Montana Department of Environmental Quality

Demonstration of Nonanthropogenic Arsenic Levels: Yellowstone River, Montana

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EXECUTIVE SUMMARY

Arsenic concentrations along much of the Yellowstone River are consistently above Montana's human health standard of 10 µg/L. Per Montana law, it is not necessary to treat wastes to a condition purer than the natural condition (75-5-306, MCA) and the Department of Environmental Quality (DEQ) may not apply a water quality standard to a water body that has a nonanthropogenic concentration greater than the standard (75-5-222, MCA). The major source of arsenic loading to the Yellowstone River is known to be nonanthropogenic—the geothermal waters of the Yellowstone Caldera in Yellowstone National Park. However, the proportion of the total arsenic load along the Yellowstone River that is nonanthropogenic has not previously been determined.

This document presents the approach DEQ took to demonstrate the levels of nonanthropogenic and anthropogenic arsenic in the Yellowstone River Basin. This work is referred to as the demonstration of nonanthropogenic condition, or DON for short.

Hydrologic modeling and mass balance techniques were used together to calculate the nonanthropogenic levels in the study region of the Yellowstone River Basin, which includes the Yellowstone River watershed from the Montana/Wyoming Border to the mouth of the Bighorn River near Bighorn, Montana. The study region was divided into five hydrologic segments:

- Segment 1 - Montana/Wyoming border to the mouth of Mill Creek near Pray, MT
- Segment 2 - Mill Creek to the mouth of the Boulder River near Big Timber, MT
- Segment 3 - Boulder River to the mouth of the Stillwater River
- Segment 4 - Stillwater River to the mouth of the Clarks Fork of the Yellowstone River
- Segment 5 - Clarks Fork of the Yellowstone River to the mouth of the Bighorn River

DEQ compiled existing arsenic and flow data for the Yellowstone River and its tributaries from various sources. Where more data were needed, DEQ supplemented the existing data with monitoring data conducted between 2013 and 2017. Existing DEQ and other state databases supplied the anthropogenic loads for permitted sources and ground water sources. Modeling was conducted to determine the amount of arsenic present in sediment runoff from current and "natural" landscapes; the difference was attributed to anthropogenic activities. Ultimately, DEQ conducted a modified mass balance using all of these data and approaches to determine how much of the arsenic load in the Yellowstone River is nonanthropogenic, and the potential level of error in the calculation.

The modified mass balance conducted in this report showed that the arsenic load of the Yellowstone River above the confluence of the Bighorn River is approximately 97 percent nonanthropogenic. The nonanthropogenic concentrations and percentages of arsenic immediately downstream of Yellowstone National Park is highest in Segment 1, and decreases as the Yellowstone River travels downstream.

DEQ also evaluated Yellowstone River hydrograph information and determined that the Yellowstone River has a high flow season from May 1st to July 31st and a low flow season from August 1st to April 30th; the monitoring data show that the Yellowstone River arsenic concentrations vary by high and low flow season.

Based on the results of this report, the Yellowstone River Basin nonanthropogenic standards for arsenic will be selected as detailed in a separate DEQ document.

Table of Contents

List of Tables

List of Figures

ACRONYMS

AAL	Anthropogenic Arsenic Load
BLM	Bureau of Land Management
CV	Coefficient of Variation
CECRA	Comprehensive Environmental Cleanup and Responsibility Act
DEQ	Montana Department of Environmental Quality
DON	Demonstration of Nonanthropogenic
EPA	Environmental Protection Agency
GIS	Geographical Information System
GW	Ground Water
GWA	Ground Water - Anthropogenic
GWIC	Groundwater Information Center
HAWQS	Hydrologic and Water Quality System
HUC	Hydrologic Unit Code
ICIS	Integrated Compliance Information System
kg/day	kilograms per day
LOADEST	Load Estimator Model
LUST	Leaking Underground Storage Tank
MBMG	Montana Bureau of Mines and Geology
MCA	Montana Code Annotated
mg/kg	milligrams per kilogram
MLE	Maximum Likelihood Estimation
MPDES	Montana Pollutant Discharge Elimination System
MUSLE	Modified Universal Soil Loss Equation
NAL	Nonanthropogenic Arsenic Load
NAS	Nonanthropogenic Standard
NGS	National Geochemical Survey
NSE	Nash-Sutcliffe Coefficient of Efficiency
NWIS	National Water Information Service
PSL	Point Source Load
QAPP	Quality Assurance Project Plan
R^2	Coefficient of Determination
RO	Surface Water Runoff
ROA	Surface Water Runoff - Anthropogenic
RRS	Remediation Response Sites
SAP	Sampling and Analysis Plan
SWAT	Soil and Water Assessment Tool
TAL	Total Arsenic Load
Trib	Tributary
µg/L	micrograms per liter
USFS	United States Forest Service
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
WQPB	Water Quality Planning Bureau
WQSM	Water Quality Standards and Modeling Section
WDEQ	Wyoming Department of Environmental Quality
YNP	Yellowstone National Park

1.0 INTRODUCTION

This document presents the methods and results for demonstrating the levels of nonanthropogenic and anthropogenic arsenic in the Yellowstone River Basin. This work is referred to as the demonstration of nonanthropogenic condition (DON). The work was completed by the Water Quality Standards & Modeling Section (WQSM) which is in the Water Quality Planning Bureau (WQPB) of the Montana Department of Environmental Quality (DEQ). Assistance was also provided by DEQ's Water Protection Bureau. The geographic area covered in this document includes the Yellowstone River Basin from the Montana/Wyoming Border to the mouth of the Bighorn River near Bighorn, Montana, and includes associated tributaries and drainages.

For this demonstration, the terms natural and nonanthropogenic are synonymous and mean the background concentration of arsenic due only to non-human induced sources. Surface water arsenic concentrations and standards refer to total recoverable arsenic while ground water concentrations and standards refer to dissolved arsenic. Note that many figures within this document are not appropriate for grayscale and best viewed when printed in color.

1.1 PURPOSE

The purpose of this DON is to provide a scientifically defensible demonstration of the nonanthropogenic arsenic condition of the Yellowstone River Basin. Based on this demonstration, DEQ will then detail how it selected the nonanthropogenic arsenic standards (NAS) in a separate document (DEQ, 2019).

1.2 SUPPORTING DOCUMENTS

Investigations completed by the United States Geological Survey (USGS) and other researchers conclude that the elevated arsenic concentrations in the Yellowstone River are likely coming from nonanthropogenic sources. The geothermal water of the Yellowstone Caldera in Yellowstone National Park (YNP) provides the largest source of arsenic loads to the Yellowstone River and has been well documented by the following list of researchers. The complete list of citations is located in **Section 6.0**.

- Jack J. Rowe, Robert O. Fournier, and G. W. Morey, 1973.
- John D. Hem, 1985.
- K.A. Miller, M.L. Clark, and P.R. Wright, 2004.

The quality assurance descriptions for field data collection, data compilation, and modeling described in this document were provided in the DEQ Quality Assurance Project Plan (QAPP) and Sampling and Analysis Plans (SAPs; DEQ, 2015a; 2015b; 2016a; 2017a). Full citations are in the reference section of this document.

1.3 BACKGROUND

1.3.1 Yellowstone National Park

The Yellowstone Caldera provides the largest source of arsenic loading to the Yellowstone River; YNP has over 10,000 thermal features including more than 300 geysers (YNP, 2015). The Yellowstone River originates just southeast of the park and flows into YNP, feeding and draining Yellowstone Lake (Uhler, 2014). The Yellowstone River then flows north through the park, gaining geothermal arsenic loading contributions from the Lamar and Gardner rivers. The Yellowstone River leaves YNP near Gardiner, Montana and flows northeasterly until it joins the Missouri River in North Dakota.

1.3.2 Yellowstone River Arsenic Segment Delineation

In large part due to the geothermal activity in YNP, the Yellowstone River arsenic concentration is elevated above Montana's human health standard of 10 µg/L (Circular DEQ-7, June 2019) for a significant distance. The concentration does not remain constant, however; the river's concentration decreases as the Yellowstone River is diluted by flow from tributaries with lower arsenic concentrations.

DEQ evaluated Yellowstone River hydrograph information (see **Section 2.1.2**) and determined that the Yellowstone River has a high flow season from May 1st to July 31st and a low flow season from August 1st to April 30th; furthermore, monitoring data show that the Yellowstone River arsenic concentrations vary by high and low flow season.

This DON evaluation encompasses the Yellowstone River from the Montana/Wyoming border, which has an annual median arsenic concentration of 29 µg/L (represented by Corwin Springs data) down to the confluence of the Bighorn River (represented by Billings data), which has an annual median arsenic concentration of 10 µg/L (**Figure 1-1**).

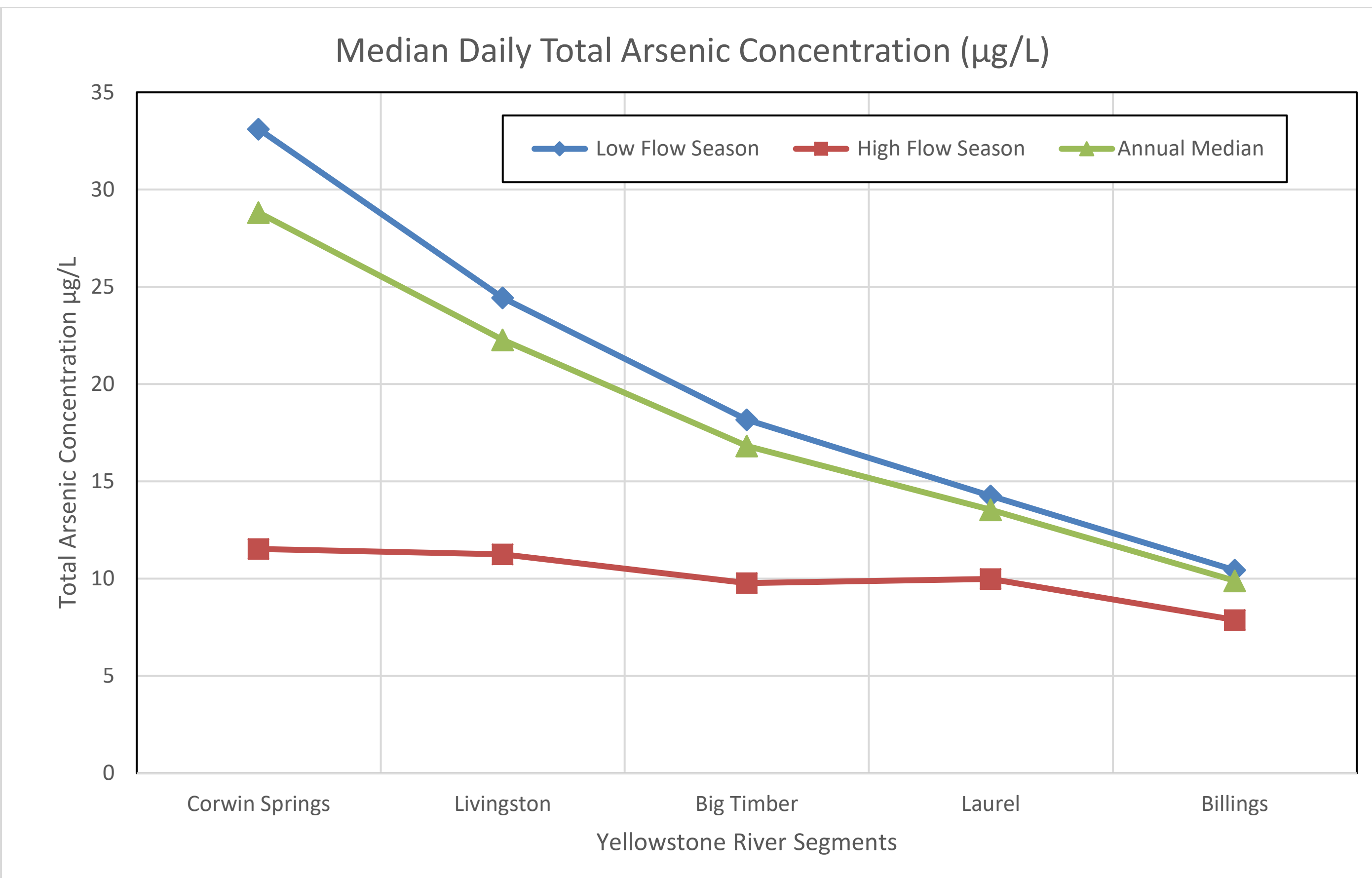

Figure 1-1. Yellowstone River Median Total Arsenic Concentrations from the Five Monitoring Stations

The river's arsenic concentrations from the Montana/Wyoming border through Livingston are consistently above 10 µg/L for both high and low flow seasons. As the Yellowstone River is diluted by tributaries with lower arsenic concentrations during the high flow season, the arsenic concentrations below Livingston are at or below the standard. However, during low flow conditions, the Yellowstone River from the Montana/Wyoming border to the mouth of the Clarks Fork of the Yellowstone River are consistently above the human health standard (DEQ, 2012; 2017b).

