Falls near Hagerman, H = King Hill, and PF = Pillar Falls.

Table 34 presents the calculated total inflows for study segments. The calculation performed to determine baseflow contributions for each study segment was similar to Equation 2 except that USGS segment total inflow was replaced with USGS segment baseflow contribution.

Table 33. Percent of USGS Segments Coincident with Study Segments

USGS Segment	Percent of USGS Segment Coincident with Each Study Segment			
	USGS: Milner Dam to Kimberly	USGS: Kimberly to Buhl	USGS: Buhl to Lower Salmon Falls Near Hagerman	USGS: Lower Salmon Falls Near Hagerman to King Hill
Milner Dam to Pillar Falls	100%	20%	0%	0%
Pillar Falls to Crystal Springs	0%	63%	0%	0%
Crystal Springs to Box Canyon	0%	17%	36%	0%
Box Canyon to Gridley Bridge	0%	0%	23%	0%
Gridley Bridge to Shoestring Bridge	0%	0%	41%	25%
Shoestring Bridge to King Hill Bridge	0%	0%	0%	74%

Table 34. Total Inflow Calculated for Study Segments

USGS Segment	Total Inflow (cfs) for Study Segments									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Milner Dam to Pillar Falls	636	592	554	539	523	503	503	584	542	513
Pillar Falls to Crystal Springs	1,014	877	885	847	827	810	925	887	864	977
Crystal Springs to Box Canyon	1,504	1,467	1,413	1,380	1,375	1,354	1,409	1,351	1,369	1,405
Box Canyon to Gridley Bridge	785	785	750	735	735	725	740	709	725	729
Gridley Bridge to Shoestring Bridge	1,895	1,860	1,759	1,701	1,693	1,697	1,888	1,693	1,714	1,707
Shoestring Bridge to King Hill Bridge	1,393	1,287	1,180	1,088	1,062	1,131	1,616	1,201	1,180	1,140

The final step in the flow balance was to determine the remaining contributing sources of flow for each study segment. Because data availability was limited, this flow balance was calculated by subtracting known contributing sources from total inflow to determine unaccounted flow for each study segment. Equation 3 provides an example calculation of unaccounted flow for a single study segment.

Equation 3:

$$\begin{aligned} &study\ segment\ total\ inflow - (baseflow + tributary\ flow + spring\ flow \\ &\quad + irrigation\ return\ drain\ flow + direct\ point\ source\ flow) \\ &\quad = study\ segment\ unaccounted\ flow \end{aligned}$$

The results of the flow balance are provided in Table 22 in Section 7.

Appendix I. Supplemental Analysis

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I-1. Purpose

In the 1990s, concern over the extensive growth of nuisance aquatic plants (e.g., algal mats and macrophytes) in the Middle Snake River resulted in an effort by the Idaho Department of Environmental Quality (DEQ) to address the problem through the TMDL process. Water quality studies identified phosphorus as the limiting nutrient contributing to the excess nuisance aquatic plant growths, particularly in the Crystal Springs Reach, which was considered the hot bed for macrophytes and algal mats. This led to development of a Total Phosphorus (TP) TMDL for the Mid Snake/Upper Snake Rock Subbasin.

From 1997 through 2005, the following TMDL documentation, developed by DEQ and approved by EPA, established targets and load and wasteload allocations for achieving the targets:

- Middle Snake River Watershed Management Plan, 1997; revised 1998
- Upper Snake-Rock Watershed Management Plan, 1999
- Upper Snake-Rock TMDL Modification, 2005

The TMDL includes the following targets: (1) total phosphorus (TP) in-stream target of 0.075 mg/L at Gridley Bridge; (2) TP instream target of 0.1 mg/L in the tributaries; and (3) a 30 percent reduction (on average) of nuisance aquatic plant growth in the Crystal Springs Reach.

DEQ conducted a five-year review in 2010, which indicated that the TP targets had not been achieved in the mainstem and multiple tributaries during 2000 to 2008. The review illustrated that flows have been reduced in the most recent decade, suggesting that the ability of the TMDL to support beneficial uses should be reevaluated. Possible causes of reduced flows are water withdrawals, drought, and climatic patterns (DEQ 2010).

In light of the above circumstances, DEQ and EPA Region 10 initiated an assessment and evaluation of all readily available data to determine the need for a TMDL revision. As the first step, the Data Summary, Evaluation, and Assessment Report (Data Report) reviewed all relevant documents and existing data. EPA, DEQ, and Idaho Department of Water Resources (DWR) provided data, technical guidance, and review of this assessment report. This technical memorandum provides supplemental data analysis and literature review to augment the Data Report. Recently collected monitoring data, not available during the Data Report development, has been incorporated into this supplemental analysis.

A subset of monitoring locations was selected to test the utility of the supplemental analysis. The Milner Pool and King Hill locations were selected to represent conditions at the inflow and outflow points of the Middle Snake River. The locations of Pillar Falls and Buhl were selected because large datasets with few seasonal or annual gaps were available for these locations, and they represent conditions in the central portions of the River, with Buhl in proximity to Crystal Springs where TP concentrations average higher than other central locations. These initial locations provided a test for whether the supplemental analysis would provide meaningful results. The following analysis methods were selected to investigate trends in TP concentration and load:

- Trend analyses using data collected in 2000 through 2013 for the following mainstem locations: Milner, Pillar Falls, Buhl, and King Hill
- Development of LOADEST models for the following mainstem locations: Milner, Pillar Falls, Buhl, and King Hill
- Evaluation of the influence of City of Twin Falls effluent on theoretical downstream TP concentrations using available monitoring data and permit limits. This evaluation was completed because the Twin Falls WWTP TP discharge is the largest within the subbasin, and TP

concentrations at the next downstream monitoring point (Buhl), are higher than other downstream locations.

In addition to these analyses, the following document was reviewed and summarized, focusing on how TP is related to macrophyte growth in the Middle Snake River: Ecological Risk Assessment for the Middle Snake River, Idaho (EPA, 2002). The methods and results for each analysis are documented in this technical memorandum, followed by recommendations for including this information in a revised version of the Data Report.

I-2. Trend Analysis

Advanced statistical analyses were performed to determine if total phosphorus concentrations exhibit significant trends over time in the Middle Snake River mainstem. The Mann-Kendall test, Seasonal Kendall test, and Sen's nonparametric slope estimator were used to test for the presence of a statistically significant trend. Four locations on the mainstem were analyzed: Milner, Pillar Falls, Buhl, and King Hill. In the following sections, detailed methods are provided, and results are presented and discussed in terms of both significance and magnitude.

I-2.1 Statistical Methods

The Mann-Kendall test for trend (Mann, 1945; Kendall, 1975) forms the basis of the method that is likely the most frequently used for trend analyses performed on water quality monitoring data – the Seasonal Kendall Test. The method was developed and popularized by USGS researchers throughout the 1980s (Hirsch et al., 1991), and USGS published computer code supporting its use. In recent years, the USGS Kendall Program (Helsel et al., 2006) has been used to conduct these analyses.

Mann-Kendall is especially useful for detecting trends in environmental variables for several reasons:

- The test is nonparametric (that is, unlike many other tests, it does not depend on an assumption that the distribution of the data follows a specific form such as the normal distribution).
- Missing values are allowed.
- Data reported at the detection limit can be used without censoring, so long as the values are set lower than the smallest observation.

This is all possible because Mann-Kendall looks only at the relative magnitudes of sequential data, so the type of distribution, gaps, and the assumptions used for non-detects become irrelevant. The probability interpretation of the original Mann-Kendall test does, however, assume that the data are not serially correlated, an assumption frequently violated by environmental monitoring data. Serial correlation (also called autocorrelation) occurs when sequential data points are not independent from each other.

The Seasonal Kendall test is a generalization of the Mann-Kendall test, developed by Hirsch et al. (1982). In its original application, data were divided into 12 "seasons", with each month representing a season. The Mann-Kendall test statistic and its variance are calculated separately on each season. The statistics are summed and a Z statistic computed, which is compared to the standard normal distribution tables. The null hypothesis H_0 is there is no trend, while the alternative hypothesis H_A is that a trend versus time exists (either an upward or downward trend; thus a two-tailed test). The effect of serial correlation in the data can be addressed by a modification of the test statistic (Hirsch and Slack, 1984). The modification is recommended in cases where there are 10 or more observations per season (i.e., 10 years of data if seasons are defined monthly) due to difficulties in accurately determining the adjustment for shorter series of data.

An estimate of the trend slope can be calculated in conjunction with the Seasonal Kendall test. The slope is based on Sen's nonparametric slope estimator (Sen, 1968). The method estimates a series of slopes between values from the same season. The Seasonal Kendall slope is the median of this series of slopes.

The presence of flow effects on concentration may mask a trend, or exaggerate it; one cannot tell from a concentration time series whether an apparent trend is due solely to systematic differences in discharge over time (for instance, a series of wet years), or truly due to a real trend in the concentration. One method for reducing extraneous variance is called LOWESS, which stands for locally weighted scatterplot smoothing (Cleveland, 1979). A smoothing window with a user-defined width in terms of the fraction of total observations is passed over the data, one observation at a time. The smoothing function gives stronger weight to observations with less variance compared to the center point, while observations with greater variation have less weight. As a result, LOWESS is less sensitive to outliers and is preferable over parametric regression procedures for time series analysis. In the case of concentration and flow, LOWESS is performed on the relationship between the two (Hirsch et al., 1991). Once the variation due to flow is removed, trend analysis is conducted on the residuals. The choice of the width of the smoothing window (denoted as *f*) may be important; the goal is to select *f* to minimize variability of concentration related to flow, while still allowing any underlying trend to remain undistorted. Cleveland (1979) recommends using a value of 0.5 for *f* as a starting point, with variations in the range of 0.2 to 0.8 being reasonable.

It is important to note that trend tests are not a prediction of the future. Each test is valid for the time period it covers, but that does not necessarily mean the trend will continue. If a trend is present, it is possible that whatever process has caused the trend will not behave in the same manner going forward.

I-2.2 MONITORING DATA

TP monitoring data were obtained for several locations along the Middle Snake River mainstem. Periods of record and data sources are shown in Table 35. Time series plots are provided in Figure through Figure 107 for each location. The nearest USGS gage to Pillar Falls (near Twin Falls 13090500) had discharge data only from 7/15/2009. Discharge data from 10/1/2000 to 7/14/2009 were estimated at this location using maintenance of variance extension regression model (MOVE.1 LOC) and daily discharge data from an upstream gage at Kimberly (13090000). The USGS SREF 1.0 program was used to produce daily discharge estimates at Twin Falls using Kimberly data and the MOVE.1 LOC method.

Table 35. TP Monitoring Data Used for Trend Analyses

Location	Flow Gage	TP Data Source	TP Period of Record
Milner	13088000	University of Idaho (U of I)	Mar 2000 – Jul 2013
Pillar Falls	13090500 13090000	Dept. of Env. Quality (DEQ)	Oct 1999 – Sep 2009
Buhl	13094000	Clear Springs Foods (CSF)	Apr 2000 – Sep 2013
King Hill	13154500	Idaho Power Company (IPC)	Jan 2001 – Sep 2013
King Hill	13154500	USGS	Oct 2000 – Aug 2013