The arsenic concentration and resulting Yellowstone River load analysis evaluated in this DON are based on measurements at five river monitoring stations—most of which are in the first third of the corresponding segment. Each segment ends immediately before the mouth of a relatively large tributary, and DEQ assumed that the arsenic concentration and load at the monitoring station for each segment is representative of the length of the segment.

The five segments of the Yellowstone River present demonstrably different median arsenic concentrations based on tributary dilution during high and low flow. Although it was not a specific criterion for selecting the five segments, the low flow median arsenic concentrations decrease by more than 20% between each successive segment indicating a significant difference between each segment.

The raw arsenic and flow data is maintained by DEQ and is available upon request. The seasonal and annual concentrations are presented in **Table 1-1**.

Table 1-1: Median Total Arsenic Concentrations in the Yellowstone River (2008- 2018) [1]

Yellowstone River Segment			**Yellowstone River Sampling Location**	**Median Total Arsenic Concentration (µg/L)**		
#	**Beginning**	**End [2]**		**High Flow Season**	**Low Flow Season**	**Annual**
1	Montana/Wyoming Border	Mill Creek near Pray	Corwin Springs	12	33	29
2	Mill Creek	Boulder River at Big Timber	Livingston	11	24	22
3	Boulder River	Stillwater River near Columbus	Big Timber	10	18	17
4	Stillwater River	Clarks Fork of the Yellowstone River at Laurel	Laurel	10	14	14
5	Clarks Fork of the Yellowstone River	Bighorn River at Bighorn	Billings	8	10	10

[1] See Yellowstone River LOADEST summary in **Section 4.2.**
[2] Each segment ends immediately before the confluence with the referenced tributary.

Per Montana law, DEQ may not apply a water quality standard to a water body that has a nonanthropogenic concentration greater than the standard (75-5-222, MCA). Furthermore, Montana law has stated since 1967 that dischargers are not required to discharge to purer than natural (75-5-306, MCA). The arsenic concentration data in **Table 1-1** does not show the amount of arsenic that is nonanthropogenic (i.e., natural) for each segment; rather, it is the total ambient arsenic concentration. In this report, DEQ quantifies the amount of the total arsenic load in the Yellowstone River Basin that is nonanthropogenic in order to provide the foundation for setting standards at the nonanthropogenic level of the water body. The standards themselves are presented in the NAS document (DEQ, 2019).

2.0 METHODS

The steps associated with the Yellowstone River arsenic DON are listed below:

- 2.1 Hydrologic Region and Seasonality
- 2.2 Methods for Calculating Arsenic Load
- 2.3 Basin-wide Modified Mass balance
- 2.4 Data Sources and Compilation

The methods are summarized in the following sections. The results of these methods are presented in **Section 4.0**. In **Section 4.0** we also cross-check the results of the Modified Mass Balance against a LOADEST model of arsenic for the mainstem Yellowstone River only. This provides information about the accuracy and relative error of the two different approaches.

2.1 HYDROLOGIC REGION AND SEASONALITY

2.1.1 Hydrologic Region

DEQ studied the Yellowstone River Basin from the Montana/Wyoming Border to the confluence with the Bighorn River. DEQ used the USGS Hydrologic Unit Code (HUC) system to classify sub-basins and watersheds within this project area. The largest division used for this project is a HUC8 (8-digit code)—also referred to as the sub-basin level—and these HUC8s are listed in **Table 2-1**.

Table 2-1. Project Associated HUC8 Sub-basins

HUC	Name of Sub-basin	Description of Sub-basin
10070001	Yellowstone Headwaters	YNP to Yellowstone River at McConnell Access
10070002	Upper Yellowstone	Yellowstone River at McConnell Access to approximately 16 river miles past Big Timber
10070003	Shields	Major Tributary Basin – Shields River
10070004	Upper Yellowstone-Lake Basin	Yellowstone River, 16 river miles past Big Timber to Billings
10070005	Stillwater	Major Tributary Basin – Stillwater River
10070006	Clarks Fork Yellowstone	Major Tributary Basin – Clarks Fork Yellowstone River
10070007	Upper Yellowstone – Pompeys Pillar	Yellowstone River, Billings to confluence of Bighorn River
10070008	Pryor	Major Tributary Basin – Pryor Creek

As mentioned, DEQ divided the project into five hydrologic segments to evaluate the Yellowstone River's nonanthropogenic arsenic condition as it flows downstream from the Montana/Wyoming Border to the mouth of the Bighorn River. The five segments, and the relevant HUC8 sub-basins that drain into the Yellowstone River over the extent of this effort, are shown in **Figure 2-1.**

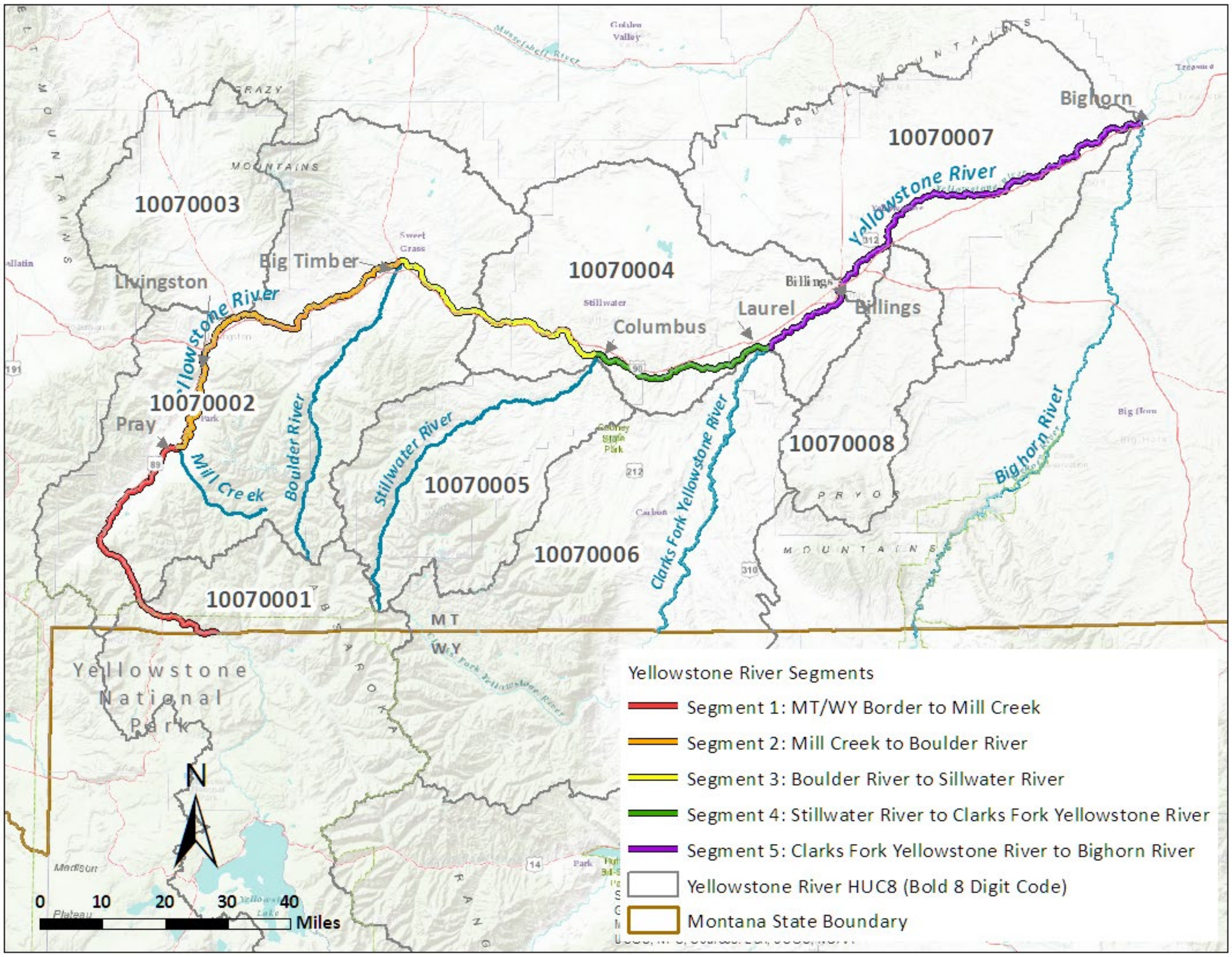

Figure 2-1. Location of Project Sub-basins (HUC8) and Segments

DEQ also used the HUC10, which divides the sub-basins into smaller watersheds, for surface water runoff modeling purposes (**Section 2.4.5.3**). There were 65 HUC10s within the hydrologic region. **Appendix A** provides a list of each HUC10 within the five hydrologic segments.

2.1.2 Seasonality Determination

DEQ reviewed available USGS flow data to evaluate seasonal fluctuation in the Yellowstone River. Daily flows for the three Yellowstone River project segments with USGS monitoring stations display a seasonal flow pattern (**Figure 2-2**).