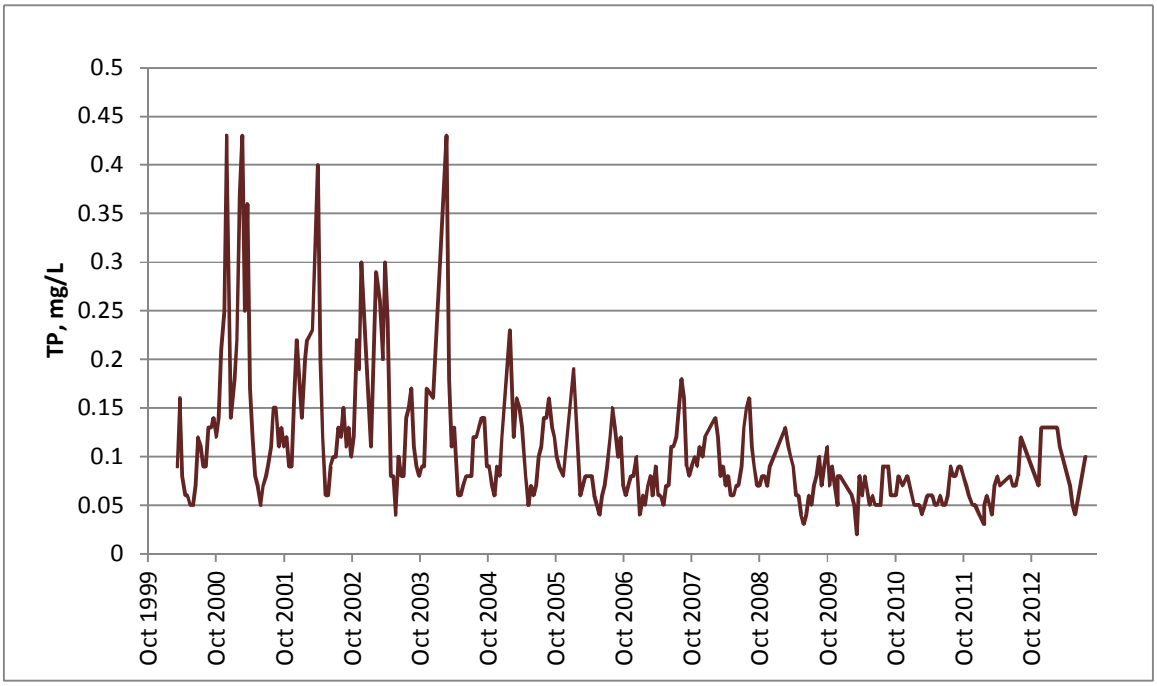

Figure 103. TP monitoring data series at Milner

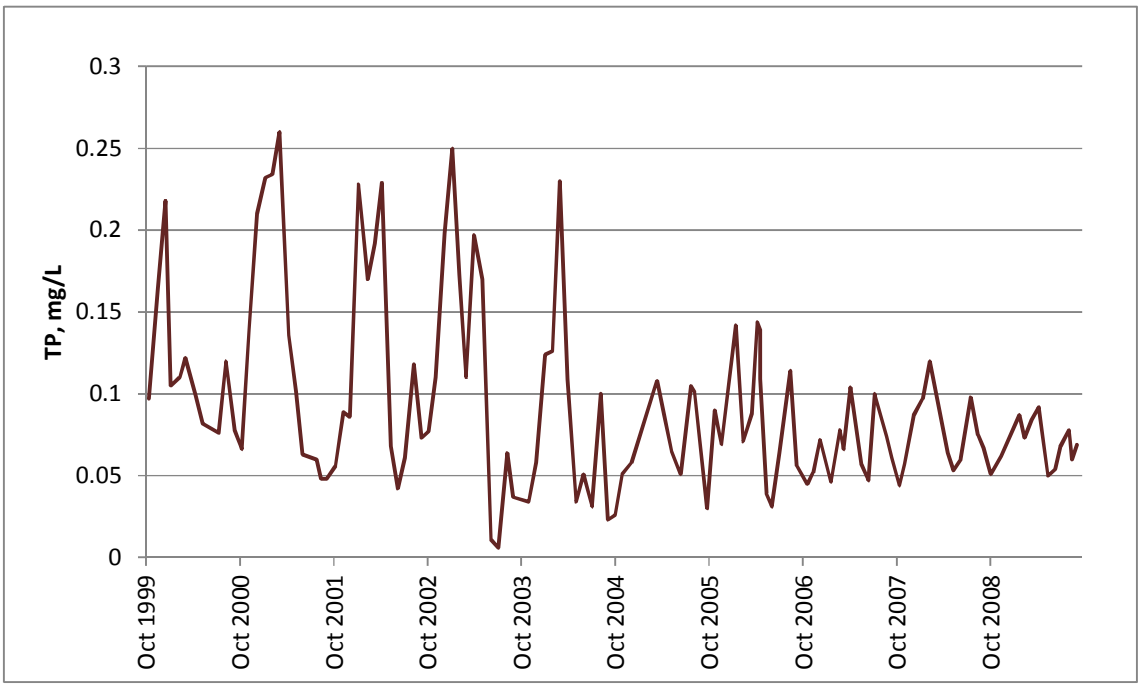

Figure 104. TP monitoring data series at Pillar Falls

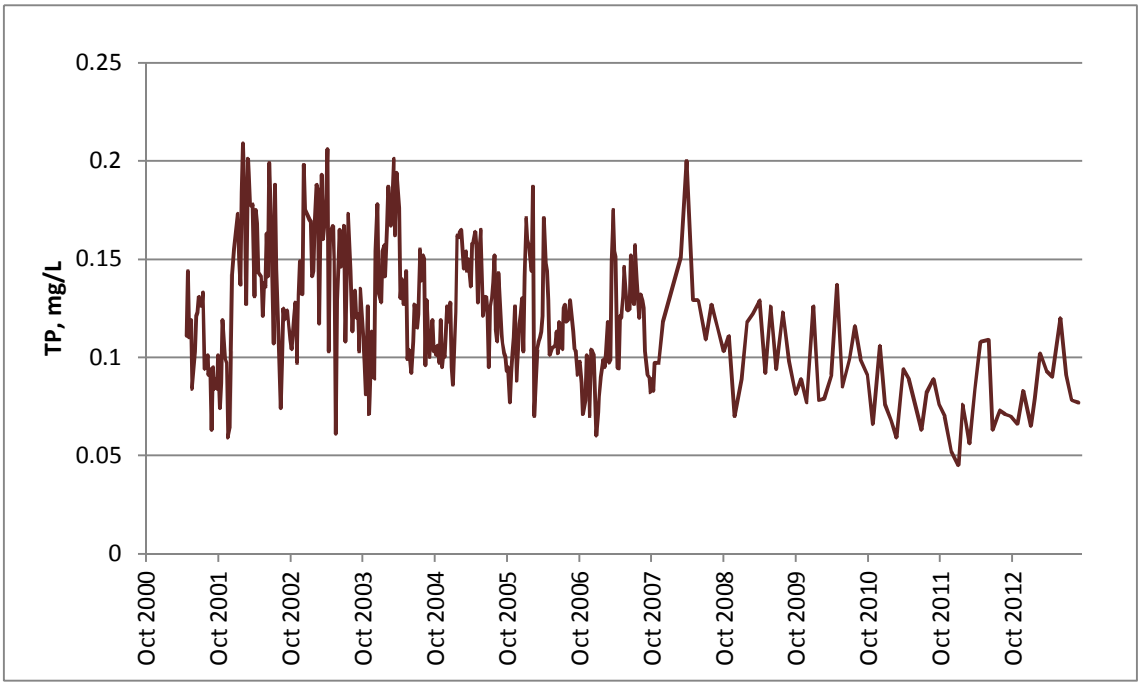

Figure 105. TP monitoring data series at Buhl

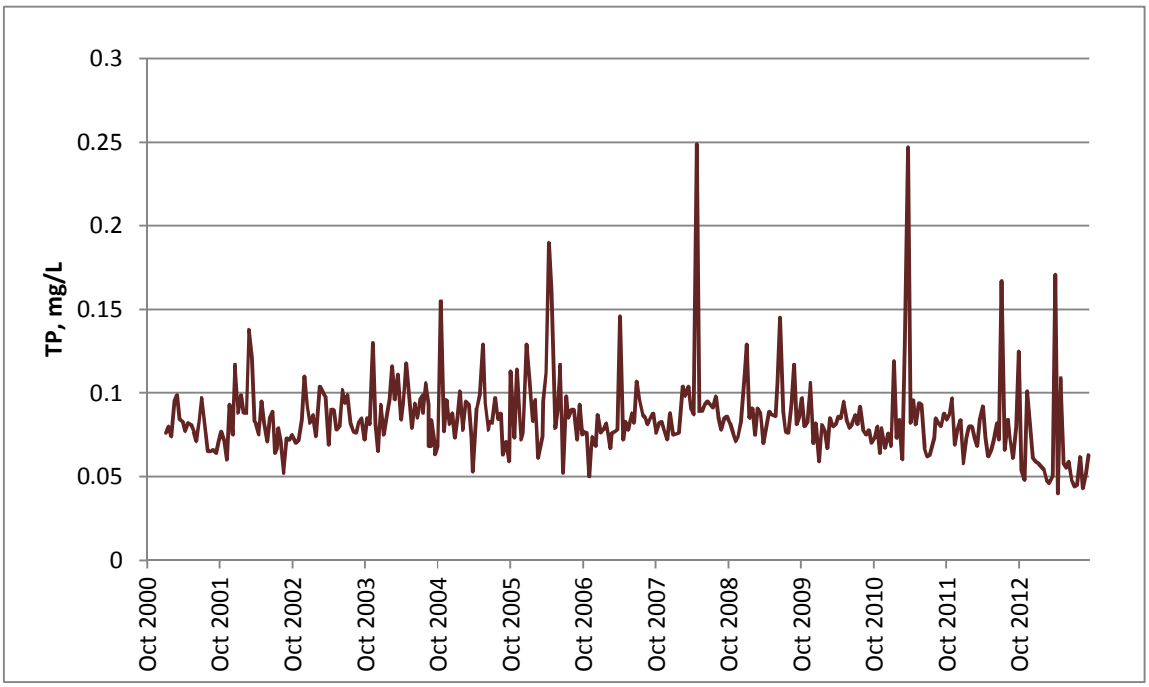

Figure 106. IPC TP monitoring data series at King Hill

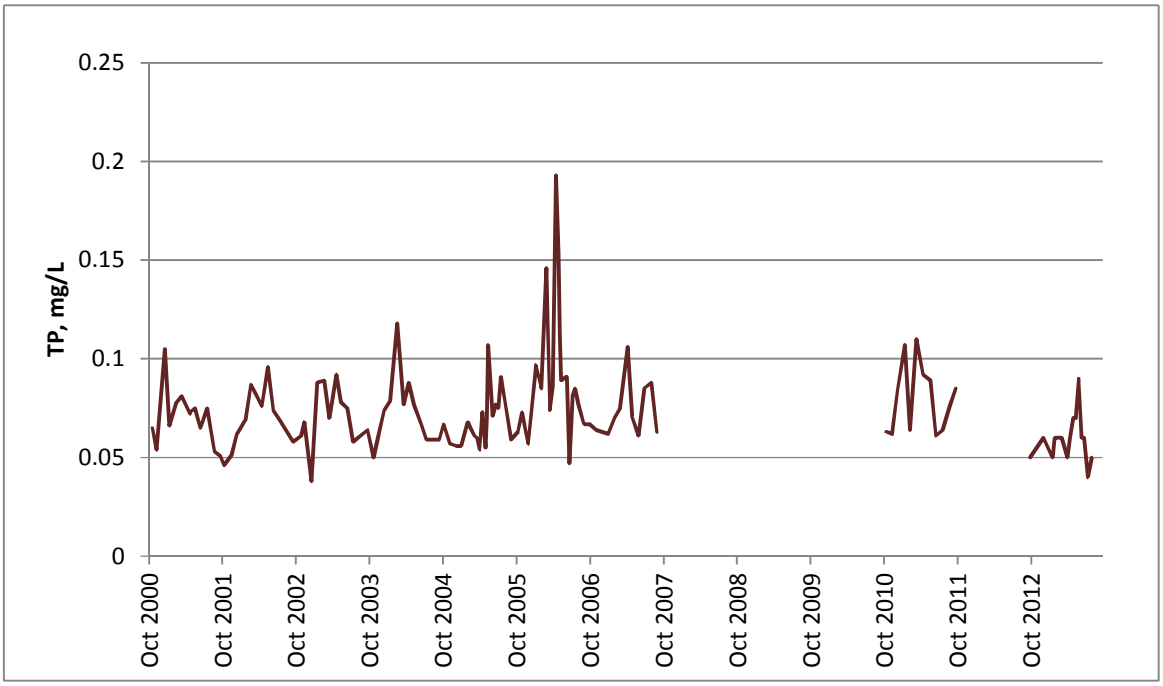

Figure 107. USGS TP monitoring data series at King Hill

Since monitoring is performed at the same King Hill location for both USGS and IPC, the potential for pooling these datasets was investigated. A plot of TP versus flow superimposed for both data sets suggests that IPC values tend to be higher than USGS values across a range of flows (Figure 108). A plot of same-day paired IPC versus USGS values shows that in most cases, the magnitude of the IPC value is higher than the USGS value (Figure 109). For this reason, the data sets were analyzed separately.

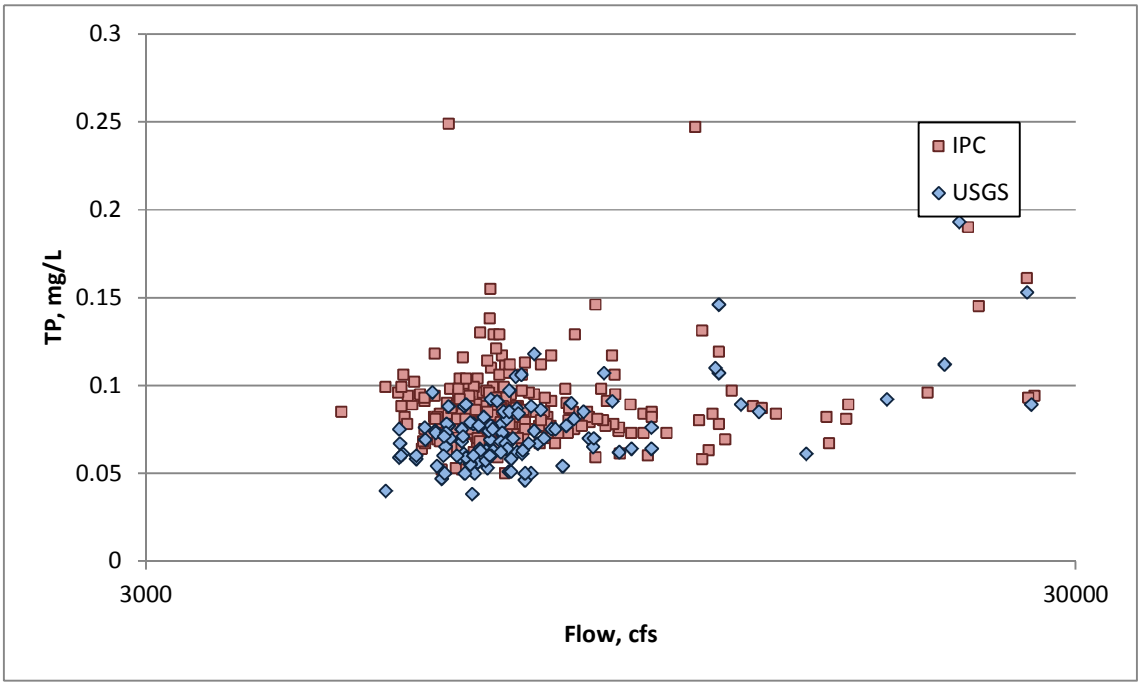

Figure 108. TP versus Flow at King Hill for USGS and IPC Data Sets

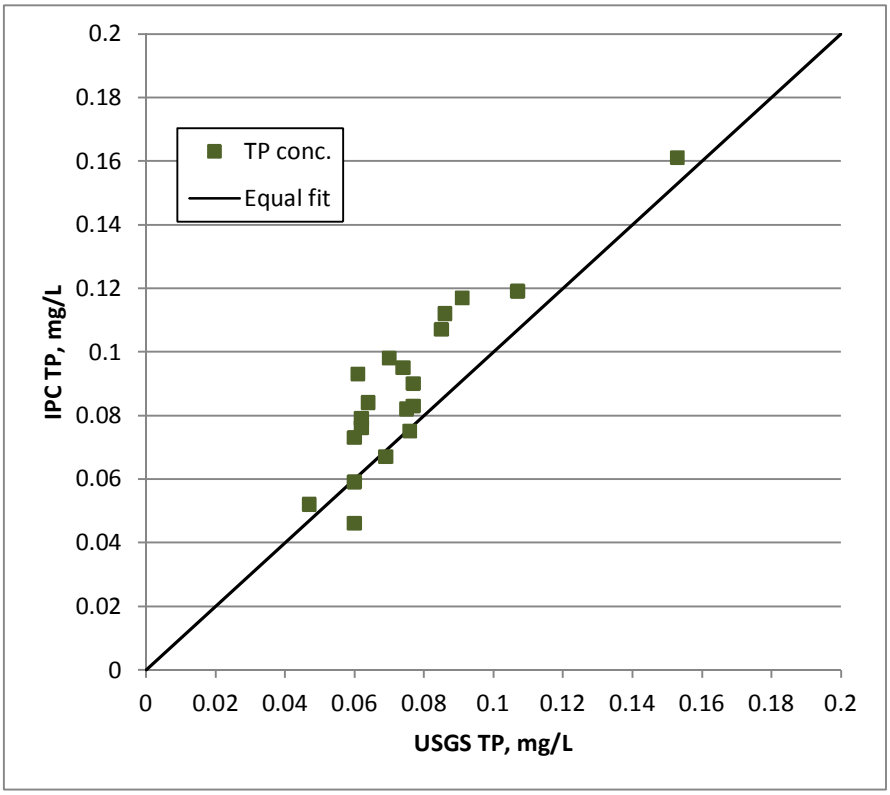

Figure 109. Paired (Same Day) Observations for IPC and USGS Data at King Hill

The monitoring data was reviewed to determine the presence of seasonality. When analyzing data for trend, the Seasonal Kendall test is preferred when seasonality is present. Otherwise, the Mann-Kendall test may attribute a trend to a data series when seasonality explains a portion of the variation in the data. The explanatory power of trend tests is improved when sources of variation other than the trend are removed prior to the tests.

To test for seasonality in the TP data, an autocorrelation function (ACF) plot was prepared for each series. Autocorrelation occurs when a particular measurement is similar to adjacent observations in time. The ACF provides the degree of autocorrelation between data points at $t + k$ lags, where t is each observation and k is the series of lags $1 \ldots n$. When seasonality is present, monthly data at each successive multiple of lag 12 are correlated to each other. Much of the data was sampled bi-weekly (though not consistently), so prior to running the ACF analysis, a monthly median value was calculated for each time series. The ACF analysis was then performed on the series of monthly values.

The degree of autocorrelation for each lag is measured in terms of a correlation coefficient ranging from -1 to 1. As autocorrelation increases, the absolute value of the correlation coefficient increases. For example, for Milner Dam in Figure 110, the correlation coefficient of 0.53 at Lag 12 suggests strong seasonality. In addition to Milner Dam, a strong signature of seasonality exists at Pillar Falls (Figure 111) and Buhl (Figure 112). Seasonality is weaker but present for the King Hill USGS data (Figure 114) but is essentially absent from the King Hill IPC data (Figure 113).

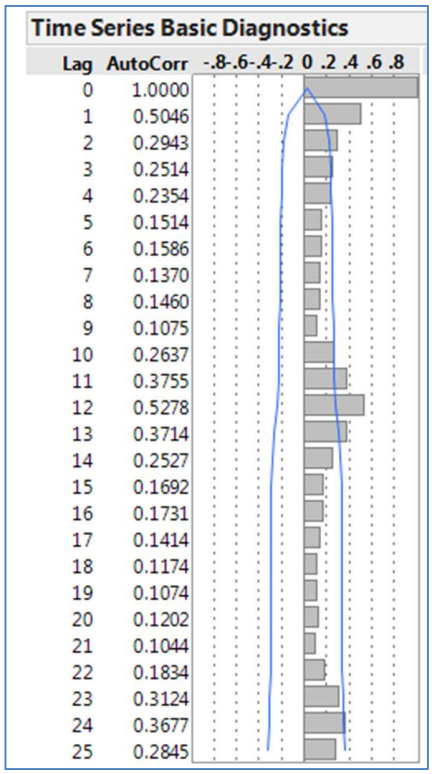

Figure 110. ACF for Milner

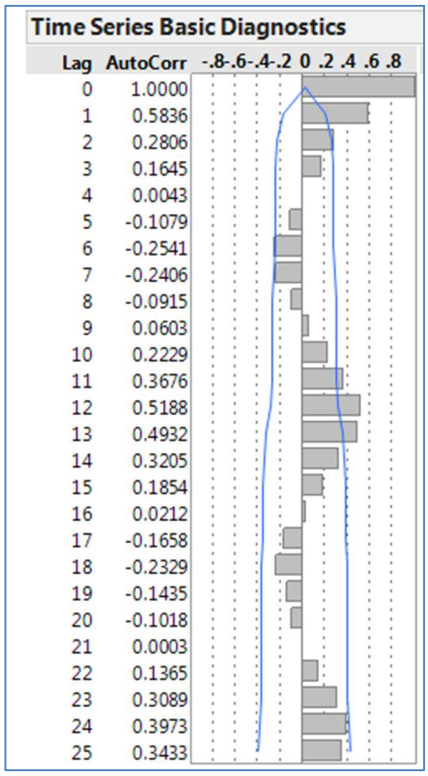

Figure 111. ACF for Pillar Falls

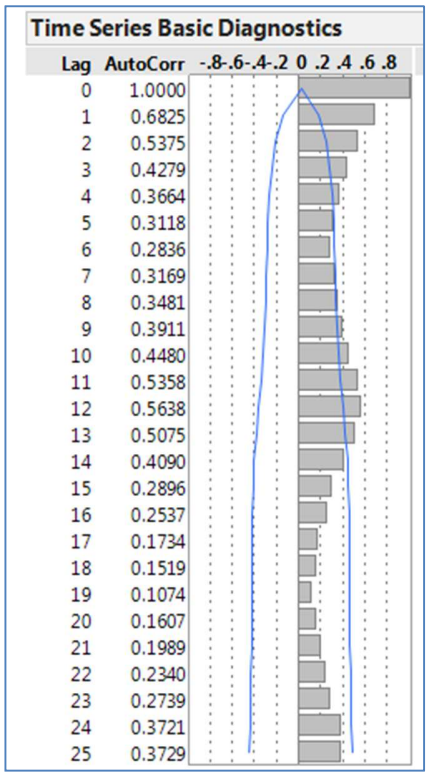

Figure 112. ACF for Buhl

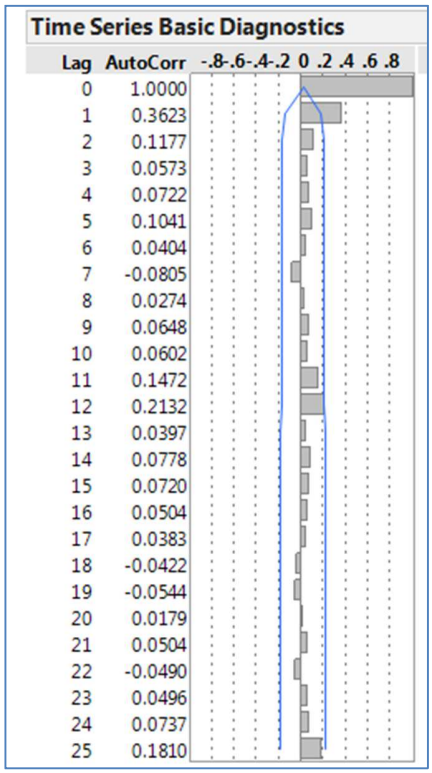

Figure 113. ACF for King Hill (IPC Data)

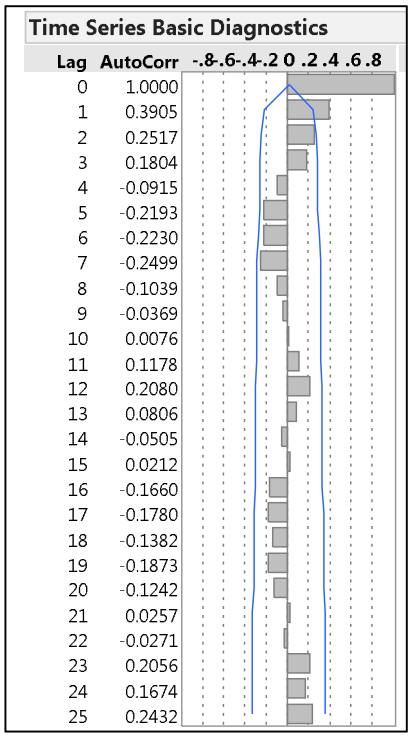

Figure 114. ACF for King Hill (USGS Data)

I-2.3 TREND ANALYSIS RESULTS

The trend analyses were performed on the entire data series (not the monthly median series prepared for the ACF plots). Mann-Kendall tests treat the data sequentially so all the data are utilized. When running the Seasonal Kendall test, the USGS Kendall program automatically calculates the median value for each season, and for the purposes of the test, each month was designated as a different season. When trend tests were run with LOWESS for flow, the smoothing value *f* was set to 0.5 as recommended by Cleveland (1979).