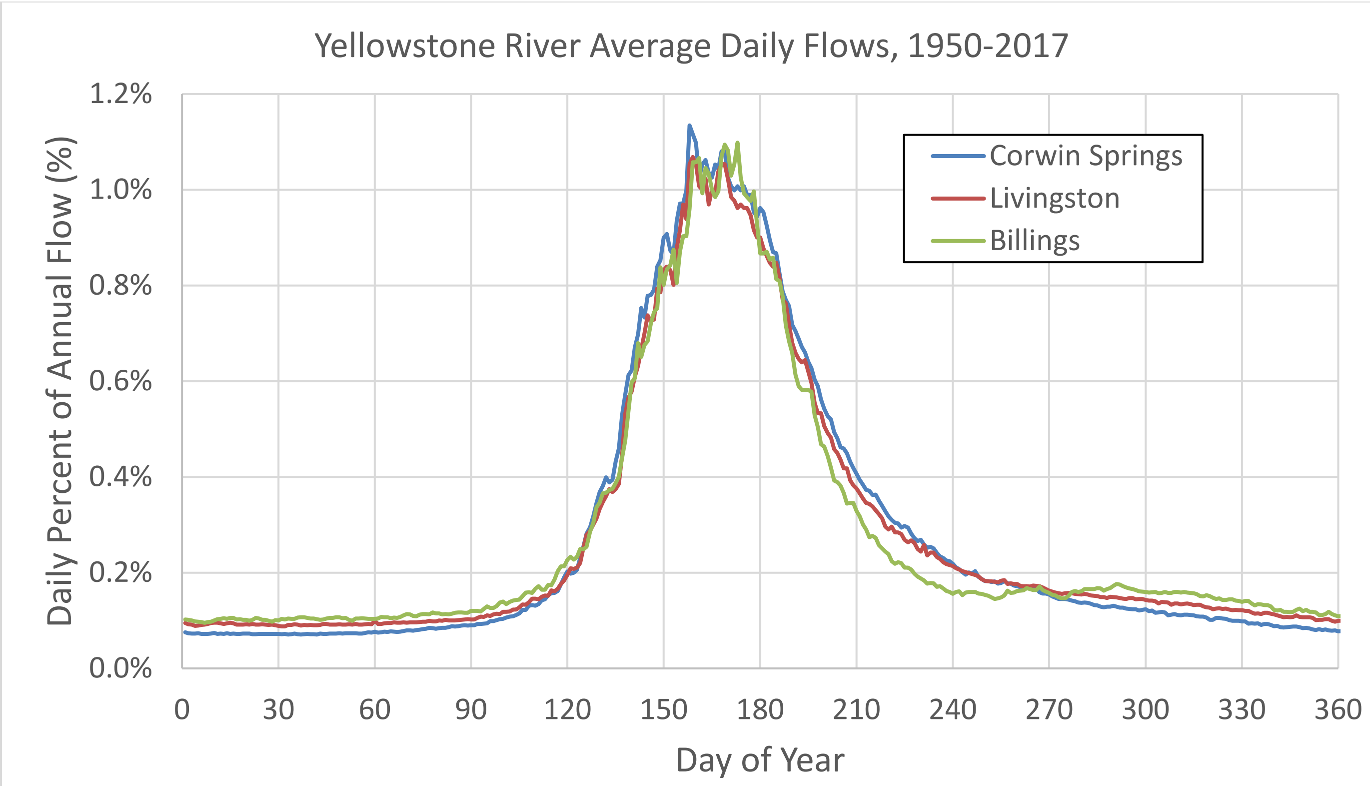

Figure 2-2. Yellowstone River Daily Flow as Percent of Annual Flow at the USGS Monitoring Stations: Corwin Springs (Segment 1), Livingston (Segment 2) and Billings (Segment 5)

Appendix B includes the hydrographs for the Yellowstone River segments 1 through 5 as well as the raw data used to evaluate seasonality. Distinguishing between high and low flow periods followed the methods of Suplee et al. (2007). In these hydrographs, the runoff period is bracketed by two points of greatest inflection and rounded to the nearest end-of-month. All segments displayed a seasonal flow pattern; the high flow runoff period is May 1 (day 121) to July 31 (day 212) and the low flow period is August 1 to April 30.

The observed arsenic concentrations from the high and low flow periods were tested for significant differences (95% confidence, or α= .05) using the Mann-Whitney test in R. The results of the Mann-Whitney test showed a p-value less than the chosen alpha (.05) in all segments, leading to the conclusion that arsenic concentrations for the high and low flow seasons are significantly different. Therefore, for all segments of the river, the standard will be seasonal (i.e. one standard for the high flow season, and one standard for the low flow season). The standard is discussed in more detail in the NAS (DEQ, 2019). The Mann-Whitney test results are presented in **Appendix B**.

An example of the seasonal arsenic concentrations observed in Segment 1 at Corwin Springs are shown in **Table 2-2**. The low flow months are shown in light gray (August through April) and high flow months shown in blue (May through July).

Table 2-2. Corwin Springs (Segment 1) Observed Arsenic Concentrations, by Season

Date	Month	Median Arsenic Value (µg/L)
5/02/2015	May	9
6/03/2015	June	7
7/08/2015	July	18
8/09/2015	August	19
9/12/2015	September	33
10/11/2015	October	33
11/07/2015	November	31
3/12/2016	March	41
5/21/2016	May	8
7/28/2016	July	24
8/16/2016	August	28
9/11/2016	September	33
10/26/2016	October	25
11/16/2016	November	24
1/17/2017	January	36
2/14/2017	February	38
3/14/2017	March	34
4/20/2017	April	18
5/23/2017	May	11
6/05/2017	June	9
6/20/2017	June	10
7/13/2017	July	15
8/08/2017	August	18
9/06/2017	September	25
10/11/2017	October	23

**High Flow Period in Blue and the Low Flow Period in Light Gray.*

2.2 Methods for Calculating Arsenic Load

Sections 2.2.1 and **2.2.2** describe the methods used to determine the arsenic load, based on the amount and type of available data.

2.2.1 Mass Load Analysis

The simplest method used for calculating the arsenic mass load is a mass load analysis calculation for each sample pair collected (flow and concentration), as shown in ***Equation 1***:

Equation 1: **ML = C x Q x t x cf**

where,

ML – Mass Load (kilograms/day)
C – Concentration (µg/L or mg/L)
Q – Flowrate at a point (cubic feet per second, cfs)
t – A period of time (season, month, or year; a day in this case)
cf – conversion factor for mass load calculation (variable depending on units of individual terms)

DEQ used a mass load analysis to calculate the arsenic load for a defined amount of time in cases where there are limited available concentration data and/or the river or stream location does not have a USGS gaging station with several years of continuous flow data.

The advantage of using mass load analysis is that a load can be estimated with less data and without a USGS gaging station. The disadvantage is that the results are only as reliable as the data collected. For instance, if the data are highly variable with limited seasonal representation, the mass load results have the same limitations. For all mass load calculations, incorporating more data with seasonality and annual fluctuations is best for statistically valid results. Data needs and statistical validity for mass load analysis are discussed further in **Section 3.0**.

2.2.2 Modeling Approach (LOADEST and HAWQS)

DEQ used the USGS computer program LOADEST (LOAD ESTimator) to model the total arsenic load (TAL) in the Yellowstone River from paired concentration and flow data for each of the five Yellowstone River segments. DEQ also used LOADEST to model the tributary arsenic load from paired concentration and flow data for four of the major tributaries: Shields River, Boulder River, Stillwater River, and Clarks Fork Yellowstone River.

DEQ used a computer program, the Hydrologic and Water Quality System (HAWQS) watershed model, to model the arsenic load in surface water runoff for all tributaries in the Yellowstone River Basin.

LOADEST and HAWQS are briefly discussed below and the results presented in **Section 4.0.**

LOADEST- Total Arsenic Load Determination

LOADEST is a USGS program that enables a direct calculation of mass flux (arsenic in this case), which is equivalent to mass load when there is a continuous record of concentration and discharge (Aulenbach et al., 2007). Mass flux (Φ) is the product of constituent concentration (*C*) and discharge (*Q*) integrated over time (*t*). LOADEST uses a regression-model method, also known as the rating-curve method, which is a standard statistical technique used to estimate concentration continuously. Given a time series of streamflow and pollutant concentrations, LOADEST produces regression models for the estimation of pollutant loads (Runkel et al., 2004). The LOADEST model provides mean load estimates, standard errors, and 95 percent confidence intervals on a monthly and/or seasonal basis.

Data inputs included daily flow data obtained from existing USGS gaging stations and total recoverable arsenic concentrations obtained from periodic grab samples taken by either USGS or DEQ (**Appendix C** - Yellowstone River and **Appendix D** - four major tributaries). The arsenic samples were typically collected monthly and include an associated flow value. The LOADEST model requires a minimum of twelve concentration-flow paired data points.

LOADEST outputs include annual and monthly load and concentration averages, daily load and concentration estimates, and calibration and modeling statistics (discussed in **Section 4.2**). The LOADEST outputs also include diagnostic tests and warnings to assist in determining the appropriate estimation method and in interpreting the estimated loads (Runkel et al., 2004). Essentially the LOADEST program finds a best fit data model of flux as a function of discharge, then interpolates these relationships to estimate flux from daily flow data. The outputs presented in this document incorporate an Adjusted Maximum Likelihood Estimation (AMLE) technique (Runkel et al., 2004) for the median daily and monthly loads. A median of the LOADEST-calculated mass loads for the Yellowstone River (TAL) and the median of the LOADEST-calculated mass loads for the four tributaries are used in the basin-wide modified mass balance equation (**Section 2.3**).

HAWQS - Arsenic from Surface Water Runoff
DEQ calculated sediment runoff from land uses into surface water for both existing and natural conditions, using the web-based version of the Soil and Water Assessment Tool (SWAT) also known as HAWQS. HAWQS calculates sediment loading based on land cover, land management practices, soil composition, soil erodibility, land slope, and climate using the Modified Universal Soil Loss Equation (MUSLE). Using existing soil arsenic concentration data and HAWQS sediment modeling results, the arsenic loading from surface water runoff was evaluated at the HUC10 scale (discussed in **Section 4.6**).

2.3 Basin-wide Modified Mass Balance

A modified mass balance model was used for calculating the sources of arsenic loading in the Yellowstone River Basin. We refer to it as “modified” because some components are based on directly-measured data (e.g., arsenic concentrations and flow at gages) while other components are based on modeling (e.g., HAWQS was used to model the arsenic load in surface water runoff for all tributaries). The mass balance equation can be expressed as follows:

Equation 2: **TAL = YNP + PSL + GW + RO (+ Trib)**

where,

TAL – Total arsenic load
YNP - Nonanthropogenic geothermal arsenic load from the Yellowstone Caldera
PSL – Point source arsenic load
GW – Ground water arsenic load
RO – Non-point source runoff arsenic load
Trib – Total arsenic load associated with tributary discharge into the mainstems (*only if not accounted for in previous terms*.)

The arsenic load is the mass of arsenic transported at a point in a waterbody during a defined period of time. The individual variables in ***Equation 2*** are all expressed as mass loads (kg per day, month, or year). Data on both hydrological conditions and the arsenic concentration are considered simultaneously.

The total arsenic load in the Yellowstone River includes both nonanthropogenic arsenic load and anthropogenic arsenic load sources, and can be expressed as follows:

Equation 3: **TAL = NAL + AAL**

where,

TAL – Total arsenic load
NAL – Nonanthropogenic arsenic load
AAL – Anthropogenic arsenic load

To distinguish between nonanthropogenic and anthropogenic sources, ***Equation 2*** is further specified as:

Equation 4: **TAL = YNP + PSL + GWA + GWN + ROA + RON (+ TribA + TribN)**

where,

- **TAL** – Total arsenic load
- **YNP** – Geothermal arsenic from the Yellowstone Caldera (nonanthropogenic)
- **PSL** – Point source arsenic load (anthropogenic)
- **GWA** – Ground water mass load contributions considered anthropogenic
- **GWN** – Ground water mass load contributions considered nonanthropogenic
- **ROA** – Surface water runoff with anthropogenic-derived arsenic loading
- **RON** – Surface water runoff with nonanthropogenic-derived arsenic loading
- **TribA** – Tributary mass load contributions considered anthropogenic (*only if not included in prior variables*)
- **TribN** – Tributary mass load contributions considered nonanthropogenic (*only if not included in prior variables*)

Equation 2 was rearranged to calculate the nonanthropogenic arsenic load. Because of the methods used in this DON, all the anthropogenic tributary contribution (TribA) is included under the previous three variables (PSL, GWA, and ROA) and is therefore not specifically identified in ***Equation 5*** below:

Equation 5: **Nonanthropogenic = TAL - [PSL + GWA + ROA]**

The final product of the modified mass balance using ***Equation 5*** is the nonanthropogenic arsenic load for the Yellowstone River. See **Section 4.8.**

2.4 Data Sources and Compilation

Within the project area, DEQ compiled total recoverable arsenic concentrations, dissolved arsenic concentrations, total suspended solids, and flow volume for the mainstem of the Yellowstone River as well as 15 tributaries. This provided data to develop the nonanthropogenic and anthropogenic arsenic loads calculated from concentration and flow values.