In order to illustrate how trend analysis results vary depending on the test used (Mann-Kendall or Seasonal Kendall, with or without LOWESS), the full range of tests were performed for Buhl (Table 36). In all cases, there is a trend of statistical significance when using a critical probability value of $p \leq 0.05$. TP is declining as shown by the negative sign on the reported trend. The two tests without LOWESS show a similar magnitude of trend in the neighborhood of -0.005 mg/L/yr, while the two tests with LOWESS are close to -0.003 mg/L/yr. A comparison of observed flow and TP at Buhl suggests that an extended period of low flow prior to 2006 is correlated to higher TP concentrations (Figure 115). It is likely that some of the variation in TP is correlated to flow, and part of the downward trend in TP is simply related to a series of wetter years. The tests with LOWESS account for the influence of flow on TP concentration, resulting in a lower trend magnitude. However, the significance of the tests still indicates there is a downward trend in TP independent of flow.

Table 36. Trend Test Results for Buhl

Trend Test	p-value*	Trend (mg/L/yr)
Mann-Kendall, no LOWESS	<0.0001	-0.0047
Mann-Kendall, with LOWESS	<0.0001	-0.0027
Seasonal-Kendall, no LOWESS	0.0015	-0.0052
Seasonal -Kendall, with LOWESS	0.0195	-0.0031

* Seasonal Kendall tests show p-value adjusted for autocorrelation

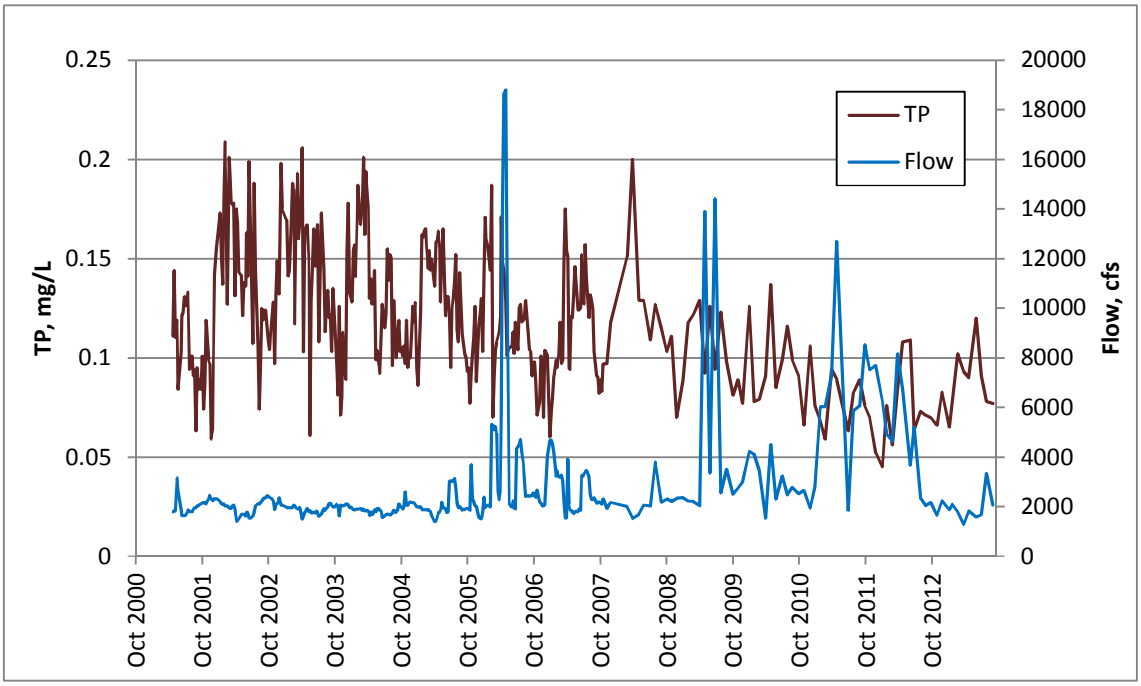

Figure 115. Comparison of TP and Flow at Buhl

Results are shown below for all four sites (Table 37). The Seasonal Kendall test with LOWESS was used at Milner, Pillar Falls, and Buhl, while the Mann-Kendall test with LOWESS was used for the King Hill IPC data (recalling that there is little if any seasonality observed in the IPC data as shown in Figure 113). Using a critical value of $p \leq 0.05$, significant trends are present at Milner, Pillar Falls, and Buhl, with relatively high magnitudes of decreasing trend in TP concentration. The results are mixed at King Hill; the Mann-Kendall test result is significant for the IPC data while the Seasonal Kendall test result is not significant for the USGS data. The lack of significance when testing the USGS data may be due to the large gaps in monitoring as shown in Figure 107. The reported trend using IPC data is weaker than the trends for the upstream stations.

A downward trend is predicted at all sites, indicating that TP has been declining over the monitoring period at a cross section of mainstem locations. The trend is strongest at Pillar Falls and is also strong at Milner and Buhl. The trend is weaker at King Hill. It is important to note that the reported trends are not a prediction of anticipated future decreases. The trend tests are valid for the periods that they cover but should not be extrapolated to other time periods.

Table 37. Trend Test Results for All Locations

Location	Test	p-value[1]	Trend (mg/L/yr)
Milner	Seasonal Kendall with LOWESS	0.0174	-0.0028
Pillar Falls	Seasonal Kendall with LOWESS	0.0082	-0.0055
Buhl	Seasonal Kendall with LOWESS	0.0195	-0.0031
King Hill (IPC data)	Mann-Kendall with LOWESS	0.0001	-0.0010
King Hill (USGS data)	Seasonal Kendall with LOWESS	0.1640	-0.0008

[1]Seasonal Kendall tests show p-value adjusted for autocorrelation

I-3. LOADEST Modeling

LOAD ESTimator (LOADEST) is a FORTRAN program developed by USGS for estimating constituent loads in streams and rivers. LOADEST (Runkel et al., 2004)was executed at four locations within the Middle Snake River watershed with grab total phosphorus (TP) data and daily discharge data. Daily loads were estimated from 10/1/2008 to 9/30/2013. LOADEST calibrations were performed using observed discharge and paired TP data from 10/1/2000 to 9/30/2013. LOADEST was run using a model number of zero, which enables the program to choose the best model from 9 in-built regression models.

LOADEST provides three methods for load estimation, namely, Maximum Likelihood Estimation (MLE), Adjusted Maximum Likelihood Estimation (AMLE) and Least Absolute Deviation (LAD). AMLE is the primary load estimation method used by LOADEST. When the calibration dataset is uncensored AMLE converges to MLE. AMLE and MLE methods apply under the assumption that the model residuals are normally distributed. If this assumption is not satisfied then results from the LAD method should be used. Tests for normality of residuals were performed for LOADEST models at all four locations prior to summarizing results.

I-3.1 MILNER

TP data from the University of Idaho (U of I) and paired discharge from USGS (Milner Dam 13088000) were used for the analysis. There were numerous instances where the USGS reported zero discharge at this location. Since LOADEST requires non-zero discharges for the entire estimation period, zero discharges were substituted with a nominal value of 0.1 cfs.

Figure 116 and Figure 117 show paired TP and discharge at Milner, and daily hydrograph at Milner along with U of I TP data, respectively.

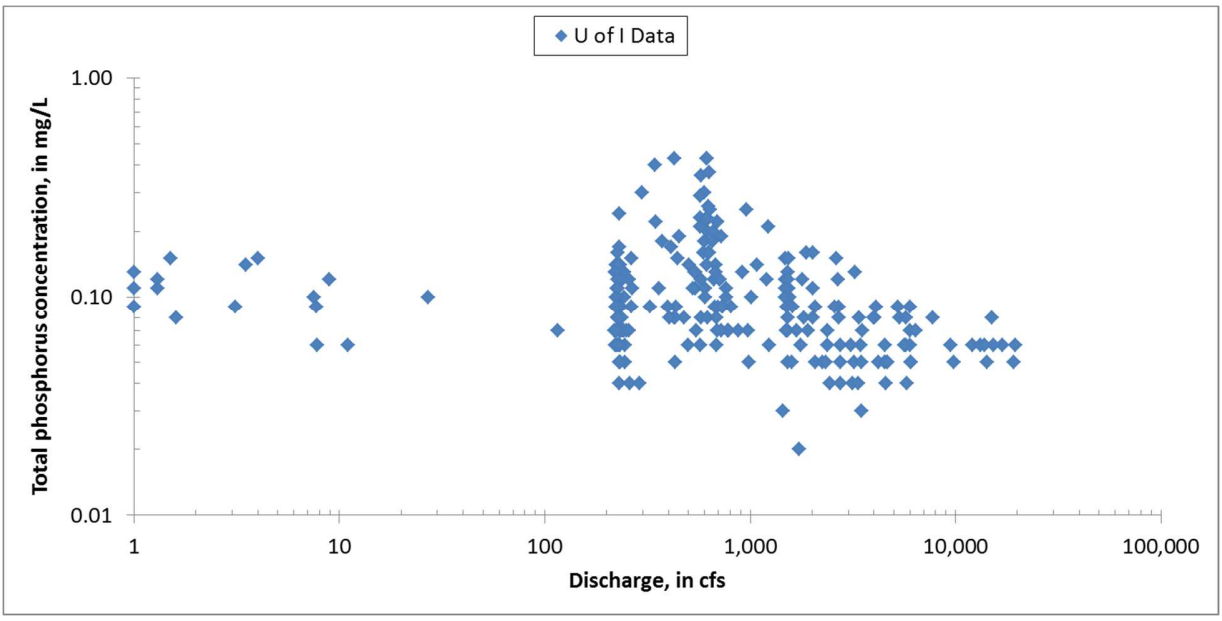

Figure 116. Paired TP concentration and discharge at Milner

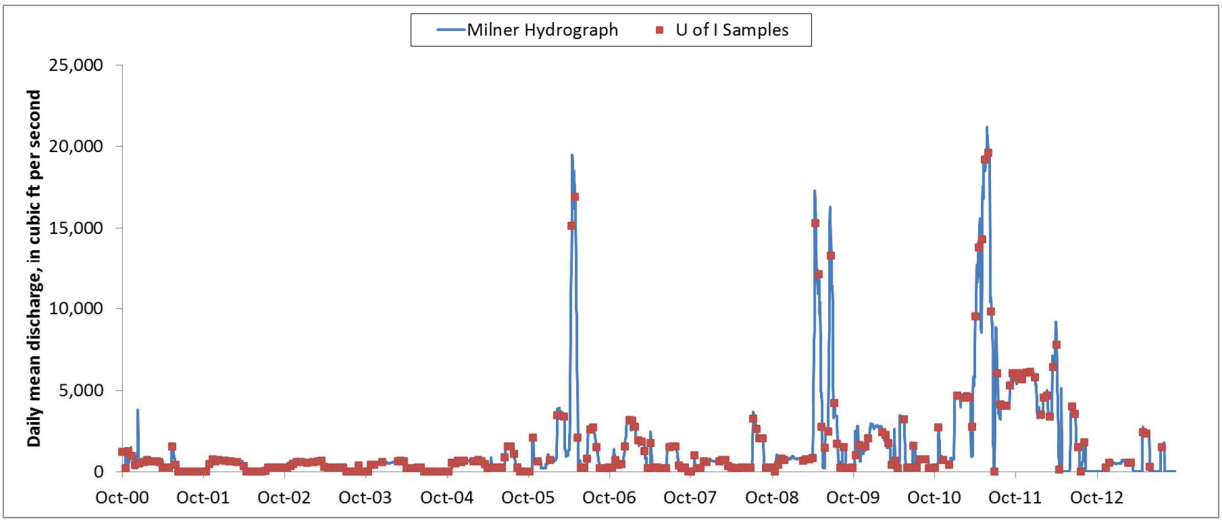

Figure 117. Milner hydrograph overlain by U of I TP data

LOADEST chose regression model # 8,

$$Ln(Load) = a_0 + a_1 Ln(Q) + a_2 Ln(Q^2) + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime$$

where,

Load = constituent load (kg/d)

Ln(Q) = Ln(Q) - center of Ln(Q)

dtime = decimal time - center of decimal time

The model coefficients and their respective p-values for the Milner model are shown in Table 38.

Table 38. Model coefficients and p-values for the Milner model

Coefficients	Value	p-value
a_0	2.5857	<0.0001
a_1	0.9927	<0.0001
a_2	-0.0061	0.0472
a_3	0.1326	<0.0001
a_4	-0.1261	0.0009
a_5	-0.0631	<0.0001

The linearity of the normal probability plot (Figure 118) suggests that the residuals are normally distributed and hence, fulfills the assumptions for the AMLE or MLE methods. Since none of the sample observations were censored, the AMLE and MLE methods produce the same estimates.

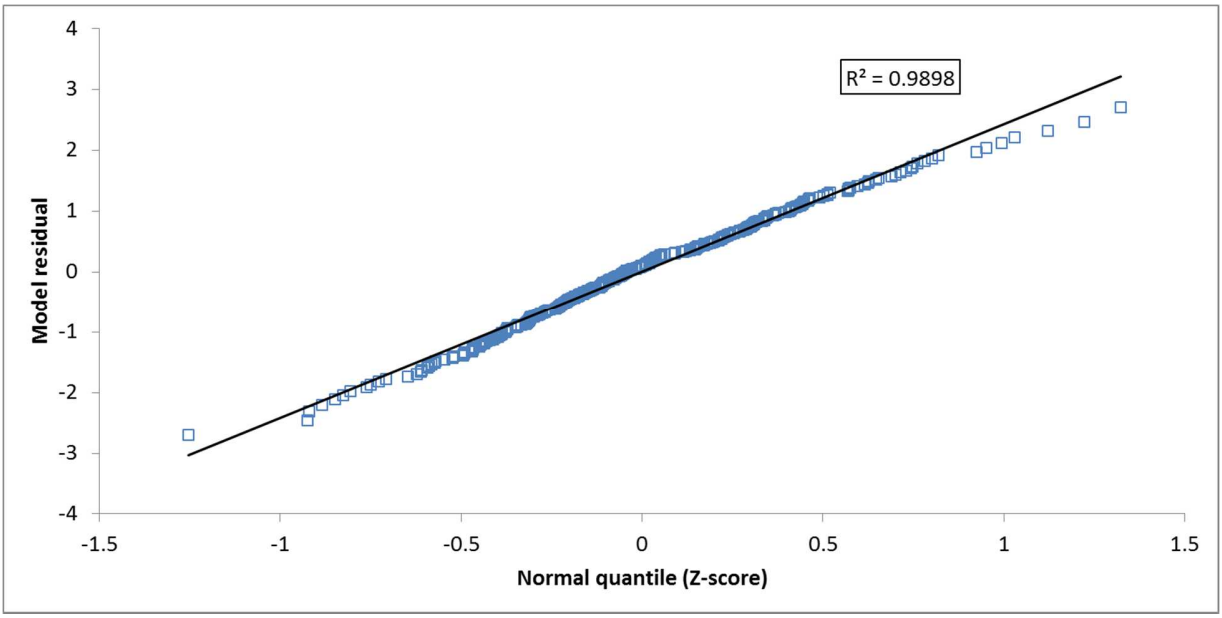

Figure 118. Normal probability plot for AMLE regression at Milner

Figure 119 and Figure 120 show LOADEST estimated flow weighted monthly TP concentration and monthly TP load, respectively, at Milner. The error bars show the upper and lower 95th percentile confidence interval.

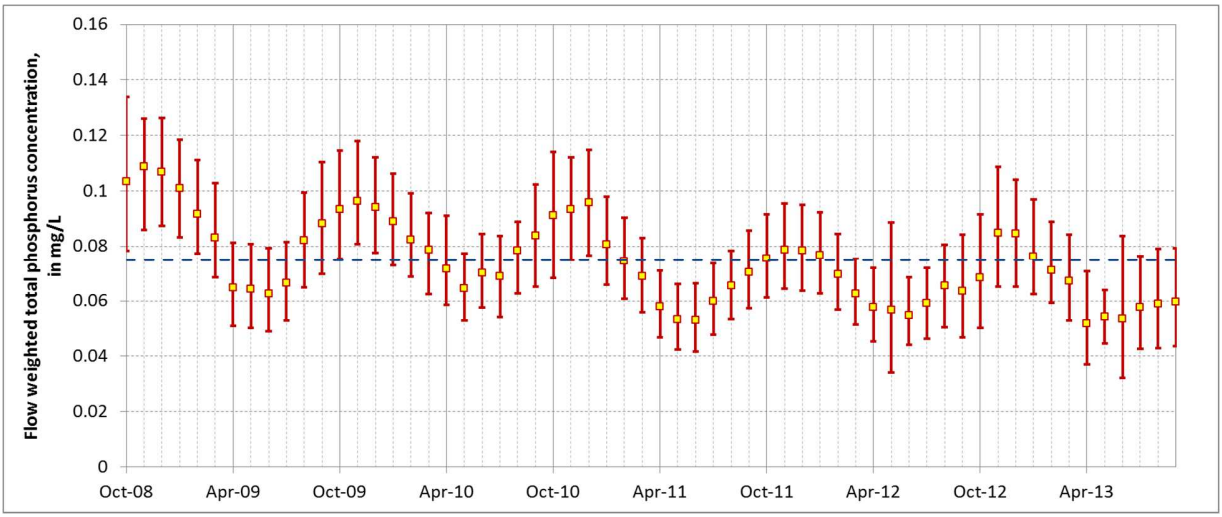

Figure 119. Flow weighted monthly TP concentration at Milner as estimated by LOADEST

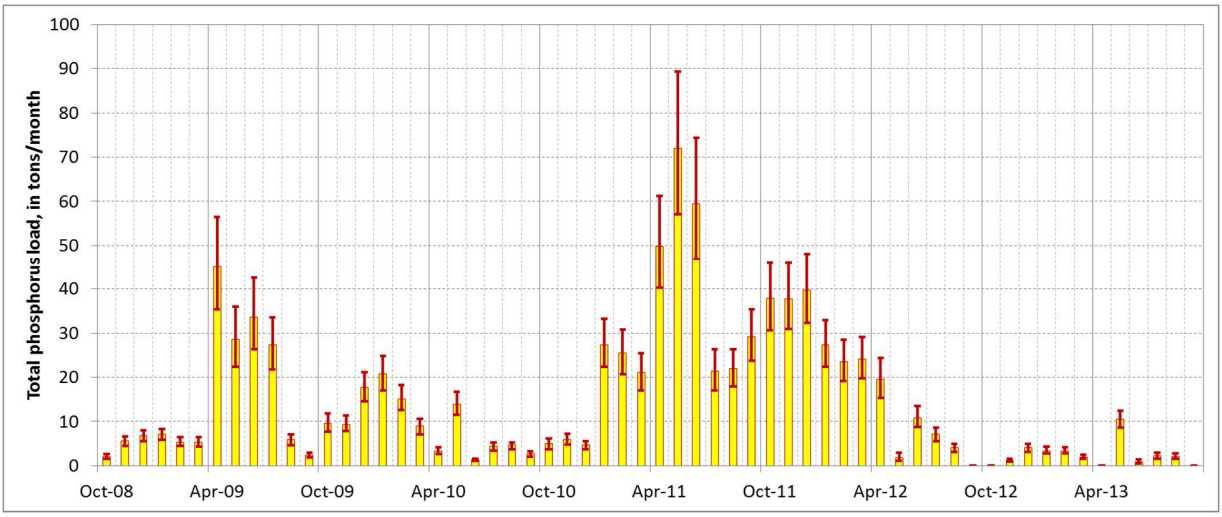

Figure 120. Monthly TP load at Milner as estimated by LOADEST

I-3.2 PILLAR FALLS

TP data from DEQ and paired discharge from USGS were used for the analysis. The nearest USGS gage (near Twin Falls 13090500) had discharge data only from 7/15/2009. Discharge data from 10/1/2000 to 7/14/2009 were estimated at this location using maintenance of variance extension regression model (MOVE.1 LOC) and daily discharge data from an upstream gage at Kimberly (13090000). The USGS SREF 1.0 program was used to produce daily discharge estimates at Twin Falls using Kimberly data using the MOVE.1 LOC method.

Figure 121 and Figure 122 show paired TP and discharge at Pillar Falls, and daily hydrograph at Pillar Falls along with DEQ TP data, respectively.

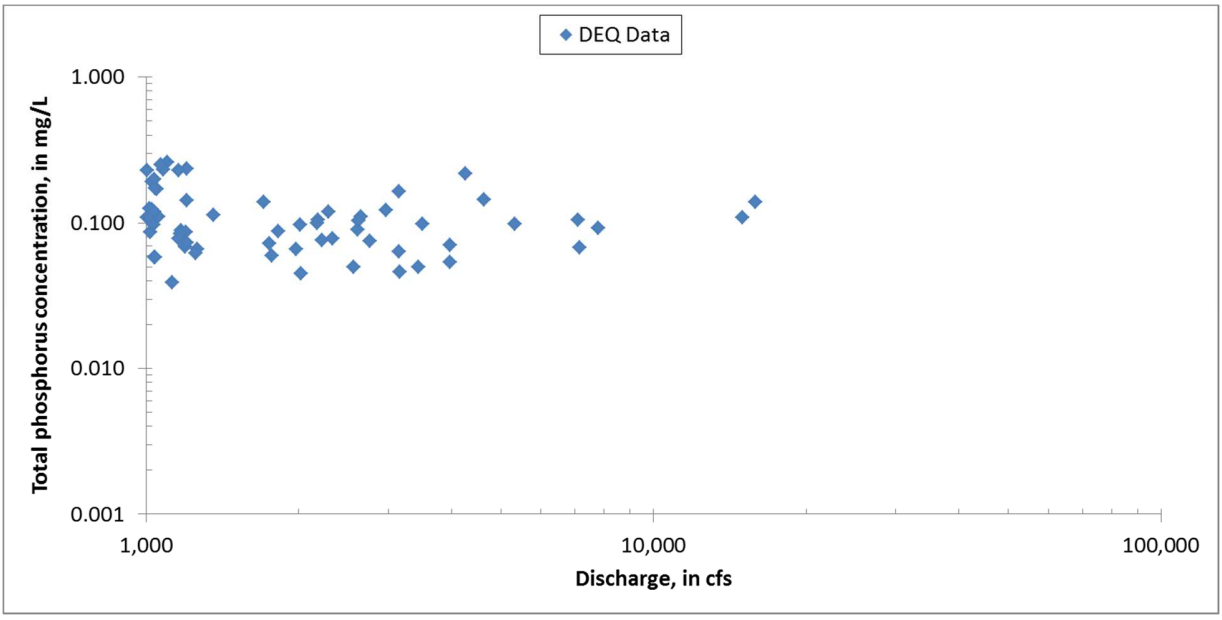

Figure 121. Paired TP concentration and discharge at Pillar Falls

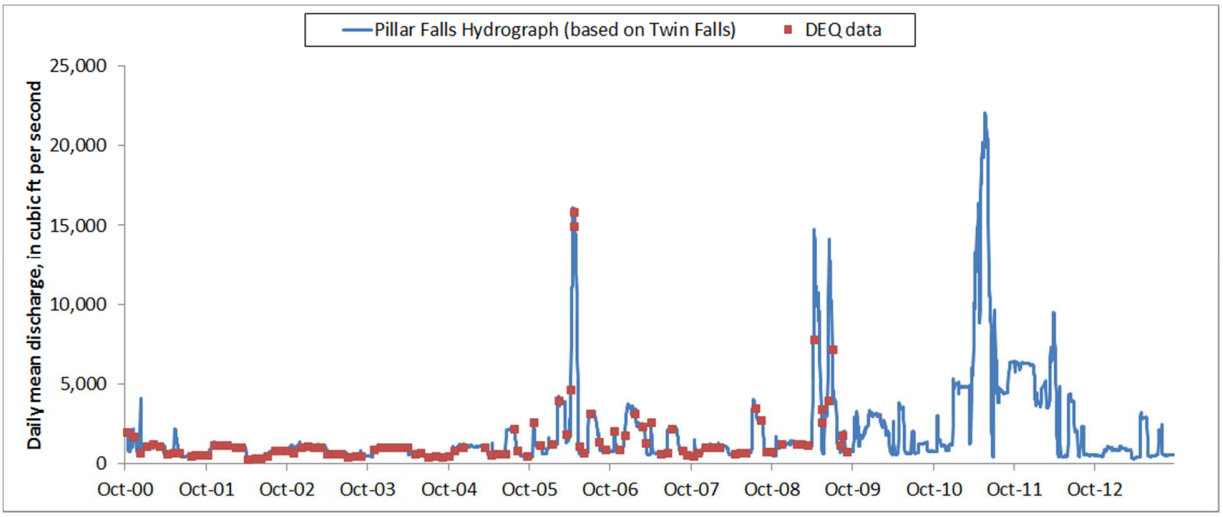

Figure 122. Pillar Falls hydrograph along with DEQ TP data

LOADEST chose regression model # 8,

$$Ln(Load) = a_0 + a_1 Ln(Q) + a_2 Ln(Q^2) + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime$$

where,

Load = constituent load (kg/d)

Ln(Q) = Ln(Q) - center of Ln(Q)

dtime = decimal time - center of decimal time

The model coefficients and their respective p-values for the Pillar Falls model are shown in Table 39.

Table 39. Model coefficients and p-values for the Pillar Falls model

Coefficients	Value	p-value
a_0	5.9501	<0.0001
a_1	1.1777	<0.0001
a_2	-0.0838	0.1413
a_3	0.3316	<0.0001
a_4	-0.1204	0.0616
a_5	-0.0594	0.0002

The linearity of the normal probability plot (Figure 123) suggests that the residuals are normally distributed and hence, fulfills the assumptions for the AMLE or MLE methods. Since none of the sample observations were censored, the AMLE and MLE methods produce the same estimates.

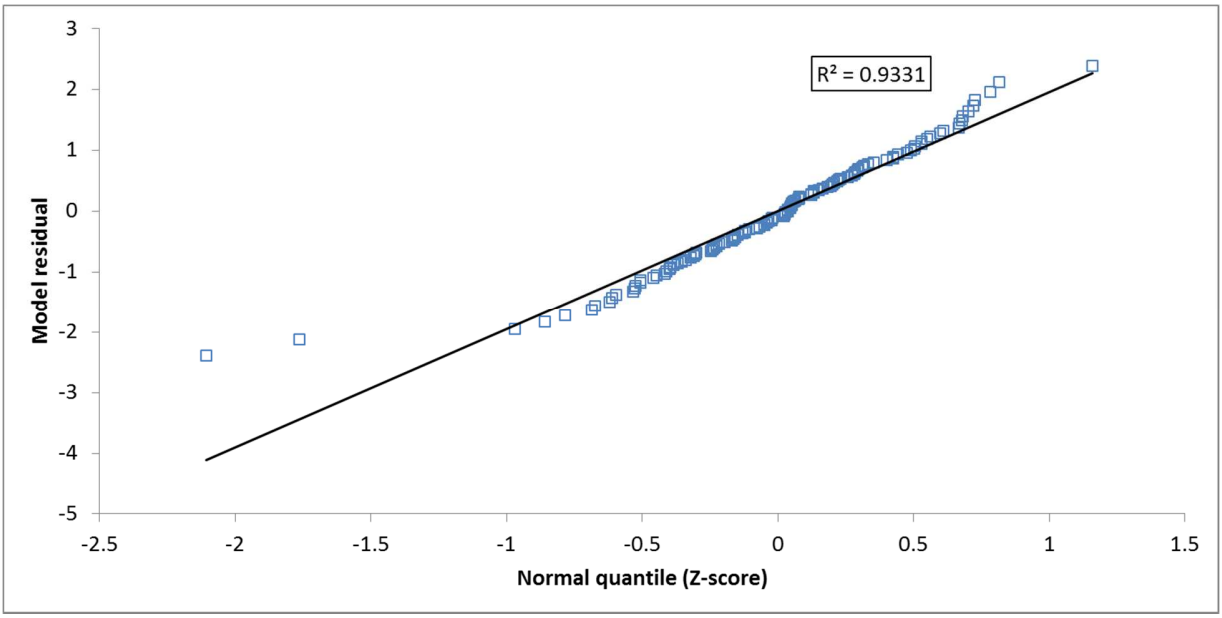

Figure 123. Normal probability plot for AMLE regression at Pillar Falls

Figure 124 and Figure 125 show LOADEST estimated flow weighted monthly TP concentration and monthly TP load, respectively, at Pillar Falls. The error bars show the upper and lower 95th percentile confidence interval.

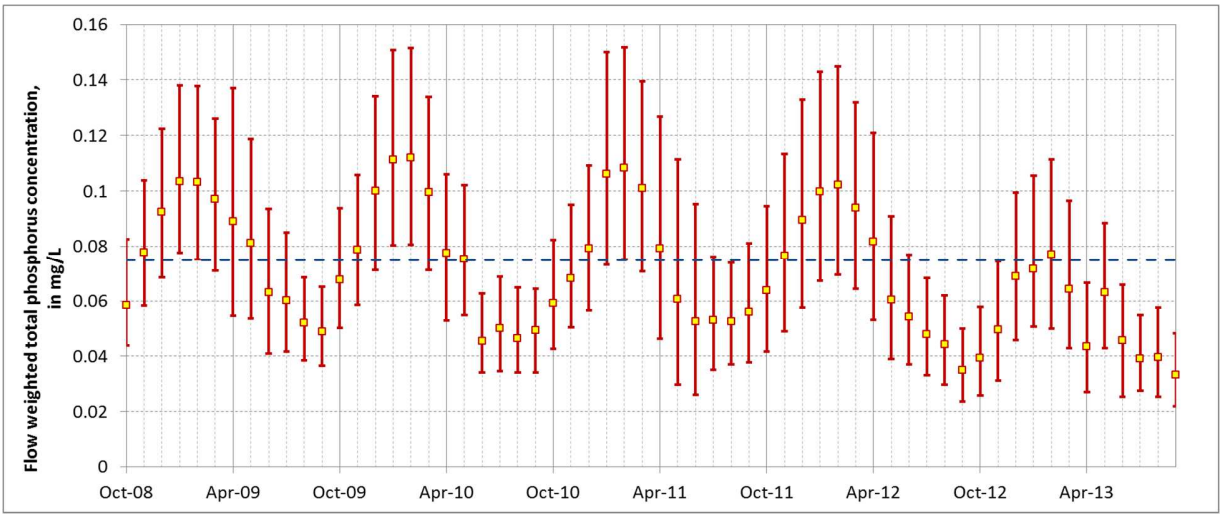

Figure 124. Flow weighted monthly TP concentration at Pillar Falls as estimated by LOADEST

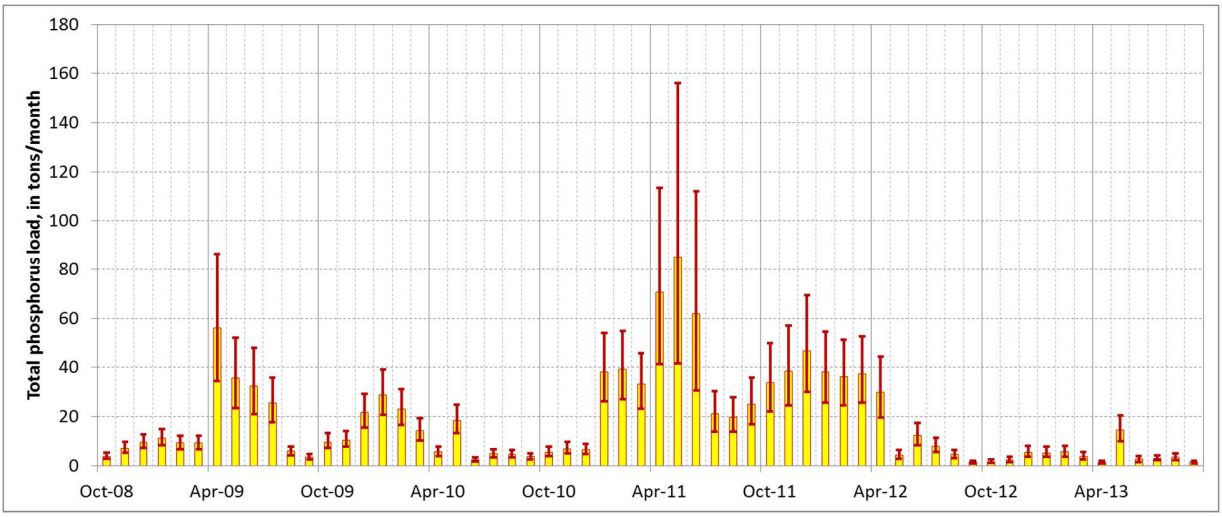

Figure 125. Monthly TP load at Pillar Falls as estimated by LOADEST

I-3.3 BUHL

TP data from Clear Springs Foods (CSF) and paired discharge from USGS (Buhl 13094000) were used for the analysis. Figure 126 and Figure 127 show paired TP and discharge at Buhl and daily hydrograph at Buhl along with CSF TP data, respectively. TP data from USFS and U of I were also reviewed but these datasets were less representative of the timeframe of interest and may have introduced seasonal bias due to gaps in the sampling periods.

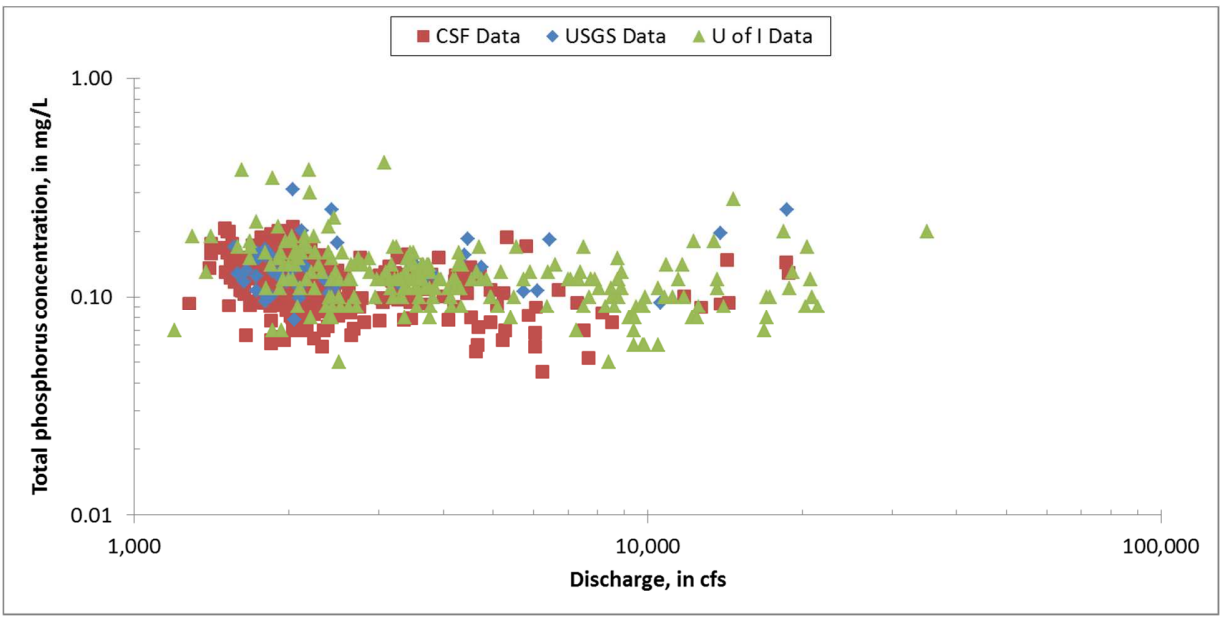

Figure 126. Paired TP concentration and discharge at Buhl

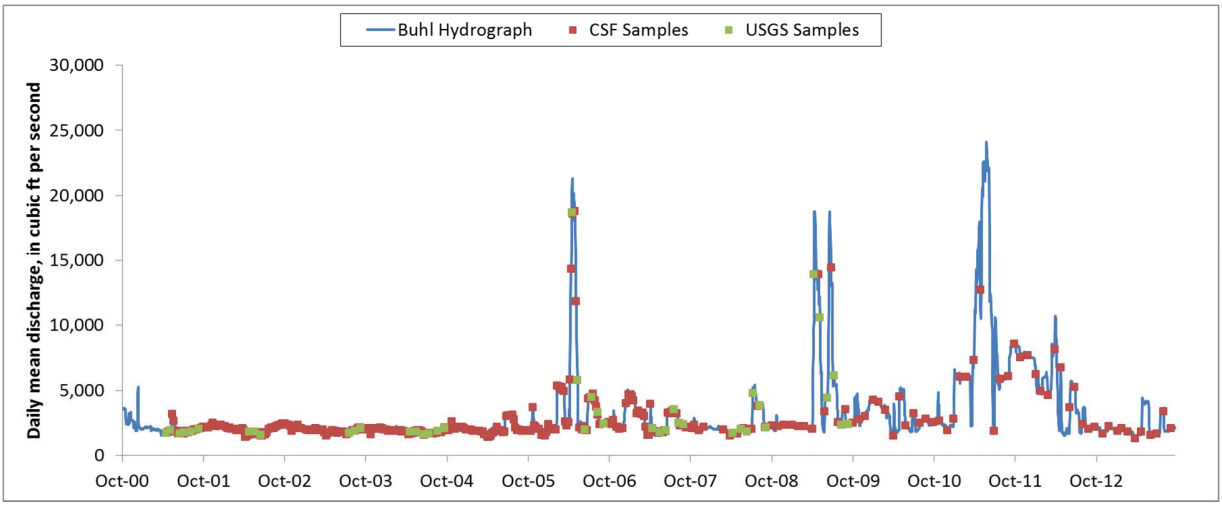

Figure 127. Buhl hydrograph along with CSF and USGS TP data

LOADEST chose regression model # 9,

$$Ln(Load) = a_0 + a_1 Ln(Q) + a_2 Ln(Q^2) + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime + a_6 dtime^2$$

where,

Load = constituent load (kg/d)

Ln(Q) = Ln(Q) - center of Ln(Q)

dtime = decimal time - center of decimal time

The model coefficients and their respective p-values for the Buhl model are shown in Table 40.