Existing data for the Yellowstone River Basin were compiled using the methodology described in the project QAPP (DEQ, 2015a). The results were used to develop additional sampling efforts as described in the project SAPs (DEQ, 2015b; 2016a; 2017a). The sampling objectives, sampling design, and data quality objectives are described in the project QAPP (DEQ, 2015a).

Historical data locations and additional sampling locations are shown on **Figure 2-3**.

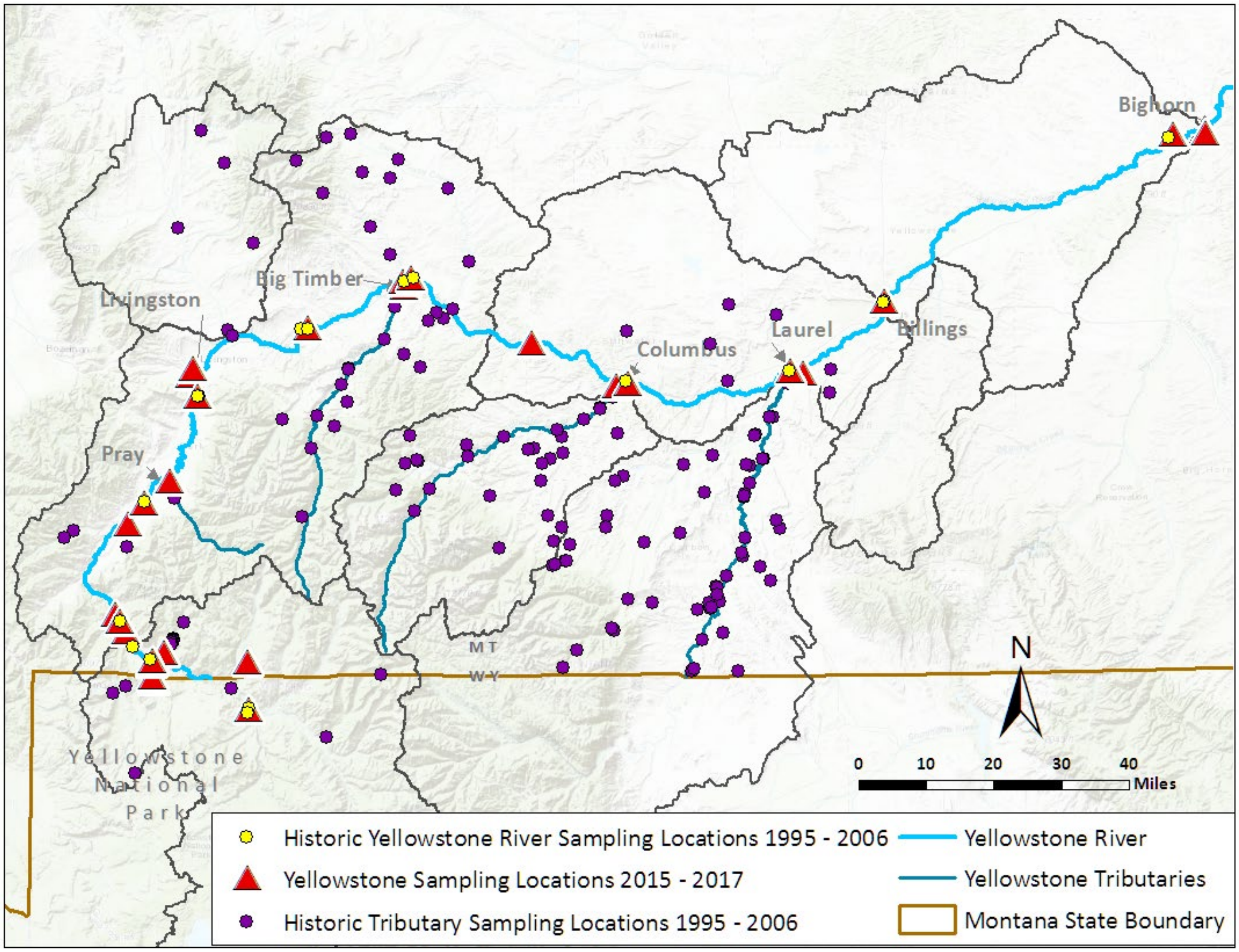

Figure 2-3. Map Showing Historic and Recent Sampling Locations

The following subsections address each of the data types needed to determine the amount of the arsenic load that is nonanthropogenic:

- 2.4.1 Total Arsenic Load (TAL)
- 2.4.2 Yellowstone National Park (YNP)
- 2.4.3 Point Source Loads (PSL)
- 2.4.4 Ground Water (GW)
- 2.4.5 Surface Water Runoff (RO)
- 2.4.6 Tributaries (Trib)

2.4.1 Total Arsenic Load (TAL) for the Yellowstone River

The project area was separated into five unique Yellowstone River segments (**Section 1.3.2**). **Table 1-1** presented the five river segments and their associated monitoring locations; **Figure 2-3** provided additional detail on the monitoring locations.

DEQ used LOADEST to model TAL at a monitoring location for each of the five hydrologic segments. The calculation of the TAL for each hydrologic segment is presented in **Section 4.2**. The TALs for each segment are calculated from data at the monitoring location; this introduces a minor amount of potential error since tributaries and other flow contributions occur before and after the monitoring station within each segment.

These loads are expressed as the median of the model's daily estimated loads, which includes both anthropogenic and nonanthropogenic sources of arsenic. The arsenic concentrations and flow data for the Yellowstone River are maintained at DEQ and are available upon request (DEQ, 2017b).

2.4.2 Yellowstone National Park (YNP)

The entire arsenic load from YNP, including the Yellowstone River as it crosses the Montana/Wyoming border and the Gardner River at the confluence of the Yellowstone River, is considered nonanthropogenic. This is discussed in **Section 4.3.**

2.4.3 Point Source Loads (PSL)

Point source contributions of arsenic loading potentially include: Montana Pollutant Discharge Elimination System (MPDES) and Montana Ground Water Pollution Control System (MGWPCS) permitted point sources, active & abandoned mines, remediation response sites, underground storage tanks, and hazardous waste sites. These sources are discussed in **Section 4.4**.

Internal DEQ and public Geographical Information System (GIS) information was searched at: http://svc.mt.gov/deq/wmadst and https://deqgis.mt.gov/arcgis/rest/services to identify abandoned mines, remediation response sites, underground storage tanks, and hazardous waste sites in addition to other data sources as described below.

2.4.3.1 MPDES & MGWPCS-Permitted Point Sources

DEQ reviewed MPDES- and MGWPCS-permitted dischargers discharging into the project watershed. The arsenic effluent concentration data from these facilities was extracted from the EPA's Integrated Compliance Information System (ICIS) database. Only Montana facilities with effective (including administratively extended) permits were analyzed, as discussed in **Section 4.4.1.**

DEQ also accessed permitted discharges in Wyoming through the Environmental Protection Agency (EPA) Enviro Mapper program (https://www.epa.gov/emefdata/em4ef.home) and the Wyoming Department of Environmental Quality (WDEQ) permitting website (http://deq.wyoming.gov/wqd/permitting-2/) as discussed in **Section 4.4.1**.

2.4.3.2 Active & Abandoned Mines

Active mines in the Montana portion of the Yellowstone River Basin are subject to MPDES permitting and are included in the ICIS database as described above. Active mines are included as a permitted point source load.

For inactive mines in Montana, DEQ's Abandoned Mines program maintains information on abandoned mines in a GIS database. The database identifies the location of known inactive mining projects although, typically, only the high priority abandoned mines have associated soil or water quality data. Sampling results for high priority abandoned mines were accessed at http://deq.mt.gov/Land/AbandonedMines/priority. Additional information regarding water quality from abandoned mines was available from the Montana Bureau of Mines and Geology (MBMG) Groundwater Information Center (GWIC) database at http://mbmggwic.mtech.edu. The GWIC database contains primarily water well information but also includes springs, mines and other miscellaneous sources. GWIC was searched under the site type category with the phrases "mine," "mine drainage," "adit," or "tailings pond" to find any data potentially related to mining activities.

The results of the DEQ GIS inventory, internal records, and GWIC searches are summarized in **Section 4.4.2.**

Permitted mines in the Wyoming portion of the watershed were accessed through the EPA Enviro Mapper program (https://www.epa.gov/emefdata/em4ef.home. Neither abandoned mine inventories nor site information for the Wyoming portion of the watershed was available through WDEQ.

2.4.3.3 Remediation Response Sites

A DEQ GIS inventory of contaminant releases for remediation response sites throughout Montana includes the location, site name, DEQ contact name if available, and the period of operation. Specific information including water quality for some of these sites is available via the listed DEQ contact or the DEQ website at one of the following links:

- http://deq.mt.gov/Land/FedSuperfund
- http://deq.mt.gov/Land/statesuperfund
- http://deq.mt.gov/Land/brownfields

Three Montana sites were identified that could potentially contribute arsenic to the Yellowstone River via ground water. The arsenic load from these sites is discussed in **Section 4.4.3** and has been included as "Other" anthropogenic point source loads.

Information on remediation sites in the Wyoming portion of the watershed is limited to sites in the Wyoming Voluntary Remediation Program: http://deq.wyoming.gov/shwd/voluntary-remediation-program/resources/site-lists-maps/, which is also discussed **in Section 4.4.3**.

2.4.3.4 Underground Storage Tanks

An inventory of known leaking underground storage tank (LUST) sites in Montana is located at http://deq.mt.gov/Land/lust/lustsites. The DEQ Petroleum Tank Cleanup Section does not have an electronic database for water quality data collected from LUST sites, however, the data is available in hard copy. Petroleum discharge sites are not typically a source of arsenic; therefore, petroleum LUST sites were not included as anthropogenic arsenic sources for this assessment.

2.4.3.5 Hazardous Waste

DEQ maintains a GIS inventory of hazardous waste handlers including the site name and the locations. These sites are not associated with contaminant releases unless they are indicated as a remediation response site (see **Section 2.4.3.3**). There were no hazardous waste sites that were also identified as remediation response sites; therefore, there are no hazardous waste sites considered sources of arsenic to the Yellowstone River Basin.

2.4.4 Ground water (GW)

Arsenic concentrations in ground water are assumed to be naturally occurring and originating from the local geologic conditions when no anthropogenic sources can be identified through database searches.

When anthropogenic sources of arsenic are identified, the anthropogenic arsenic load to surface water from the ground water is estimated from the available aquifer data.

One potential anthropogenic ground water source is agricultural practices: when water percolates through agricultural soil, it has the potential to cause migration of contaminants through ground water into local surface waters from soils and/or fertilizers/pesticides used at these locations. The Montana State Extension Service was contacted for purposes of determining whether arsenic is a common component in locally applied pesticides. Dr. Cecil Tharp, a Pesticide Education Specialist at Montana State University, confirmed that lead arsenate pesticides were used historically but have been effectively eliminated from use within the past 50 years. The use of arsenate pesticides was most common in late 19th and early 20th century orchards. Due to its persistence, it is possible that some soils would still carry residuals. However, orchards are not common in the Yellowstone River Basin. Therefore, the anthropogenic risk of arsenic loading from percolation of arsenate pesticides through the ground water is not likely to be an anthropogenic arsenic source for the Yellowstone River Basin.

Background ground water concentration data not related to a particular site are available through two databases: the MBMG GWIC database (http://mbmggwic.mtech.edu); and the USGS National Water Information Service (NWIS) database (https://www.waterqualitydata.us/portal_userguide). Both databases compile information from various entities including: DEQ, EPA, Bureau of Land Management (BLM), United States Forest Service (USFS), county agencies, and private watershed groups. DEQ used the two database queries and edited the reports to remove duplicate data; the data files are available upon request. Additional ground water concentration data is available through databases described in previous sections.

A state-wide ground water arsenic map and corresponding GIS database was created by DEQ in 2016 for identifying locations with high arsenic ground water concentrations (DEQ, 2016b). The database was not published but is available from DEQ upon request. This DEQ ground water database was updated with data from the GWIC and NWIS databases collected since 2016 through 2018 as well as pre-2000 data from the DEQ abandoned mines program. DEQ used the updated arsenic ground water database to identify any anthropogenic and/or nonanthropogenic ground water sources to the total arsenic load in the Yellowstone River in **Section 4.5**.

2.4.5 Surface Water Runoff (RO)

The arsenic load attributed to surface water runoff over land includes both anthropogenic and nonanthropogenic sources. The anthropogenic surface water runoff (ROA) sources are from agricultural practices in addition to any exposed surface conditions that result from mining or other industries as discussed in the previous section. ROA includes both the anthropogenic tributary and mainstem runoff contribution within the Yellowstone River Basin. The results are provided in **Section 4.6**.

This section is focused on the data and methods used for determining the naturally occurring arsenic composition in the native soils, the anthropogenic land uses (primarily agriculture related), and the modeling used to calculate arsenic loads from surface water runoff in the Yellowstone River Basin.

2.4.5.1 Soil/Stream Sediment Arsenic Composition

The arsenic composition of the native soil is used for estimating the load to surface water from runoff events. The USGS report *Geochemical and Mineralogical Maps for Soils of the Conterminous United States* (Smith et al., 2014) summarizes the results of randomly distributed soil sampling across the United States, including 25 sites in the Yellowstone Basin and is available at:

https://pubs.usgs.gov/of/2014/1082. DEQ also maintains a GIS layer of Montana soil sampling locations. The soil arsenic concentration data was used in conjunction with the calculated sediment loading to calculate arsenic load found in **Appendix A.**

The arsenic composition in stream sediment in both Montana and Wyoming is also available through the USGS, and is useful for identifying arsenic hot spots. The USGS, in collaboration with other federal and state government agencies, industry, and academia conducted the National Geochemical Survey (NGS) to produce a body of geochemical data for the United States based primarily on stream sediments (USGS, 2008), which are available at https://mrdata.usgs.gov/geochem. Sediment data are also available through the USGS NWIS database, https://waterdata.usgs.gov/nwis.

Additional soil and stream sediment arsenic concentrations for Montana streams is available via the abandoned mines and remediation databases described previously. However, these data were not used in this DON.

2.4.5.2 Agriculture

DEQ considered whether agricultural practices in the Yellowstone River Basin may result in an increased anthropogenic load of arsenic to the Yellowstone River from water diversion practices and increased sediment loading from runoff.

Irrigation water may be diverted from one surface water source to another, thereby potentially migrating contaminants across watershed boundaries. The DNRC water rights database for Montana, http://geoinfo.msl.mt.gov/geography/water_information_system/water_rights.aspx, was searched for agricultural points of diversion, points of use, and types of use. The types of uses include domestic, industrial, stock watering, agricultural irrigation, and lawn and garden. For purposes of determining anthropogenic effects, typically the use of concern is irrigation as that water is diverted, distributed on the land, and a certain portion is eventually returned to surface water.

Agricultural practices can increase loading of arsenic-containing sediment into nearby waterbodies through overland runoff. The HAWQS method DEQ used to model sediment loading is discussed in **Section 2.2.2** and the following section. The potential for loading from agricultural inputs of arsenic-laden sediment in the Yellowstone River Basin is summarized in **Section 4.4**.

2.4.5.3 Modeling Sediment and Arsenic Runoff

DEQ used interpolated arsenic concentration in the soil for each HUC10 watershed as discussed in **Section 2.4.5.1** and the associated calculated anthropogenic sediment loss discussed below, to calculate the anthropogenic surface water runoff (ROA) arsenic load within the five hydrologic segments (**Appendix A**).

As discussed in **Section 2.2.2**, DEQ used HAWQS, which is a web-based interactive water quantity and quality modeling system that employs, as its core modeling engine, SWAT. HAWQS substantially enhances the usability of SWAT to simulate the effects of management practices based on an extensive array of crops, soils, natural vegetation types, land uses, and other scenarios. DEQ subtracted the HAWQS-predicted *natural* sediment load from the HAWQS-predicted *existing* sediment load to calculate the anthropogenic sediment runoff load for each HUC10. This sediment load and the soil arsenic concentration was used to estimate an anthropogenic arsenic load to the Yellowstone River Basin from runoff for each HUC10 (**Table 4-2 and Appendix A**).

The results of the following modeling steps are presented in **Section 4.6.2**:

- ***SWAT Existing*** - the sediment load from each of the 65 Yellowstone watershed HUC10s was modeled under existing land uses and conditions based on the 2011 National Land Cover Database (NLCD).

- ***SWAT Natural*** - to determine the corresponding sediment loads under pre-anthropogenic (natural) conditions, the existing land uses are modified to reflect the most probable land use under natural conditions. The modifications include setting all urban and cropland (including hay/alfalfa) land uses to near zero (HAWQS doesn't allow a land use to be reduced completely to zero) and changing those land uses to one of the natural condition land uses such as rangeland, forest, or wetland.

  As most anthropogenic land uses occur in rangeland instead of forested or wetland areas, anthropogenic land uses are converted to rangeland where possible. Due to the structure of HAWQS, conversion of land uses is limited to land uses that exist in each sub-basin and to the same soil type. Thus, in some cases anthropogenic land uses are converted to forest or wetland when rangeland is not available. Conversions of land uses are only done in similar soils so that an existing anthropogenic land use is not converted to a natural land use in a different soil type, which could have different runoff characteristics.

  Despite being limited by the HAWQS structure, 96% of the anthropogenic land uses were converted to natural land uses in the model. The 4% of anthropogenic land uses not converted are comprised predominantly of hay/alfalfa. This does not create significant error in the final results because the average sediment loading calculated by HAWQS for hay/alfalfa (0.0142 tons/acre) is nearly identical to the average sediment loading for rangeland (0.0139 tons/acre). The remaining 0.2% of the anthropogenic land uses that could not be converted to natural land uses is urban or winter wheat land uses. In those cases, the HAWQS results are modified externally to match sediment load from a natural land use (rangeland or forest) in the same soil type from another sub-basin.

- ***SWAT Anthropogenic*** - the difference in sediment loads between the two model scenarios (existing conditions and natural conditions) is attributed to anthropogenic land uses.

- ***USGS Soil Arsenic Concentration*** - the arsenic concentration of the calculated sediment load is interpolated from the soil data (Smith et al., 2014) discussed in **Section 2.4.5.1**. The top five centimeters of soil data is used in the analysis, as it is the soil most likely to be transported with runoff. A summary of this data by land use and associated land uses for the entire Yellowstone Basin are presented in **Figures 2-4 and 2-5**. The average soil arsenic concentration (7.7 mg/kg) of the planted/cultivated anthropogenic land use identified in the USGS report (Smith et. al., 2014) is similar to the rangeland land use (herbaceous upland) in the report, 7.5 mg/kg (**Figure 2-5**). These similar concentrations support using the same soil arsenic concentration for anthropogenic land uses that were converted to rangeland in the HAWQS model natural conditions scenario.

ROA outputs are presented in **Section 4.4**.

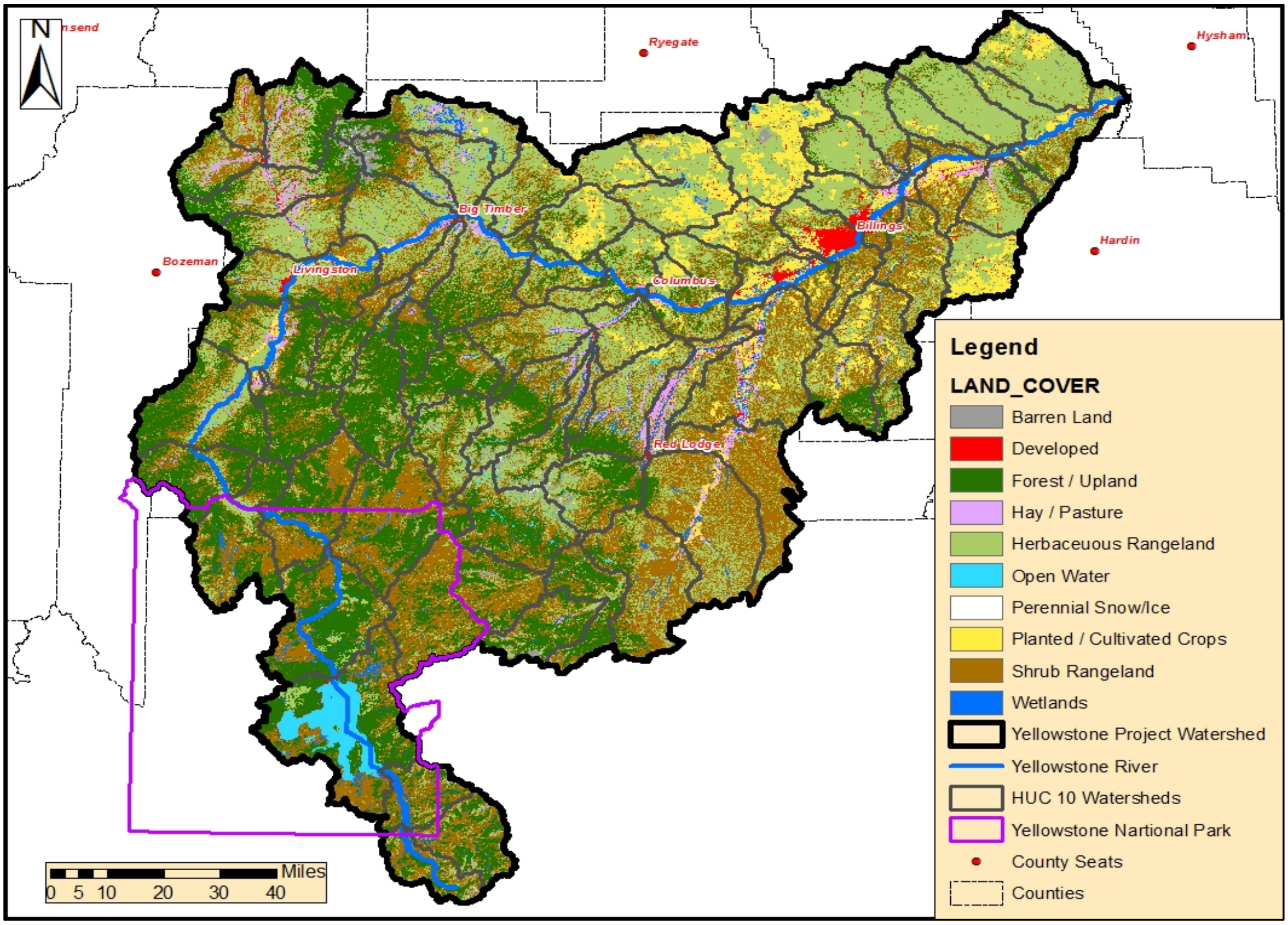

Figure 2-4. Existing Conditions Land Use Map of Project Area (based on 2011 NLCD)