Table 40. Model coefficients and p-values for the Buhl model

Coefficients	Value	p-value
a_0	6.9123	0.0000
a_1	0.8716	<0.0001
a_2	0.0677	0.0817
a_3	0.0797	<0.0001
a_4	-0.1317	<0.0001
a_5	-0.0347	<0.0001
a_6	-0.0055	<0.0001

The linearity of the normal probability plot (Figure 128) suggests that the residuals are normally distributed and hence, fulfills the assumptions for the AMLE or MLE methods. Since none of the sample observations were censored, the AMLE and MLE methods produce the same estimates.

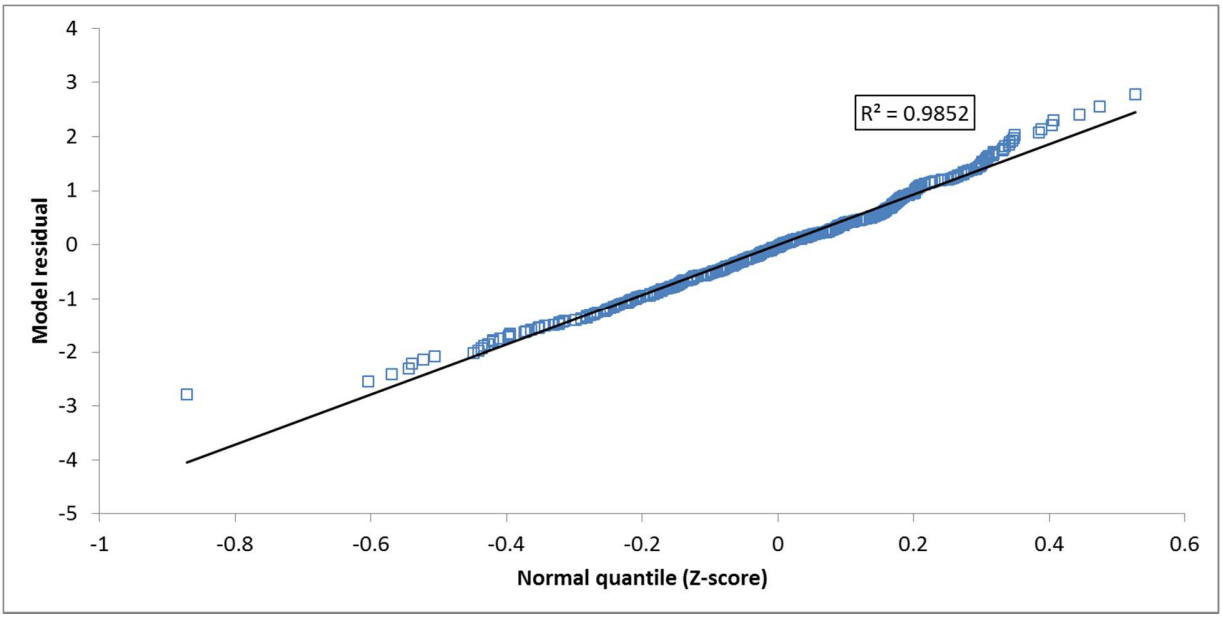

Figure 128. Normal probability plot for AMLE regression at Buhl

Figure 129 and Figure 130 show LOADEST estimated flow weighted monthly TP concentration and monthly TP load, respectively, at Buhl. The error bars show the upper and lower 95th percentile confidence interval.

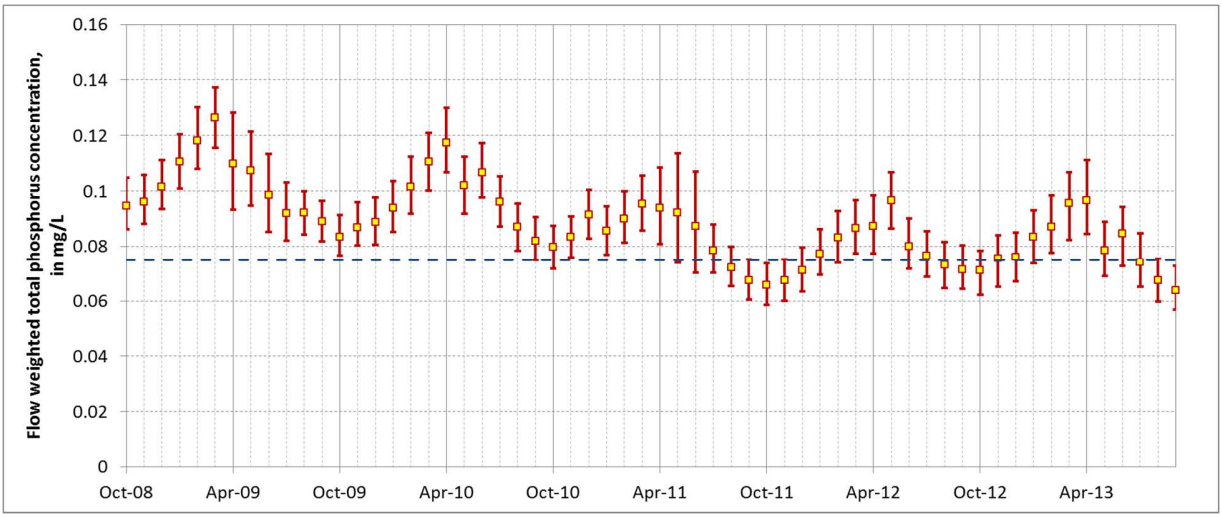

Figure 129. Flow weighted monthly TP concentration at Buhl as estimated by LOADEST

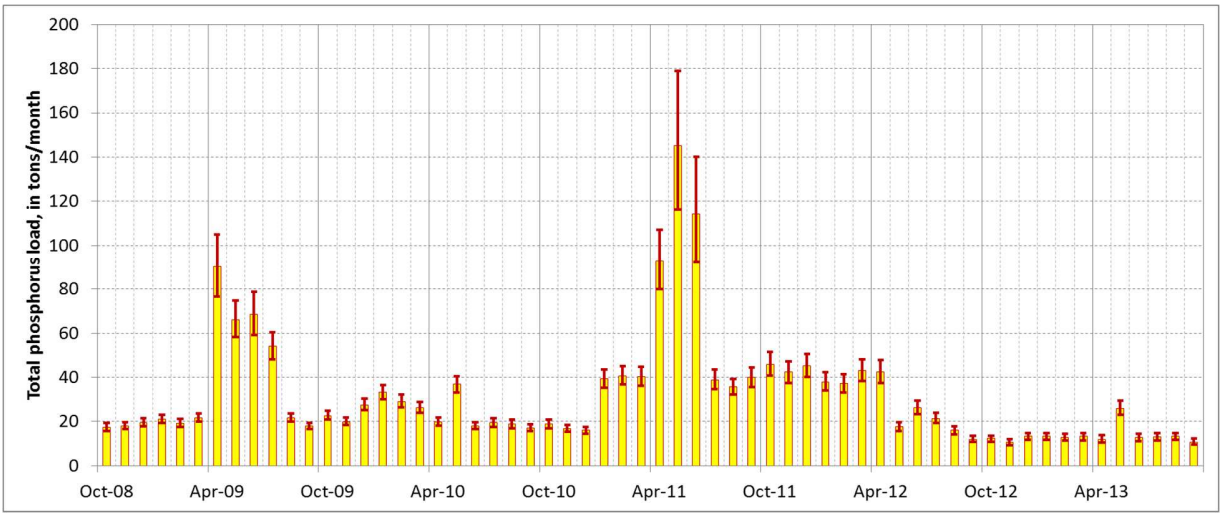

Figure 130. Monthly TP load at Buhl as estimated by LOADEST

I-3.4 KING HILL

TP data from IPC and USGS were available at this location. Two separate LOADEST models were run using IPC and USGS data paired with discharge data from USGS (King Hill). Figure 131 and Figure 132 show paired TP and discharge at King Hill and daily hydrograph at King Hill along with IPC and USGS TP data, respectively.

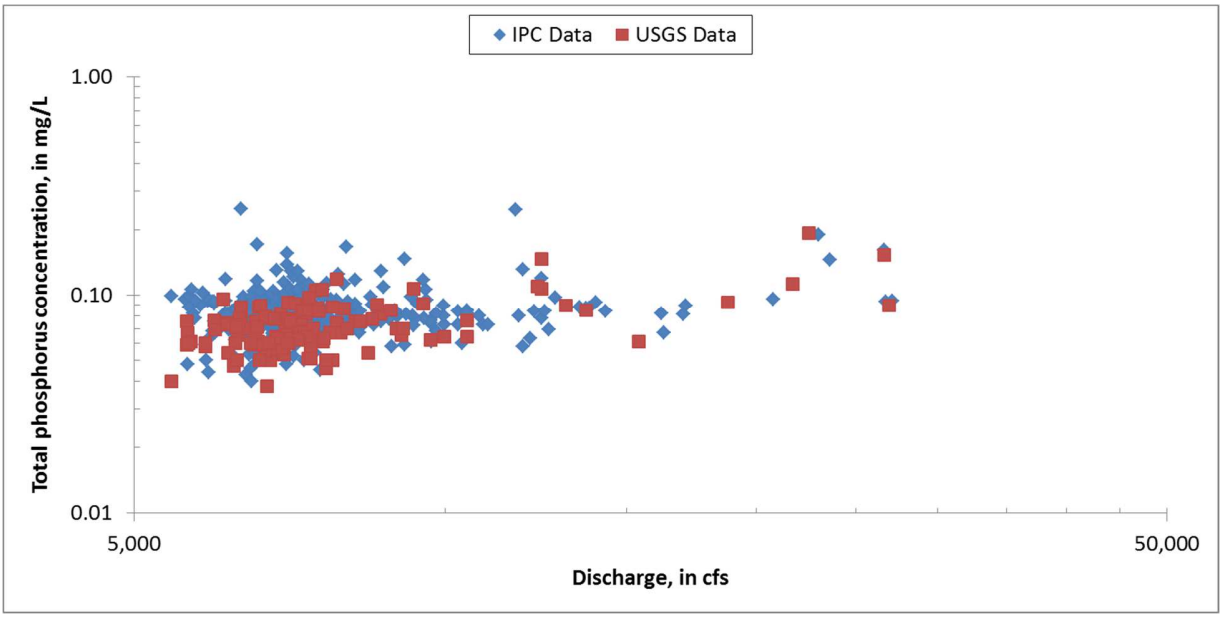

Figure 131. Paired TP concentration and discharge at King Hill

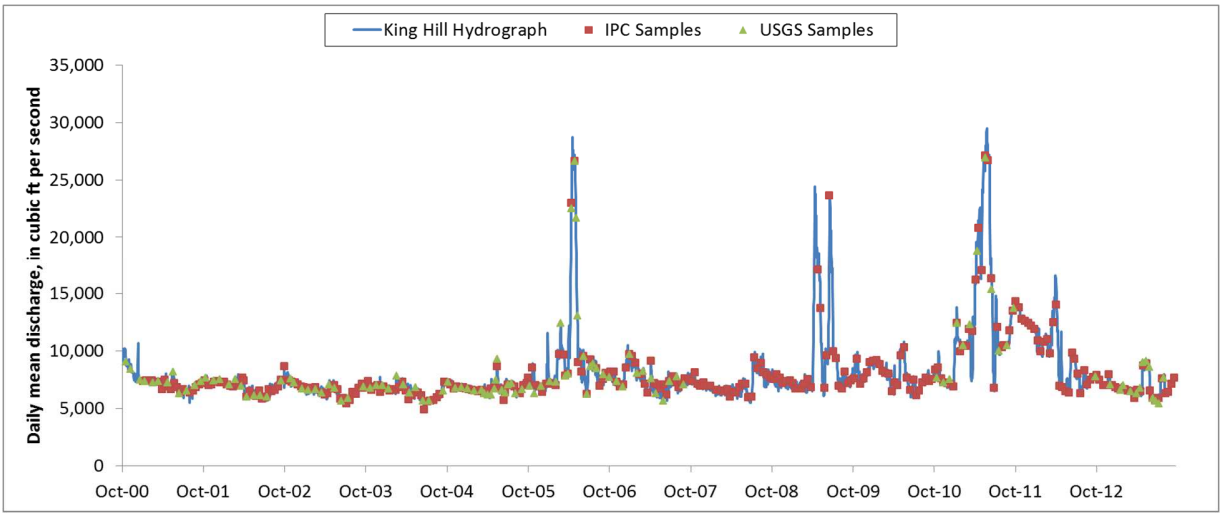

Figure 132. King Hill hydrograph along with IPC and USGS TP data

LOADEST chose regression model # 9,

$$Ln(Load) = a_0 + a_1 Ln(Q) + a_2 Ln(Q^2) + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime + a_6 dtime^2$$

where,

Load = constituent load (kg/d)

Ln(Q) = Ln(Q) - center of Ln(Q)

dtime = decimal time - center of decimal time

The model coefficients and their respective p-values for the King Hill USGS model are shown in Table 41.

Table 41. Model coefficients and p-values for the King Hill USGS model

Coefficients	Value	p-value
a_0	7.7833	<0.0001
a_1	1.4468	<0.0001
a_2	-0.1956	0.1054
a_3	-0.0824	0.0007
a_4	0.1137	<0.0001
a_5	-0.0157	0.0006
a_6	-0.0039	0.0012

The model coefficients and their respective p-values for the King Hill IPC model are shown in Table 42.

Table 42. Model coefficients and p-values for the King Hill IPC model

Coefficients	Value	p-value
a_0	7.7947	0.0000
a_1	1.2642	<0.0001
a_2	0.0209	0.8357
a_3	-0.0361	0.0270
a_4	0.0511	0.0035
a_5	-0.0185	<0.0001
a_6	-0.0059	<0.0001

The linearity of the normal probability plots (Figure 133 and Figure 134) suggest that the residuals are normally distributed and hence, fulfill the assumptions for the AMLE or MLE methods. Since none of the sample observations were censored, the AMLE and MLE methods produce the same estimates.