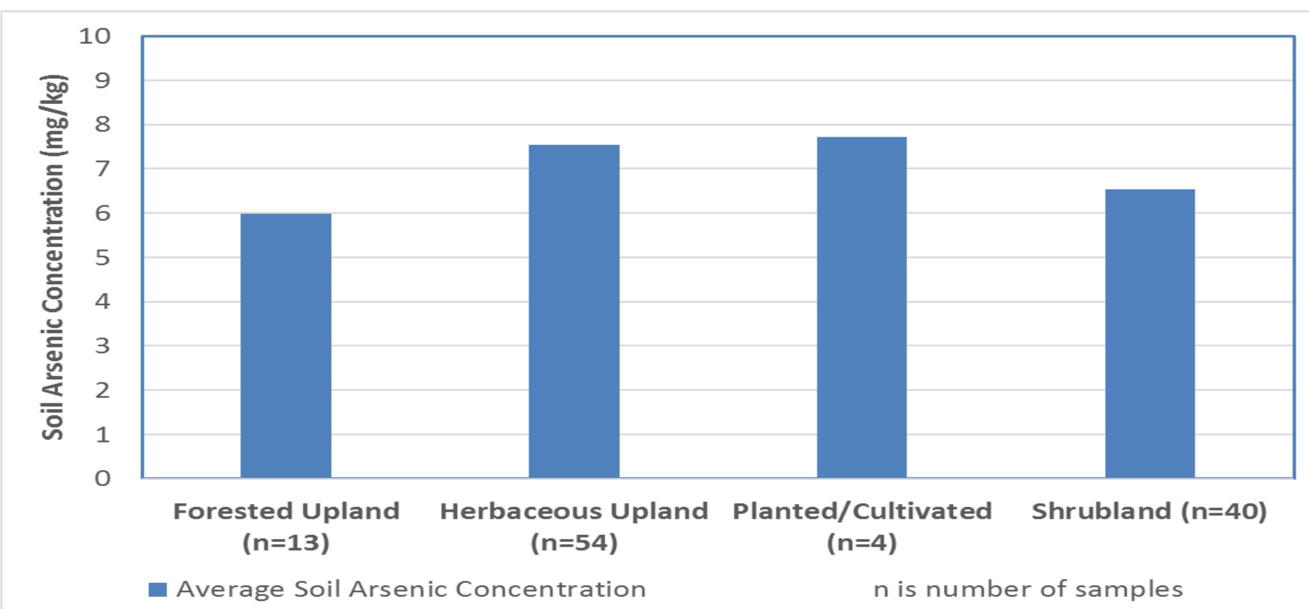

Figure 2-5. Soil Arsenic Concentrations in Upper and Lower Yellowstone Watershed (adapted from Smith et al., 2014)

2.4.6 Tributaries (Trib)

DEQ calculated the total arsenic loads—including both anthropogenic and nonanthropogenic loads—from the tributaries contributing to Yellowstone River flow from the Montana/Wyoming border to the mouth of the Bighorn River. The specific methodology for each tributary depended upon whether DEQ characterized it as major or minor, and the extent of paired flow and arsenic concentration data that was available.

Major tributaries were defined as having average low flow volumes (flows from August through April) greater than five percent of the 7Q10 low flow of the Yellowstone River. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. Minor tributaries have average low flow volume less than five percent of the 7Q10 low flow.

The following steps were conducted:

- **Appendix D-1:** DEQ determined the median daily arsenic load (kg/day) for 14 tributaries that had sufficient flow and arsenic concentration data, arranged by segment. Each of these tributaries' total arsenic loads were calculated for Yellowstone River high flow (May through July) and low flow (August through April). Of these tributaries:
  - Four were major tributaries that had sufficient flow and arsenic data to be modeled using LOADEST;
  - Two were major tributaries that had 10 to 23 paired arsenic concentration and flow data points; and
  - Eight minor tributaries that had minimal (3 to 6) paired data points with additional flow data.

- **Appendix D-2:** DEQ converted the daily arsenic loads for each monitored tributary (**Appendix D-1**) to median monthly arsenic loads. For areas with tributaries that did not have flow and/or arsenic data, the areas' arsenic load was interpolated from those tributaries that had data and were "accounted for." The unaccounted for tributary watershed areas were determined using GIS and their arsenic load was projected by multiplying the arsenic loading rate by area for the "accounted for" tributary watersheds in that segment by the area of the un-accounted for watersheds.

Results are provided in **Section 4.7**.

3.0 Data Needs

A thorough search of all available databases, as described in **Section 2.0**, produced enough information to determine whether there are anthropogenic influences in the watershed. However, where there are questions regarding anthropogenic influence, missing data in tributaries or on the main stem of the Yellowstone River, or other concerns about data limitations, additional sampling was required.

Several minor tributaries with either some mining history or high arsenic soil concentrations have no data available, and several others have historic data where detection limits are very high. Therefore, additional sampling was performed on several tributaries to fill in these data gaps.

3.1 Determination of Sufficient Data

Displayed in **Figure 3-1** is a decision flowchart showing the process of determining whether additional sampling was needed.

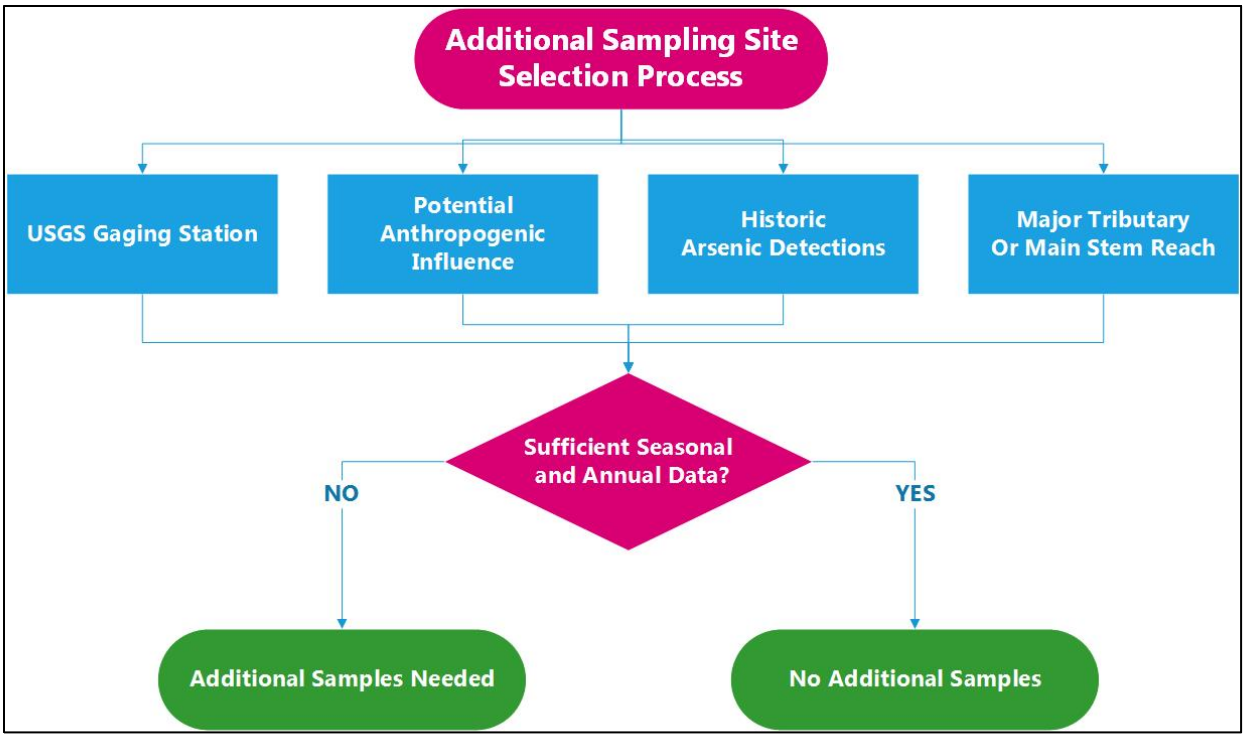

Figure 3-1. Decision Flow Chart for When to Carry Out Additional Sampling for Tributaries

After completing all database searches and compiling the anthropogenic and nonanthropogenic data into one dataset, an analysis was performed as to whether sufficient data existed to complete a defensible and valid DON. The process of determining whether there is sufficient data is presented in **Figure 3-2**.

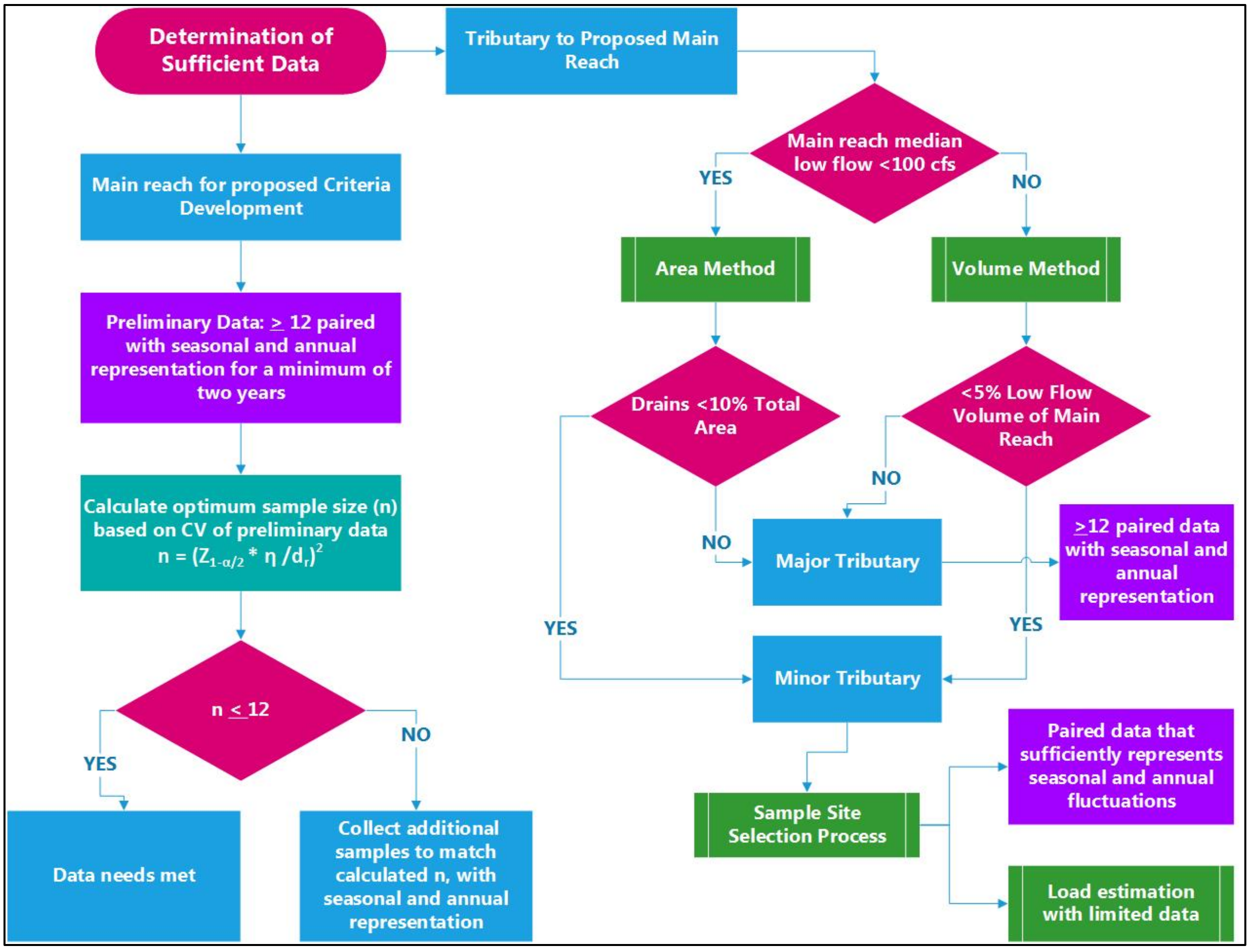

Figure 3-2. Flow Chart for Determination of Sufficient Data

For the major tributaries and each of the five segments within the Yellowstone River watershed project area, 12 paired water quality and flow samples with seasonal and annual representation for a minimum of two years was collected. The following sections explain how this sample size was determined.