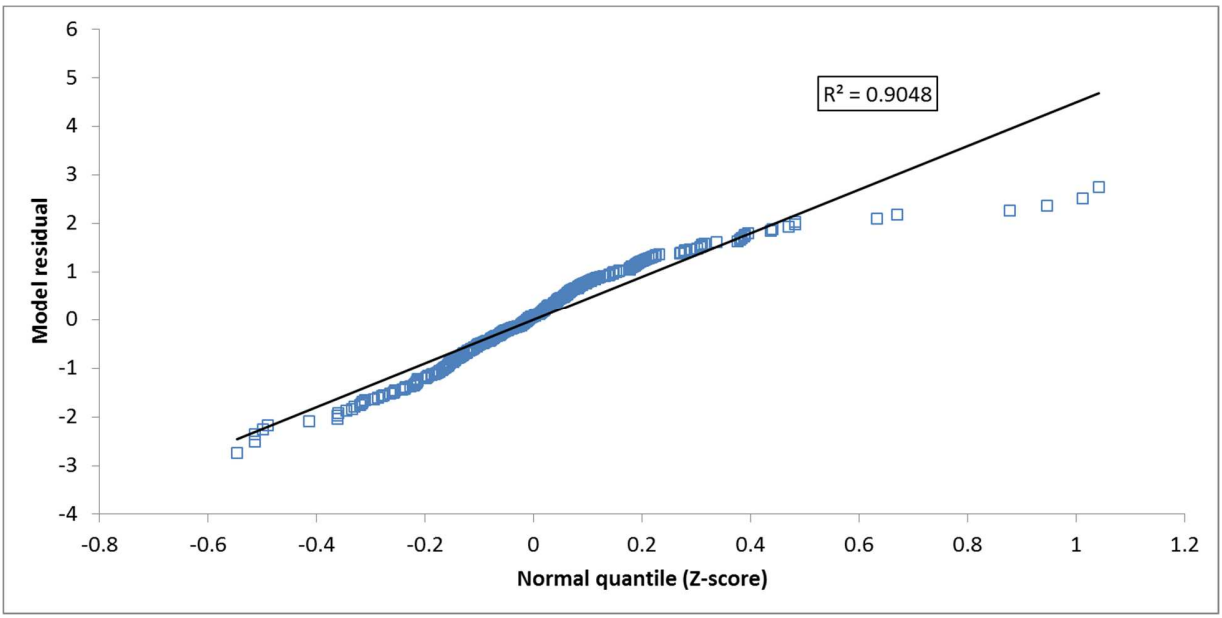

Figure 133. Normal probability plot for AMLE regression at King Hill using IPC data

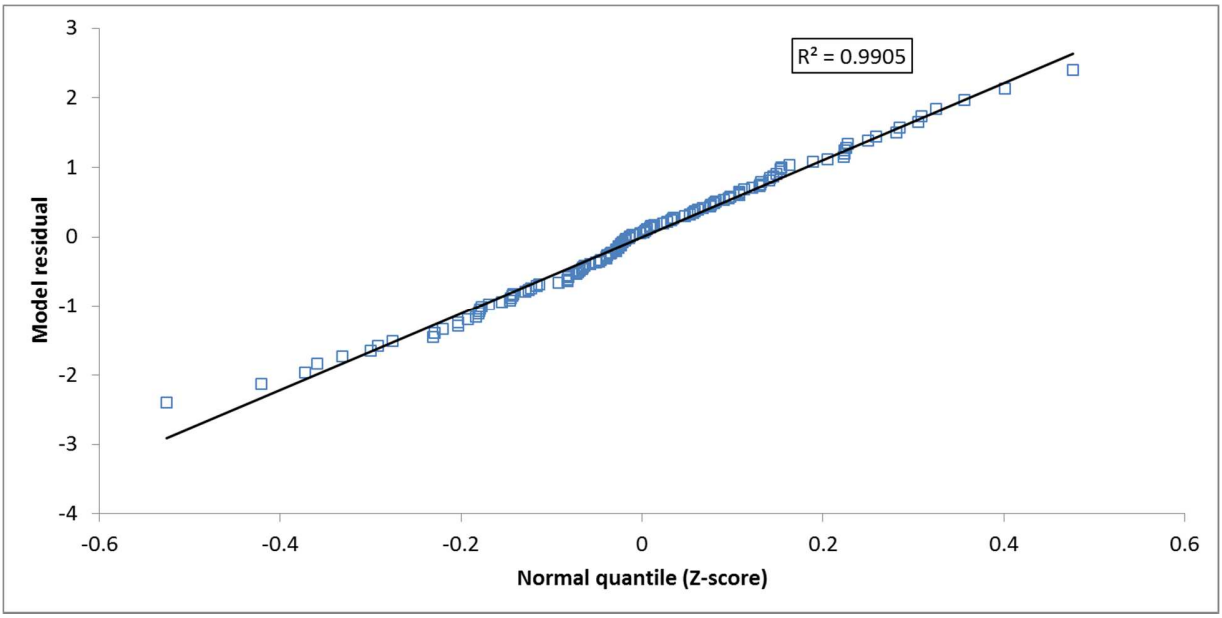

Figure 134. Normal probability plot for AMLE regression at King Hill using USGS data

From the normal probability plots above it is evident that the LOADEST model with the USGS data produces a better fit than the model with IPC data. However, it is important to note that there were more IPC samples than USGS for the calibration period (2009 to 2013). Fewer samples can introduce seasonal bias in the LOADEST estimates. Figure 135 and Figure 136 show LOADEST estimated flow weighted monthly TP concentration and monthly TP load, respectively, at King Hill using IPC data. The error bars show the upper and lower 95th percentile confidence interval.

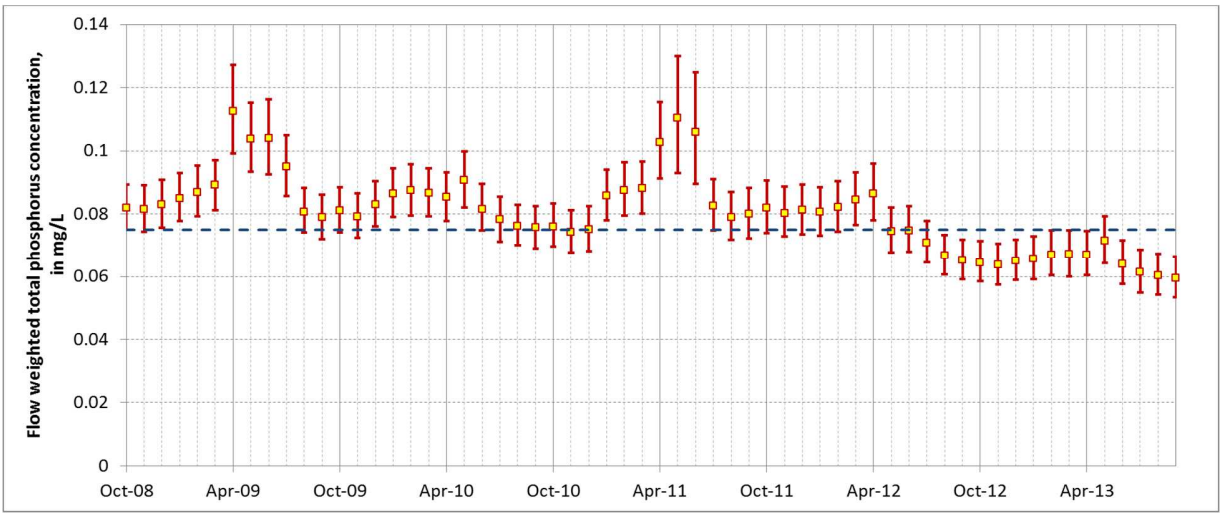

Figure 135. Flow weighted monthly TP concentration at King Hill as estimated by LOADEST using IPC data

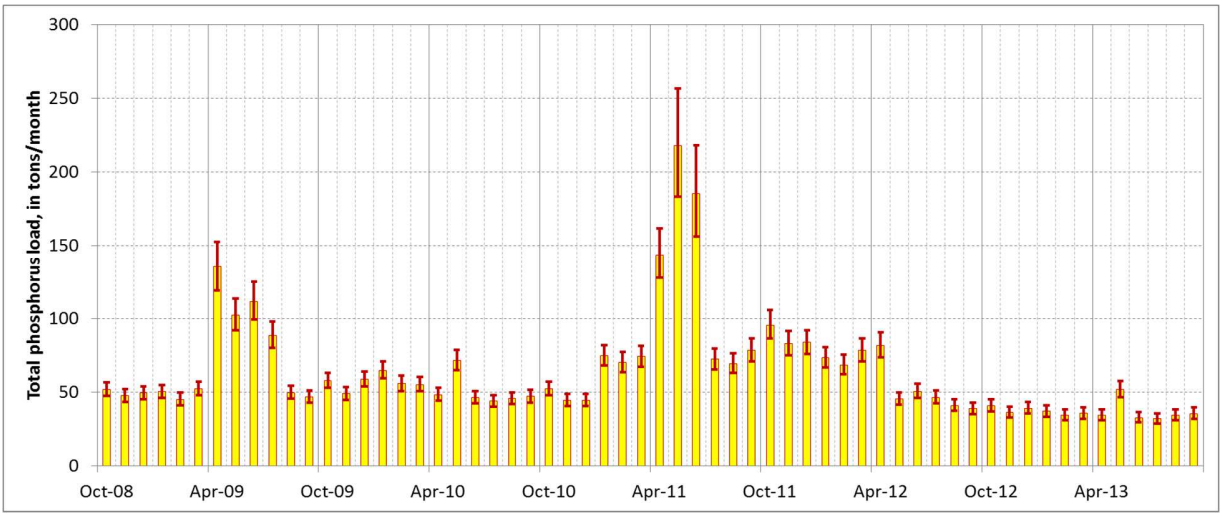

Figure 136. Monthly TP load at King Hill as estimated by LOADEST using IPC data

Figure 137 and Figure 138 show LOADEST estimated flow weighted monthly TP concentration and monthly TP load, respectively, at King Hill using IPC data. The error bars show the upper and lower 95th percentile confidence interval.

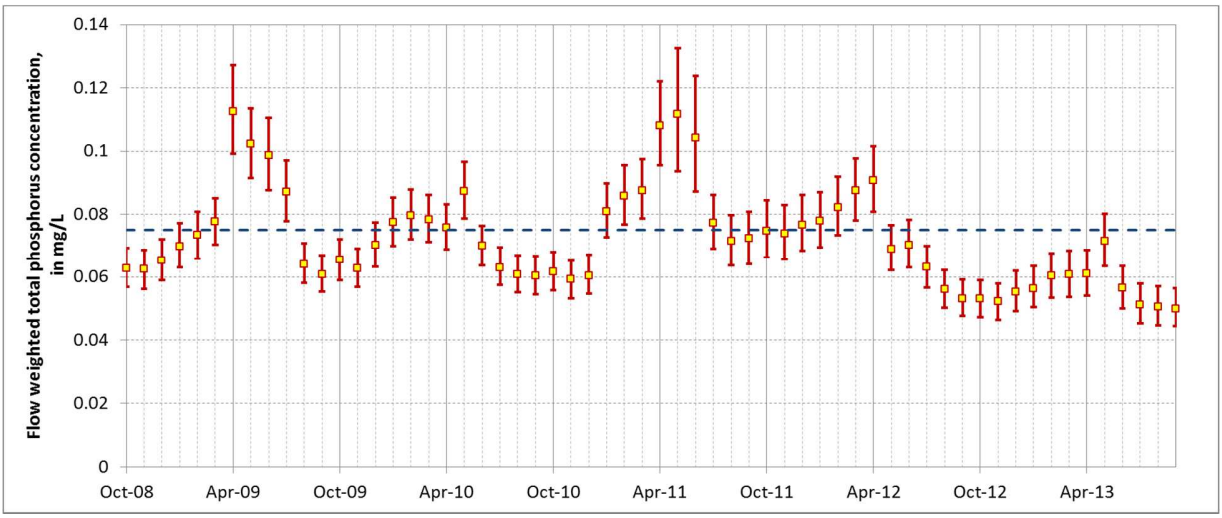

Figure 137. Flow weighted monthly TP concentration at King Hill as estimated by LOADEST using USGS data

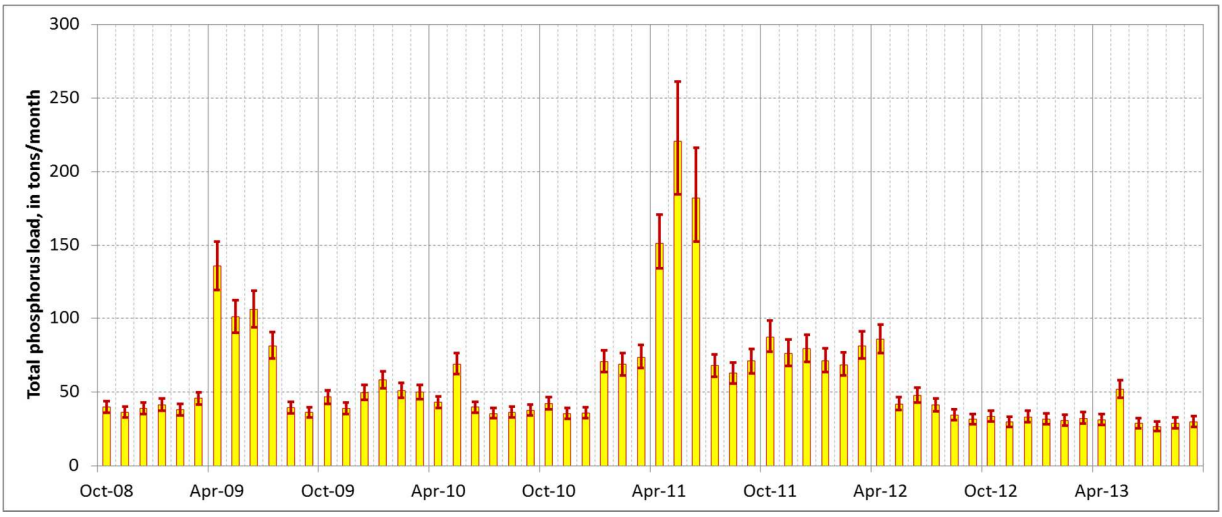

Figure 138. Monthly TP load at King Hill as estimated by LOADEST using USGS data

I-3.5 SUMMARY

This section provides a combined summary of the LOADEST analysis at four locations in the Middle Snake River watershed. Table 43 shows the annual TP loads and flow-weighted concentrations at Milner, Pillar Falls, Buhl and King Hill. Figure 139 and Figure 140 show the LOADEST estimated daily and annual TP loads. Figure 141 and Figure 142 show the annual flow-weighted TP concentrations at Milner, Pillar Falls, Buhl and King Hill, respectively. The LOADEST analysis shows a downward trend at all sites with time. The trend is strongest at Milner and Pillar Falls. The flow weighted TP concentrations are consistent with the trend analysis findings in Section 2. It is important to note that the above analyses were conducted to study the trend, and the selected time period is not necessarily appropriate to evaluate target compliance for regulatory purposes.

Table 43. LOADEST estimated annual loads and flow-weighted concentrations (on a water year basis)

Water Year	Milner		Pillar Falls		Buhl		King Hill IPC		King Hill USGS	
	Load (tons)	FWC (mg/L)	Load (tons)	FWC (mg/L)	Load (tons)	FWC (mg/L)	Load (tons)	FWC (mg/L)	Load (tons)	FWC (mg/L)
2009	175	0.070	210	0.076	435	0.103	830	0.093	737	0.083
2010	111	0.082	148	0.085	289	0.096	643	0.083	554	0.071
2011	343	0.061	414	0.069	638	0.086	1126	0.092	1080	0.088
2012	233	0.070	292	0.079	387	0.077	786	0.079	745	0.075
2013	30	0.064	51	0.056	164	0.078	444	0.065	387	0.057

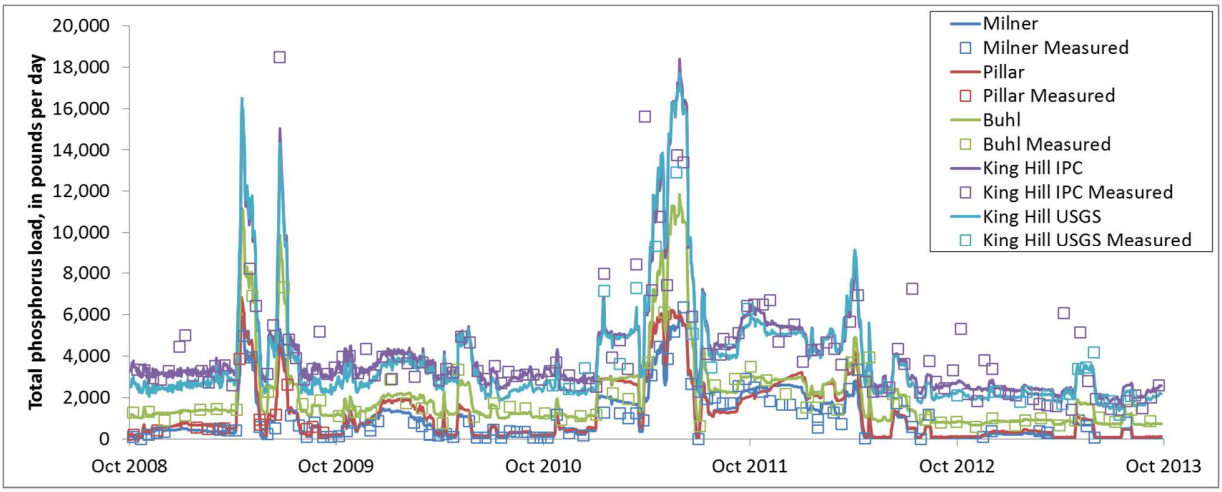

Figure 139. Daily estimated and measured TP loads

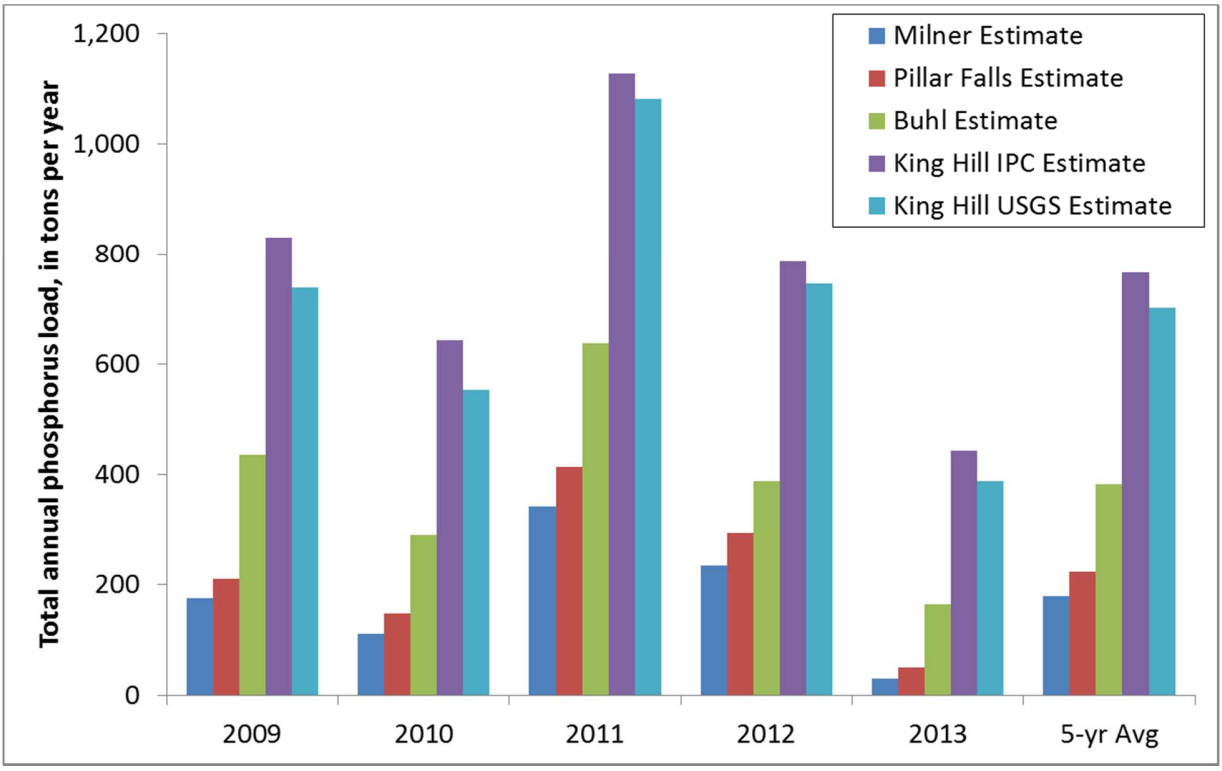

Figure 140. Annual estimated TP loads (on a water year basis)