3.2 SAMPLE SIZE DETERMINATION

Most methods for sample size determination require some knowledge about the desired outcome and population in advance, including:

- Desired accuracy of results;
- Confidence level; and
- Variability of data

While the desired accuracy and confidence can be determined *a priori*, understanding the variability of the data requires some advanced knowledge of the population. Metrics such as standard deviation (σ), mean (μ), and the coefficient of variation (CV) or relative standard deviation (σ/μ) are influenced by the spread of the data and thus influence parameters such as confidence intervals and prediction intervals. The central tendency of datasets with high variability can be very difficult to characterize by sampling.

Consider **Figure 3-3**; Stream B would be easier to characterize with fewer samples because there is less variability in the concentration data.

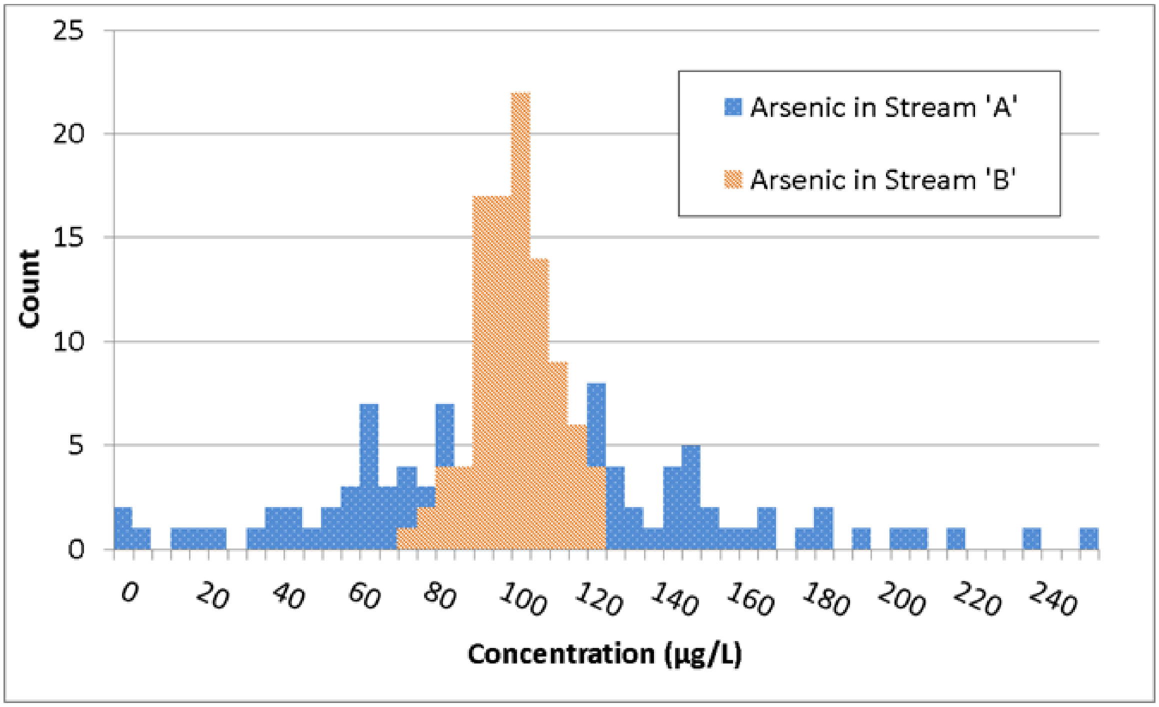

Figure 3-3. Example of Variability Between Two Environmental Datasets

The CV is useful as it allows comparison of any given sample dataset's standard deviation to all other sample datasets' standard deviations (DEQ, 2011), regardless of whether the arsenic concentrations in the datasets are high, low, or in between. The required sample size depends on the CV. Datasets with a low CV require a handful of samples to achieve a strong estimate of means, whereas datasets with a high CV may require hundreds of samples.

One of the most common methods to determine sample size in environmental data is to implement a two-stage sampling procedure. In this process, preliminary data is collected from the population to approximate the relative standard deviation, and then the necessary sample size is calculated from this data (with a predetermined confidence level and acceptable error). Then, if the required sample size is less than what has already been collected, data collection is complete. If the required sample size is larger than what has already been collected, more data is needed. This common method (Gilbert, 1987) provides a good estimate of needed sample size. The formula for calculating sample size with a pre-determined relative error is:

Equation 6: $$n = (Z_{1-\alpha/2} * \eta / d_r)^2$$

where n is the required number of samples, Z is the standard normal deviate (often looked up in statistical tables) for the confidence level desired, α is the desired significance level, η is the coefficient of variation or relative standard deviation, and d_r is the pre-specified relative error from the mean. The advantage of this method is simplicity, but one disadvantage is that it may not account for asymmetry and non-normal distributions.

The size of the preliminary data was initially estimated at 12 samples; this sample size is more than 10, which is typically a minimum for capturing adequate seasonal and annual variability, and less than the 30 that is typically considered a large data set in statistics (Ott, 1993). Thus, to determine the required sample size, 12 preliminary samples were collected which were spatially and/or temporally independent as needed. DEQ calculated the approximate variance and mean from the 12 samples. Then, using a pre-specified relative error and a confidence interval, DEQ determined the required sample size.

The Yellowstone River concentration data sets described in the next section had optimal sample sizes ranging from 6 to 25 based on a 90% confidence level and 15% error. In other words, a minimum collection of 6 samples allows 90% confidence that the average concentration calculated for the Yellowstone River at Billings station is within ± 15% of the *true* average concentration. This low sample minimum is due to the lesser variability in seasonal concentrations. The actual number of samples collected for the Yellowstone River at Billings was 28. A much greater minimum sample collection for the Yellowstone River at Corwin Springs of 25 was calculated due to the greater seasonal variability in concentration.

4.0 RESULTS

Section 4.0 presents the total arsenic load—and the nonanthropogenic and anthropogenic portions of the total arsenic load—for each hydrologic segment. From this information, DEQ calculated the nonanthropogenic condition of the Yellowstone River segments using the modified mass balance equation in **Section 4.8**.

4.1 HYDROLOGIC SEGMENTS

The Yellowstone River and associated tributaries within the project area were divided into five hydrologic segments for the arsenic load mass balance analysis as discussed in **Section 1.3.2.** The segments are:

- Segment 1 - Montana/Wyoming Border up to Mill Creek near Pray
- Segment 2 - Mill Creek up to the Boulder River near Big Timber
- Segment 3 - Boulder River up to the Stillwater River
- Segment 4 - Stillwater River up to the Clarks Fork of the Yellowstone River
- Segment 5 - Clarks Fork of the Yellowstone River up to the Bighorn River

4.2 YELLOWSTONE RIVER TOTAL ARSENIC LOAD (LOADEST MODELING)

DEQ modeled the TAL for the five Yellowstone River hydrologic segments at the stations listed in **Table 4-1** using LOADEST, based on flow and arsenic concentration data.

Table 4-1. Yellowstone River Stations Modeled using LOADEST

Hydrologic Segment	USGS ID	Yellowstone River Monitoring Station Description	Latitude	Longitude	# Data (n)[1]
1 – Montana/Wyoming Border to Mill Creek	06191500	Corwin Springs	45.11212	-110.7937	25
2 – Mill Creek to Boulder River	06192500	Livingston	45.59721	-110.5665	28
3 – Boulder River to Stillwater River	N/A	Big Timber (immediately after confluence with Boulder River)	45.8544	-109.9169	19
4 – Stillwater River to Clarks Fork Yellowstone River	N/A	Laurel	45.65411	-108.760	21
5 – Clarks Fork Yellowstone River to Bighorn River	06214500	Billings (after Yegen Drain, immediately upstream from WWTP)	45.80012	-108.4680	28

[1] Number of data points are number of paired flow and arsenic concentration results. Results for the five Yellowstone River stations are presented in **Appendix C-2**.

LOADEST input files included daily flow data from 2009 to 2018 (ten years). DEQ considered ten years to be the minimum amount of time to achieve a representative long-term average flow. The LOADEST runs for the five segments were based on at least 19 paired flow-arsenic concentration data points for each station, as shown above; the paired data sets for Livingston and Billings were from 2013-2017, and the paired data sets for Corwin Springs, Big Timber, and Laurel were from 2015-2017. The model requires a minimum of 12 paired flow-arsenic concentration data points to calibrate.

Figure 4-1 presents the monitoring locations for each of the five Yellowstone River segments. Note that segments were divided based on major tributary inputs, thus the monitoring stations are not spatially consistent within each segment. Segments 1, 2, and 5 have USGS monitoring stations located in the first third of the segment while segments 3 and 4 use an addition-by-parts method near the beginning of the segment (discussed later in Equations 9 and 10). These locations are used as the basis for the entire segments' TAL, thus a degree of error may be introduced due to potential arsenic concentrations before or after the monitoring stations.

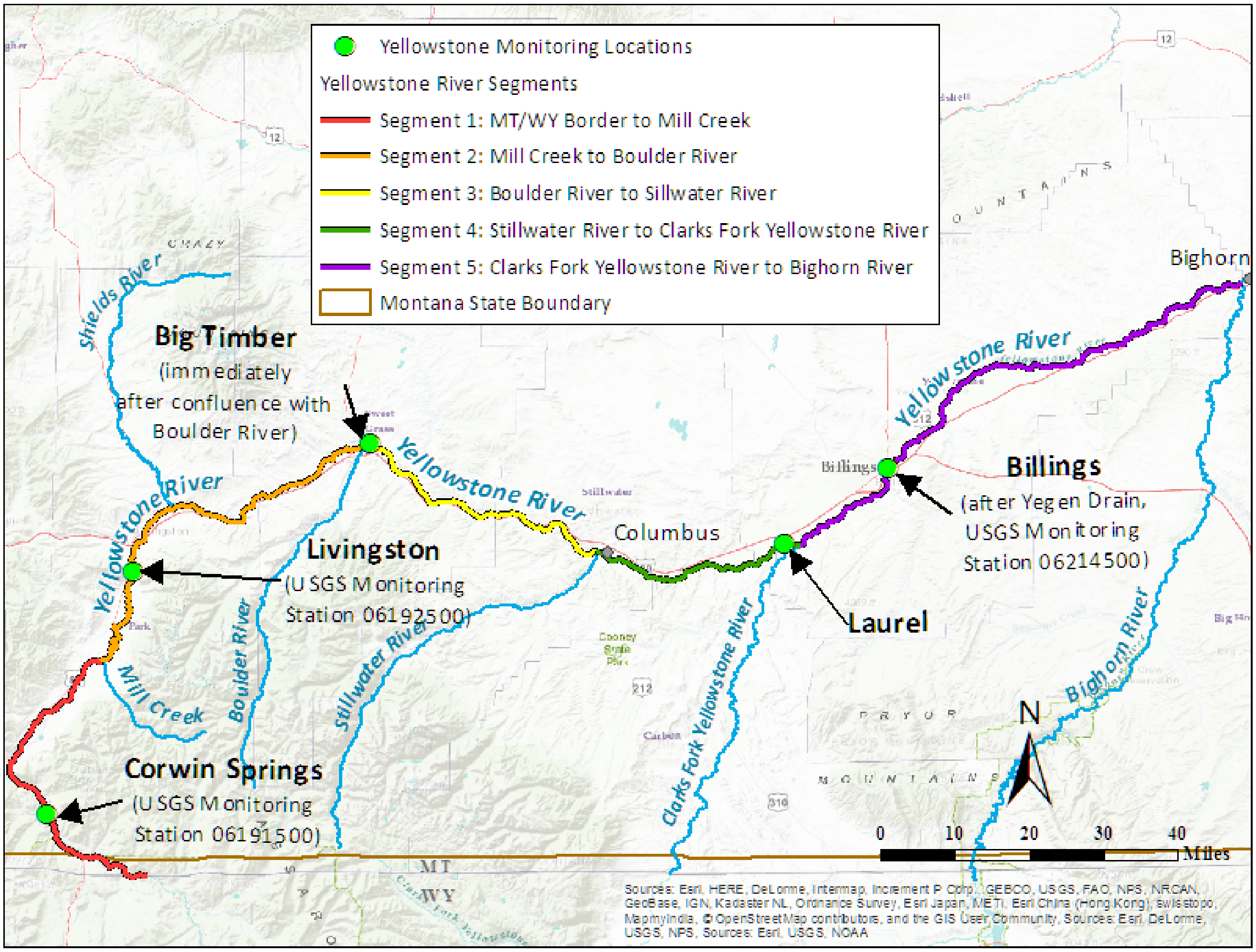

Figure 4-1. Yellowstone River Monitoring Stations Used for Arsenic Load Mass Balance