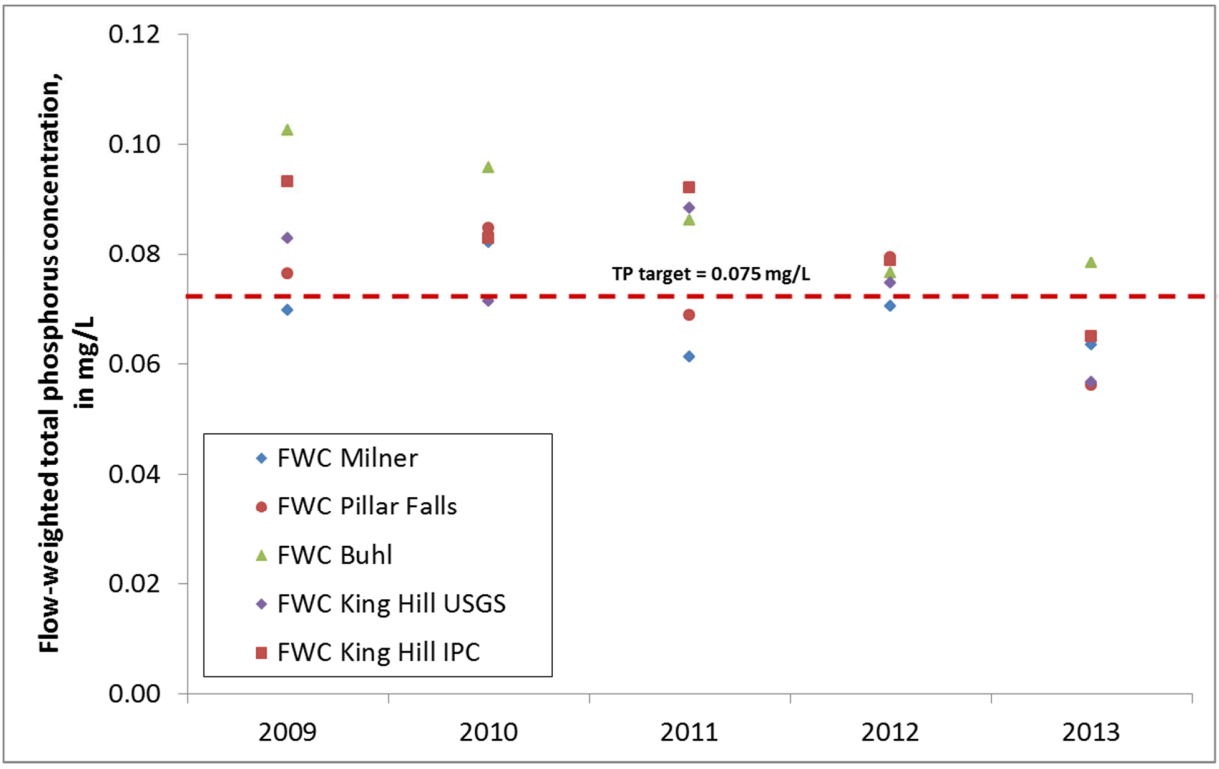

Figure 141. Flow weighted TP concentrations (on a water year basis)

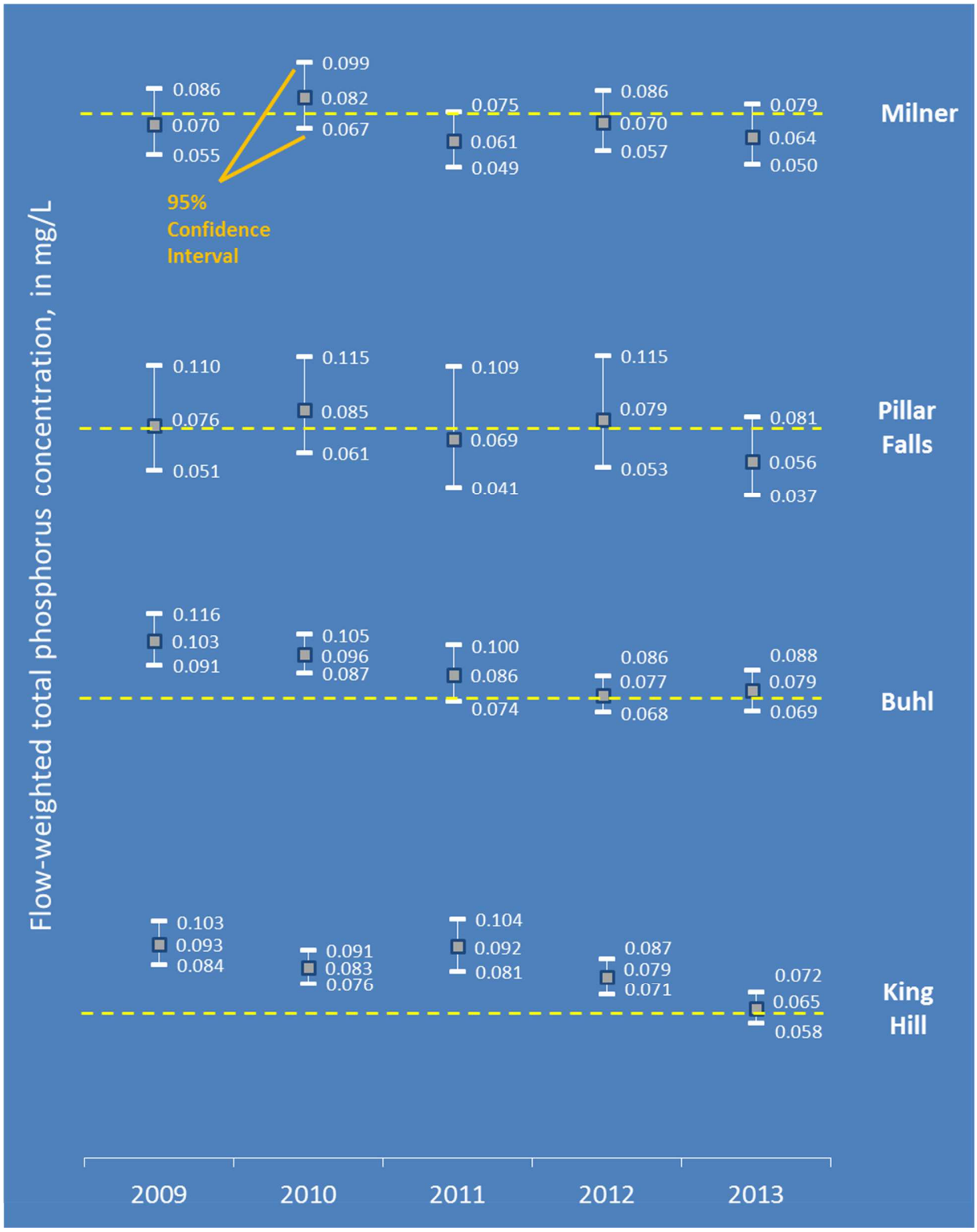

Figure 142. Flow weighted TP concentrations (on a water year basis)

I-4. City of Twin Falls WWTP

About 80 point sources were identified in the Data Report, and among these point sources, the City of Twin Falls Wastewater Treatment Plant (WWTP) discharges the highest daily loads measured for any single source. Given that this facility is the most significant point source discharger in the reach, recent monitoring data was used to assess the magnitude of TP concentration and load from the Twin Falls WWTP relative to the receiving water, the Middle Snake River. Two years of monitoring data spanning 2012-2013 were used. Data were available as part of the plant's monitoring requirements and included a set of daily measurements collected on a quarterly basis. The data used for this evaluation included effluent flow and effluent TP concentration, as well as upstream flow and TP concentration in the Middle Snake River. The values are shown in Table 44. The analysis was also conducted using the plant's permit limits in place of the monitoring data. The current permit does not include a limitation on outflow but does list a weekly average TP load limit of 990 lbs/day and a monthly average TP load limit of 710 lbs/day (USEPA, 2010).

Table 44. Twin Falls POTW Monitoring Data

Quarter	Date	TP, Middle Snake River Upstream of Discharge (mg/L)	TP, Effluent (mg/L)	Flow, Snake River (MGD)	Flow, Discharge (MGD)
2012, Q1	2/8/2012	0.052	11.18	2307	6.86
2012, Q2	5/2/2012	0.183	4.92	8337	6.25
2012, Q3	8/8/2012	0.058	6.43	711	5.44
2012, Q4	11/28/2012	0.13	4.2	475	8.4
2013, Q1	3/6/2013	0.324	5.9	544.8	8.1
2013, Q2	5/29/2013	0.171	5.54	1803	7.6
2013, Q3	8/14/2013	0.142	3.74	361	11.79
2013, Q4	11/6/2013	0.065	10.8	589	7.1

Using the monitoring data, flow-weighted concentrations were calculated to show the expected concentration of TP in the Middle Snake River assuming the effluent is fully mixed with upstream flow. The calculation was performed for three conditions:

1. Using effluent concentrations from the monitoring data (referred to as "effluent" concentration).
2. Using an estimated concentration corresponding to the permit limit weekly average TP load 990 lbs/day (referred to as "weekly permitted" concentration). Flow was assumed to be equal to plant flow on the quarterly monitoring date.
3. Using an estimated concentration corresponding to the permit monthly average TP load of 710 lbs/day TP (referred to as "monthly permitted" concentration). Flow was assumed to be equal to plant flow on the quarterly monitoring date.

Results are shown in Figure 143, Figure 144, and Figure 145 for each of the three conditions and compared to the upstream concentration. As seen in Figure 143, on dates when high flows were measured in the Middle Snake River (2012, Q1; 2012, Q2; 2013, Q2), mixing of effluent had little effect on TP concentration. On the dates when lower flows were observed, effluent TP had a noticeable effect on downstream concentration. Figure 38 also compares the instream concentrations to the TMDL instream target of 0.075 mg/L TP. The upstream concentrations exceed the target during four of the seven events. Across all events, the mixed "effluent" concentration exceeded the target. A similar trend exists for the estimated "weekly permitted" and "monthly permitted" concentrations (Figure 144 and Figure 145, respectively), though the concentrations are considerably higher. This comparison indicates that effluent concentrations may contribute to target exceedance for some of the events, and exacerbate exceedances in other events, but upstream flows and concentrations are likely to be a significant factor as well.

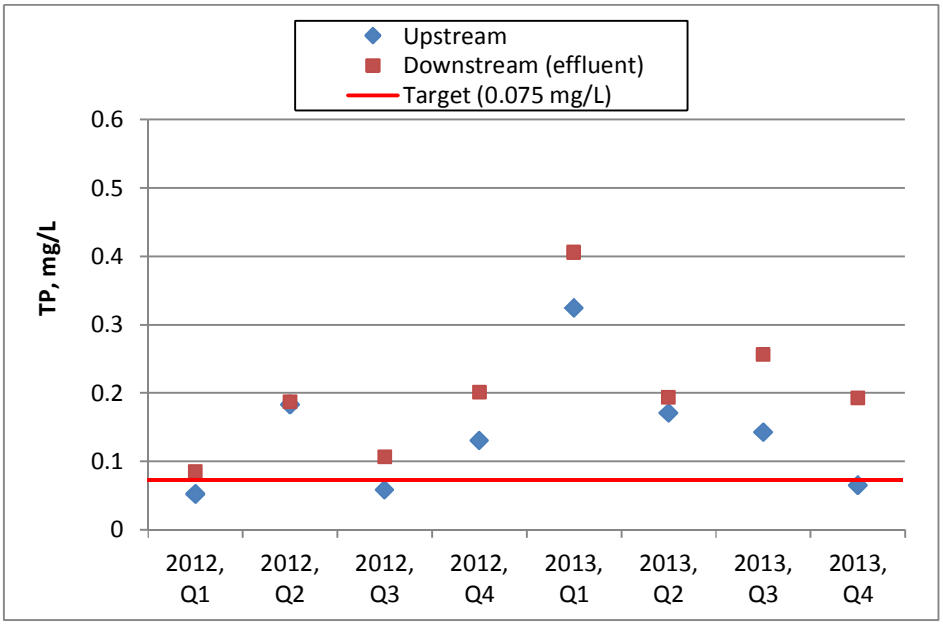

Figure 143. Comparison of TP Concentrations Upstream and Downstream of Twin Falls WWTP Using Measured Effluent Concentrations

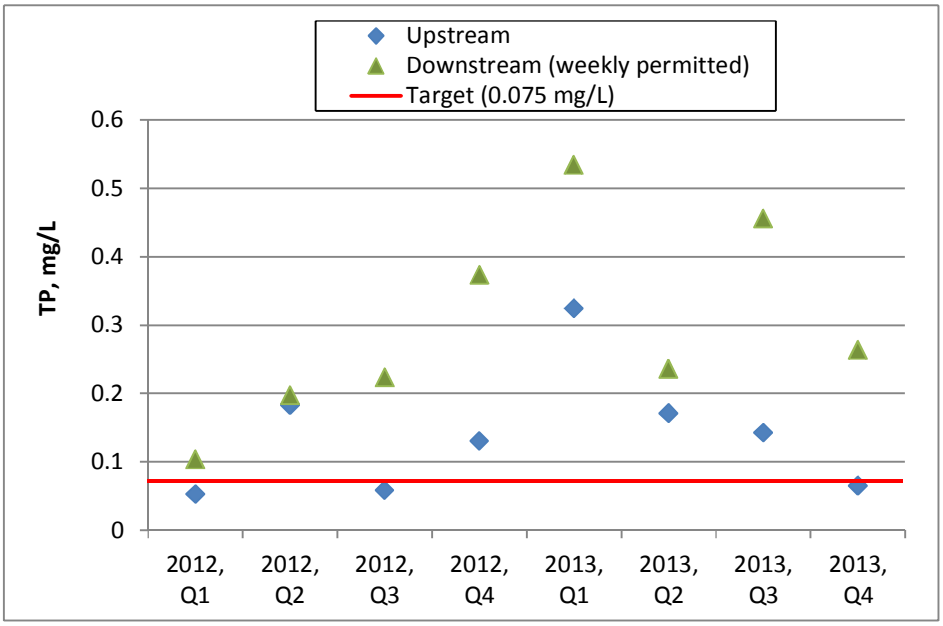

Figure 144. Comparison of TP Concentrations Upstream and Downstream of Twin Falls WWTP Using Weekly Permitted Limit

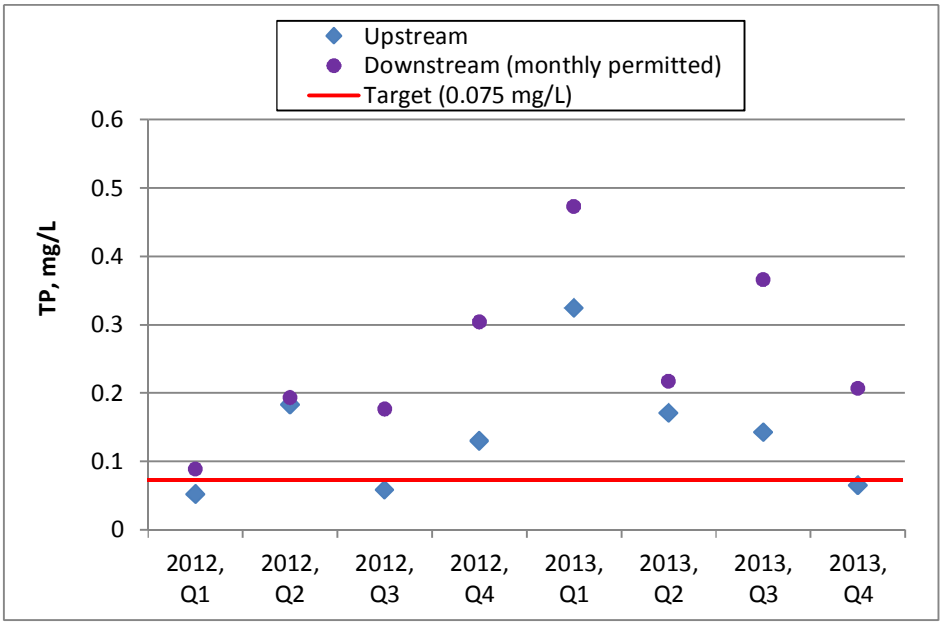

Figure 145. Comparison of TP Concentrations Upstream and Downstream of Twin Falls WWTP Using Monthly Permitted Limit

TP loads were also calculated from the monitoring data, representing both upstream conditions and load from the WWTP (Figure 146). With one exception (2013 Q4), background loads in the Middle Snake River are higher than the WWTP loads. If the weekly average TP load permit limit was evaluated, then the value of 990 lbs/day would simply substitute for the WWTP loads, as shown in Figure 147. Likewise, the monthly permitted load of 710 lbs/day is shown in Figure 148.

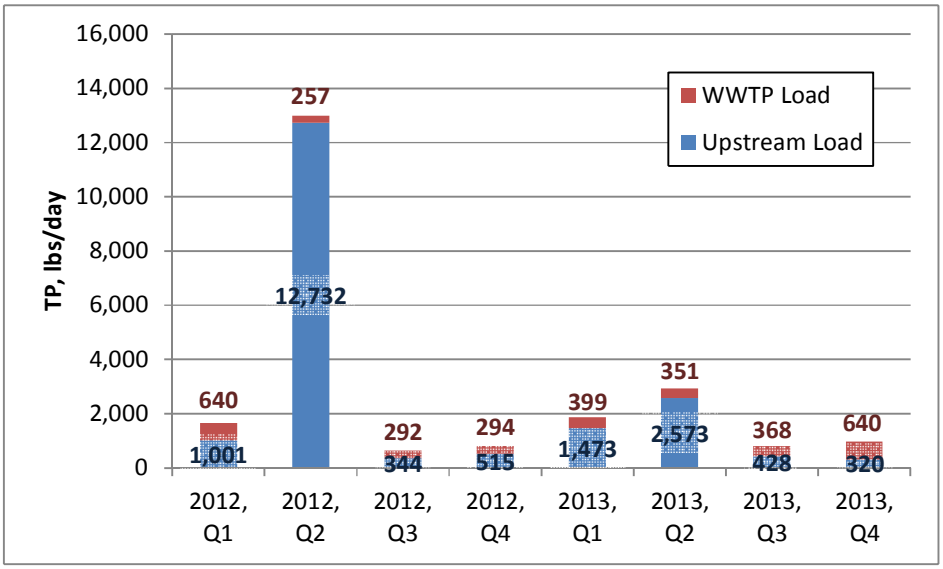

Figure 146. TP Loads from the Middle Snake River and Twin Falls WWTP

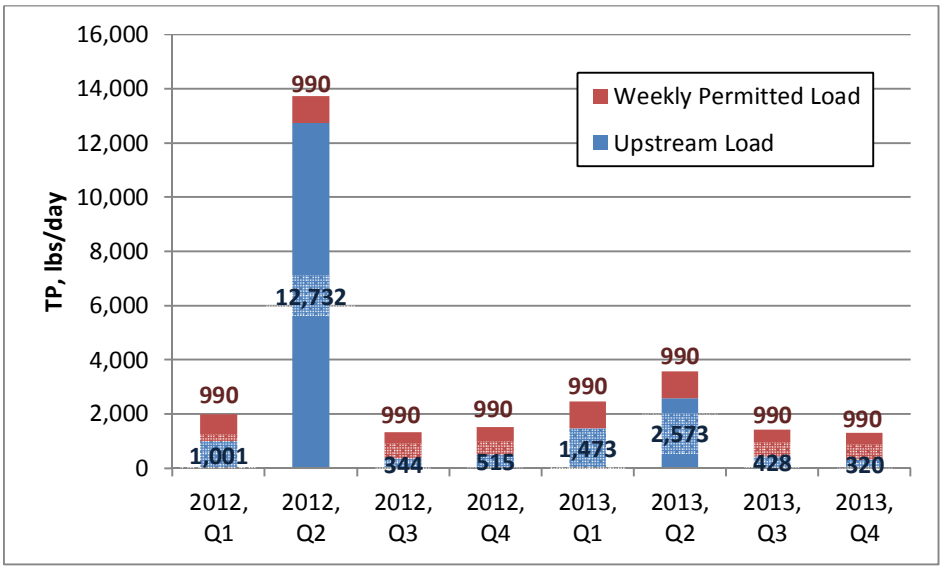

Figure 147. TP Loads from the Middle Snake River compared to Twin Falls WWTP weekly permitted load

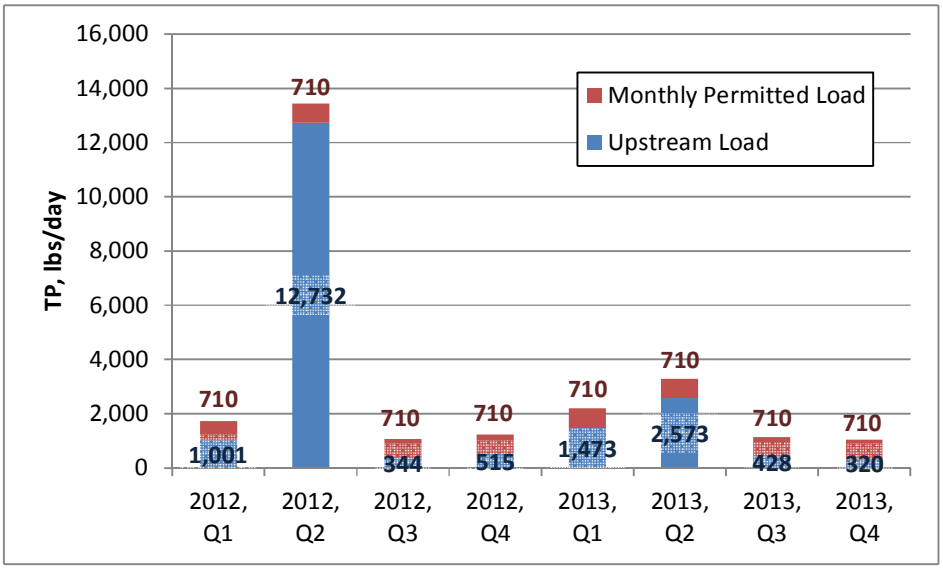

Figure 148. TP Loads from the Middle Snake River compared to Twin Falls WWTP monthly permitted load

I-5. EPA Risk Assessment

In the late 1990s and early 2000s, EPA conducted an ecological risk assessment of the Middle Snake River, which was documented in EPA (2002). The study selected tolerance limits for fish populations, macroinvertebrates, and aquatic plants as well as nutrients and other state variables. Then, a model simulation estimated the probability of exceeding these tolerance limits. Two major ecosystem components were assessed: 1) chemical, physical, and biological characteristics of the moving water column, and 2) the benthic plant community of the river bottom. EPA (2002) discusses how changes to the river's hydrology have altered aquatic species diversity, composition, and other indicators of ecosystem health.

EPA (2002) assessed ecological risk to the Middle Snake River using the model River Basin Model-10 (RBM10), which was a dynamic river basin model of mass and energy developed by Yearsley (1991, modified in 1996). Using standard kinetics, the model simulated temperature, dissolved oxygen, nitrogen, phosphorus, and algal biomass. Time scales ranged from hours to decades, and the model allowed for both vertical and longitudinal segmentation. Despite these functionalities, the model presented several limitations to understanding the complex ecological processes in the river system. The simulation mass and energy flow was limited to the water column and could not be simulated for sediments. Flow of mass and energy from sediment to roots of vascular plants was assumed to be unlimited by plant uptake, and neither gain nor loss of substrate to deposition or scouring was addressed.

A comprehensive monitoring dataset supported model development, and a discussion of previous studies on the Middle Snake River was included to support the assessment's findings. Assessment endpoints included:

- Reproduction and survival of three select fish species (rainbow trout, mountain whitefish, and white sturgeon);
- Reproduction, survival, and diversity of macroinvertebrates; and
- Growth and diversity of phytoplankton, macrophytes, and epiphytes.

EPA (2002) discussed, in detail, the formation of aquatic plant beds and the feedback loops that perpetuate and exacerbate nuisance aquatic plant growth in the Middle Snake River (Figure 149). EPA (2002) describes how the plant beds initially form from sedimentation, which reduces river depths and provides light availability and an ideal substrate for macrophytes[5]. This concept was supported by findings that dense aquatic plant beds in the Middle Snake River exist downstream of agricultural return flows and aquaculture discharges, which were significant sediment sources during the development of EPA (2002). Once established, the plant beds slow the river's velocity and increase sedimentation, encouraging further growth and establishment of aquatic plant beds.

Within the aquatic plant beds themselves, the macrophytes extract nutrients from the sediment and water column. High nutrient concentrations during the late growing season can lead to the dominance of non-rooting macrophytes since these species obtain nutrients exclusively from the water column. This plant growth forms a feedback loop in which nutrients are removed from the water column and deposited to the bed sediments during senescence, which are then available for uptake by rooted macrophytes. These processes can lead to an increase in nutrients in the bed sediments and perpetuate macrophyte growth.

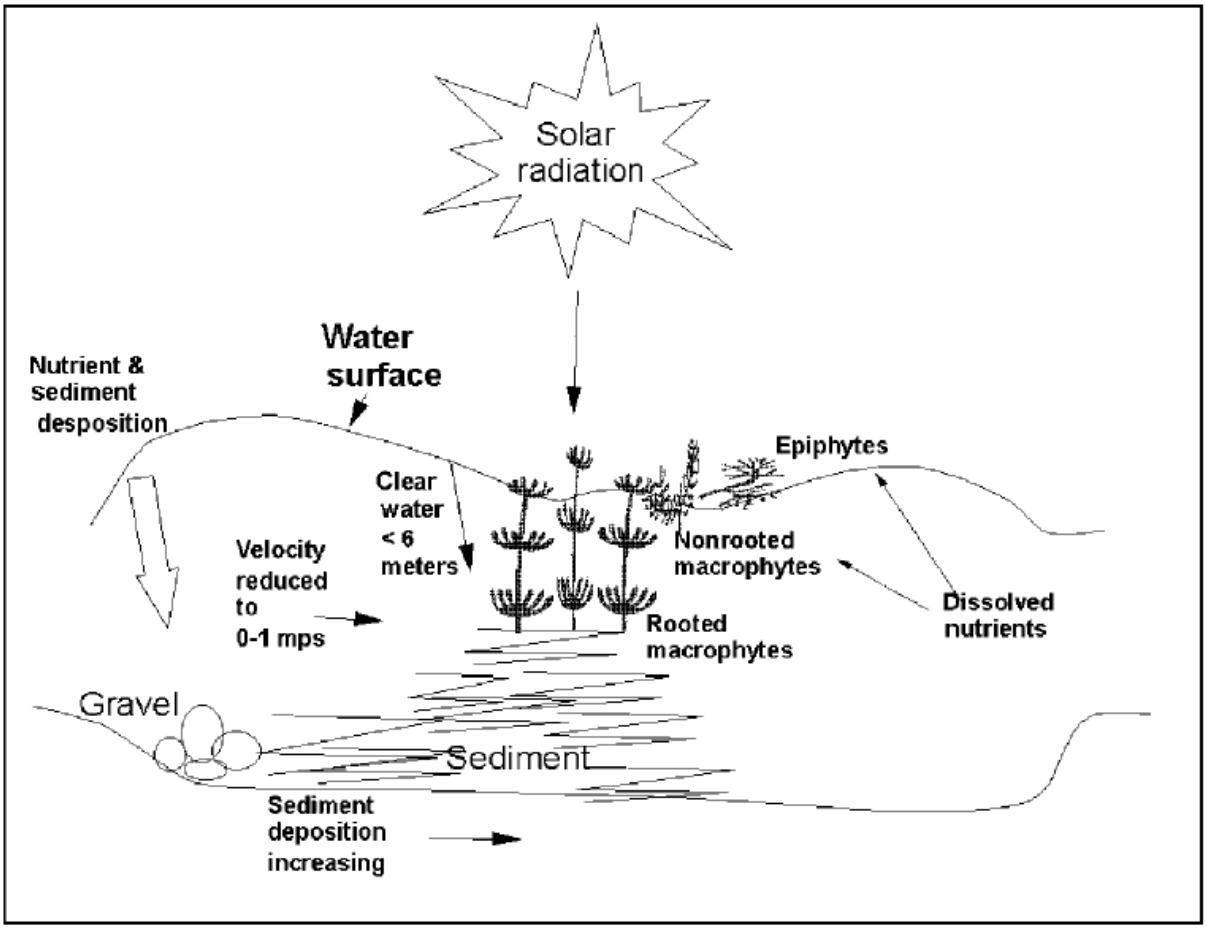

Figure 149. Factors controlling aquatic plants in the Middle Snake River, reproduced from EPA (2002)

[5] The macrophytes generally occur beyond 90 to 200 meters downstream of the elevated sediment discharges because sediments more proximate to the discharge are highly anaerobic, and the macrophytes are not able to grow under such conditions despite the high nutrient content (EPA, 2002).

Falter and Carlson (1994), Falter et al. (1995), and Falter and Burris (1996) provided results from detailed studies of aquatic macrophytes in the Middle Snake River as a supplement to the RBM10 modeling. These studies addressed aquatic macrophyte growth from Twin Falls to Upper Salmon Falls dam, with the greatest focus on Crystal Springs and Box Canyon. These reaches were considered to represent the greatest macrophyte density within the Middle Snake River while being representative of the processes occurring throughout the River. Among the reaches studied, the Crystal Springs reach had the highest biomass density and the least diversity of macrophyte species. Falter and Burris (1996) also found that a significant relationship between biomass and soluble reactive phosphorus (SRP) in the water column existed within the Crystal Springs reach, and this was the only reach for which this relationship was found to be significant. Across all reaches, EPA (2002) indicated that a poor correlation between dissolved nutrients and macrophyte biomass existed; however, the poor correlation was attributed to the inherent complexity of aquatic systems and the ability of rooted macrophytes to extract nutrients from both the sediment and water column.

The relationship between water column nutrients and biomass was more apparent when considering nonrooted macrophytes or epiphytes, which obtain nutrients exclusively from the water column. As cited in EPA (2002), Howard-Williams (1981) found that the development of epiphytes (*Cladophora*) on *P. pectinatus* communities increased with N and P fertilizer input but did not increase the rooted plant biomass. This effect was consistent with the observations in the Crystal Springs reach, where both epiphytic dominance and nutrient inputs were greatest compared to the other studied reaches, and the relationship between biomass and SRP was significant.

Sediment nutrient content provided further insight into processes occurring in the Middle Snake River. Regarding the relationship between sediment total phosphorus and aquatic plant biomass, Falter et al. (1995) and Falter and Burris (1996) reported the following results:

- Maximal aquatic plant biomass occurred at a total phosphorus level of approximately 1,100 mg/g TP dry weight (consistently measured throughout studied reaches); and
- Aquatic plant biomass generally declined above 1,100 mg/g TP dry weight.

The decline in biomass was attributed to the redox potential, low dissolved oxygen, and low pH coincident with extremely high organic matter content.

The risk assessment findings provide evidence for nutrient retention within the aquatic plant beds. EPA (2002) cited the results of Thomas et al. (1995), which studied respiration rates and organic carbon turnover rates in the Middle Snake River. Turnover time for organic carbon is the time required for the average carbon molecule to pass from being fixed in photosynthesis to being released through decomposition under aerobic conditions. Thomas et al. (1995) found that the Middle Snake River exhibited very high rates of respiration but very low organic carbon turnover rates. The slow rate of turnover suggested that high levels of nutrients, as well as detritus and energy, were being trapped, and that the sediment deposits and aquatic plant beds facilitated this process. EPA (2002) concluded that this ultimately resulted in a reduced flow of nutrients downstream of the aquatic plant beds. This effect was expected to be greatest along the Crystal Springs reach where both upstream nutrient loading and aquatic plant density were greatest. In particular, aquatic plant biomass was measured up to eight times greater in Crystal Springs than in any other studied reach (EPA, 2002). During the periods of maximum plant growth in the Crystal Springs Reach, Falter et al. (1995) demonstrated that TP and SRP decrease from upstream and to downstream of the aquatic plant beds. While flow inputs from springs within this reach may have contributed, in part, to the decrease in concentration, these findings suggest that nutrient retention may be occurring within the aquatic plant beds in the Middle Snake River.

The EPA risk assessment concluded that the macrophyte beds presented a substantial risk to the Middle Snake River ecosystem. From the Crystal Springs reach to the Boulder Rapids reach, the RBM10 simulation results indicated a high risk of exceedance for the total macrophyte and epiphyte biomass

tolerance limits.[6] EPA (2002) also compared biomass densities measured in the Crystal Springs, Box Canyon, and Thousand Springs reaches to densities cited in the literature for other systems, and all three Mid Snake locations compared with, or exceeded, levels measured in other systems classified as eutrophic. The high risk probability was especially evident for low-flow years and strongly tied to the management practices current during the model development. EPA (2002) stated that the likelihood of recovery depended on "the availability of clear, cold water, with high flows capable of scouring out long-deposited sediments." The alcove springs[7] along the Middle Snake River provided a benchmark for recovery due to the cold, clear, and significant flow input of the springs, the relatively low nutrient concentrations, and the resulting high diversity and low density of the aquatic macrophytes downstream of the springs. EPA (2002) generally suggested that efforts to address nuisance macrophyte beds should focus on reducing nutrients and sediment and returning flow patterns to a more natural hydrograph.

EPA (2002) provides a wealth of information relevant to the Data Report and future management efforts within the Upper Snake-Rock Subbasin. Tetra Tech recommends adding this information to the following sections of the Data Report:

Section 2. Setting: Add sentences to the soils and hydrology sections, directing the reader to EPA (2002) for additional information on geology and hydrology respectively.

Section 4.6. Macrophytes: Add introductory text explaining the mechanisms leading to aquatic plant bed establishment. Revise to include four subsections: 1) Macrophyte Species (including rooted versus non-rooted); 2) Macrophyte Density; 3) Seasonal Variability in Macrophyte Growth Rates; and 4) Macrophyte Harvesting. The density subsection would include brief documentation of macrophyte density measurements and a comparison across the reaches as cited in EPA (2002). The latter section would include the text currently in Section 4.6.

Section 6. Attenuation: Retain the general text discussing the breadth of attenuation mechanisms. Remove the last paragraph discussing SPARROW. Rewrite the second to last paragraph to address results from EPA (2002) and incorporate the EPA (2002) findings relating to retention of nutrients in the aquatic plant beds. Two subsections may provide improved organization: 1) General Mechanisms and 2) Macrophyte Nutrient Cycling and Retention.

Section 7. Mass Balance: Revise statements about attenuation to be consistent with the revised Section 6.

Section 8. Assessment Discussion: Revise statements about attenuation to be consistent with the revised Section 6. Incorporate conclusions from EPA (2002), including likelihood of tolerance limit exceedance and recovery potential.

I-6. Recommendations

The supplemental data analysis provides important and timely information regarding the most recent trends in TP concentration and loading as well as mechanisms for nutrient retention and management implications for the Middle Snake River. To incorporate this information, Tetra Tech recommends the following revisions to the Data Summary, Evaluation, and Assessment Report:

- Trend Analysis and LOADEST Modeling:
    - Include full methods and results text as an appendix.

[6] The biomass tolerance limits were designated as 200 g/m^2 biomass (ash free, dry matter), which represents the threshold hold above which nuisance levels occur.
[7] Alcove springs are springs that discharge from the lower canyon walls along the Snake River banks.

  - In Section 4.3 Water Quality, Mainstem, summarize the results and include Table 3 (Trend Results for All Locations) and LOADEST table and figures showing results for all locations.
  - Indicate that previous data review did not include most recent years and, therefore, did not indicate the recent decreasing trends (lower level of effort) *or* revise mainstem data figures in the main text and appendix to reflect most recent data (higher level of effort).
- Twin Falls Comparison:
  - In Section 4.5 Point Source Discharge Monitoring, include a separate subsection for the Twin Falls Comparison.
- EPA (2002) literature review:
  - Add text to multiple report sections as recommended previously in Section 5.

These recommendations are provided for discussion purposes and in order to solicit feedback from EPA and DEQ regarding the appropriate inclusion of this additional analysis in the Data Summary, Evaluation, and Assessment Report.

I-7. References

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