4.2.1 LOADEST Flow Input

There are a limited number of active USGS gaging stations on the Yellowstone River. USGS gages were used to determine daily flows in segments 1, 2, and 5. Segment 1 (Corwin Springs, 06191500), Segment 2 (Livingston, 06192500), and Segment 5 (Billings, 06214500) each have a minimum of twenty years of average daily flow data.

However, there are no USGS stations located within segments 3 and 4. For this reason, a simple mechanistic approach was taken using an addition-by-parts method to estimate daily flows in segments 3 and 4. Using USGS gage data at other locations, the flow at a downstream point from the un-monitored location was set equal to the flow at a gaged upstream point, plus all the gaged tributary flows that come in between them. To test this rough approximation, the sum at Billings was first calculated and compared to the gaged daily data at Billings (Segment 5). The equation for Billings is described below:

Equation 7: $\textit{\textbf{Yellowstone River at Billings}}_i = \textit{Yellowstone River at Livingston}_{i-2} + 1.008 * \textit{Shields River}_{i-2} + 1.004 * \textit{Boulder River}_{i-1} + 1.082 * \textit{Stillwater River}_{i-1} + 1.326 * \textit{Clarks Fork Yellowstone River}_i$

where i is the iteration value. In this case, the iteration is reported flow by day to account for travel time. Estimated travel times were used to approximate which days to compare (e.g. from Billings there is an approximate two-day travel time from Livingston and the Shields River, a one-day travel time from the Boulder and Stillwater Rivers, and <1 day travel time from the Clarks Fork of Yellowstone River). Using the formula above as an example, each tributary has a drainage area adjustment based on equation 10 of Montana StreamStats Chapter G (USGS, 2015):

Equation 8: $$\text{Adjustment factor} = \left(\frac{Aw}{Ag}\right)^{\text{exp}}$$

where A_w is the area of the watershed, A_g is the area at the gage, and the exponential factor is the coefficient for drainage area adjustment for the Upper Yellowstone region. The average value reported for this region in the USGS report was 0.89 and this was used for all calculations. For example, the USGS gage for the Shields River is very close to the mouth of the river, and thus an adjustment factor very close to one. This calculation for the period 1989-2017 (29 years) resulted in an optimal match between observed and calculated data (**Figure 4-2**).

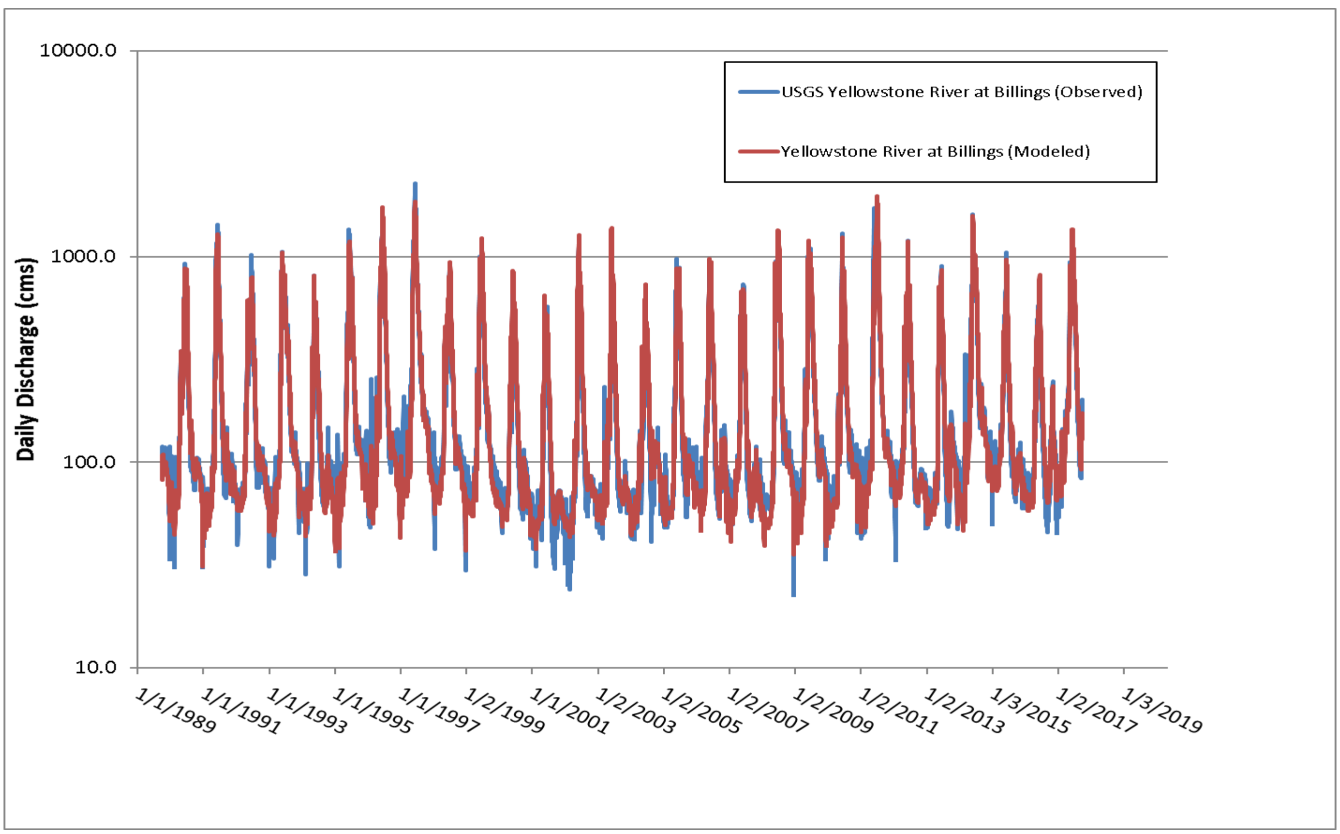

Figure 4-2. Comparison of USGS gage Yellowstone River at Billings and the Addition-By-Parts Calculation

The overall relative error of the model is 0.4%, the slope of model fit is 1.005, and the Nash-Sutcliffe coefficient of Efficiency (NSE) is 0.97[1]. The largest discrepancies (but still relatively minor) are in the winter flows (the addition-by-parts method overpredicts and under predicts winter flows equally), possibly due to ice issues. These results suggest that this is a reliable method for obtaining an approximation of daily flows without considering minor tributaries, irrigation, point source withdrawals, and other minor water transfers.

After determining that this method was successful on Segment 5, it was used to estimate the daily flow for Segment 3 and Segment 4. The formulas used for segments 3 and 4 are described in Equations 9 and 10, respectively:

Equation 9: ***Yellowstone River at Big Timber***$_i$ *= Yellowstone River at Livingston*$_{i-1}$ *+ 1.008*Shields River*$_{i-1}$ *+ 1.004*Boulder River*$_i$

Equation 10: ***Yellowstone River at Columbus***$_i$ *= Yellowstone River at Livingston*$_{i-1}$ *+ 1.008*Shields River*$_{i-1}$ *+ 1.004*Boulder River*$_i$ *+ 1.082*Stillwater River*$_i$

4.2.2 LOADEST Arsenic Concentration Input

The LOADEST report presents paired arsenic concentration and flow data from each segments' monitoring station on "Residual" tabs in an Excel workbook. The monitoring data range was either between 2013 and 2017 (Livingston and Billings) or between 2015 and 2017 (other three monitoring stations). The raw data is maintained electronically at DEQ and can be made available upon request.

4.2.3 LOADEST Model

While LOADEST will automatically fit the data to the best of nine models (with the option for the user to add several more), DEQ chose to constrain the program to use the same model for all five river segments. Although this resulted in fewer good fits in some segments, it better represents reality by not over-parameterizing river segments that are interrelated. In segments 2 through 5, model #2 was one of the top three fitting models for each segment. In Segment 1, it was not one of the best-fitting models, yet still had adequate metrics. For these reasons, model #2 from LOADEST was used for all five segments. LOADEST model #2 is shown below in Equation 11.

Equation 11: ***LOADEST Model #2: Ln(Load)*** $= a0 + a1*LnQ + a2*LnQ^2$

Modeling statistics are presented in **Table 4-2**; percent load bias, Nash-Sutcliffe model efficiency coefficient (NSE) and the coefficient of determination (R^2). The load bias is the amount that the model over or under estimates load, in percent. A load bias of over 25% indicates that the model is a poor representation of the observed data. NSE is described in footnote 1, while R^2 is a statistical measure of how close the data are to the fitted regression line and measures how well the regression line approximates the real data points. Like the NSE, the closer the R^2 to 1, the better the approximation. The R^2 value is consistent for all hydrologic segments, suggesting there is similar variance in the data for all five segments. Based on acceptable ranges used by the USGS (Anderson and Rounds, 2010), the modeling statistics are acceptable for all five stations.

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[1] The Nash–Sutcliffe model efficiency coefficient (NSE) is used to assess the predictive power of hydrological models. Nash–Sutcliffe efficiency can range from −∞ to 1. An efficiency of 1 (*NSE* = 1) corresponds to a perfect match of modeled discharge to the observed data.

Table 4-2. LOADEST Arsenic Load Model #2 Run Statistics

Hydrologic Segment	Load Bias %	NSE	R^2
1 – Montana/Wyoming Border to Mill Creek	-0.66	0.87	0.89
2 – Mill Creek to Boulder River	-0.72	0.91	0.94
3 – Boulder River to Stillwater River	-2.13	0.85	0.91
4 – Stillwater River to Clarks Fork Yellowstone River	-0.62	0.95	0.97
5 – Clarks Fork Yellowstone River to Bighorn River	-1.04	0.97	0.96
USGS Acceptable Range	***0 to +/- 25***	***0.5 to 1.0***	***0.6 to 1.0***

LOADEST model files for the Yellowstone River are contained in **Appendix C**, which is maintained by DEQ and can be made available upon request.

The model outputs include monthly arsenic loads, by segment. A summary of the monthly modeled loads is provided in **Appendix C-2** and is depicted in **Figure 4-3**, based on the USGS LOADEST Model using daily hydrologic data (2009-2018) calibrated to discrete arsenic concentration data (2013-2017).

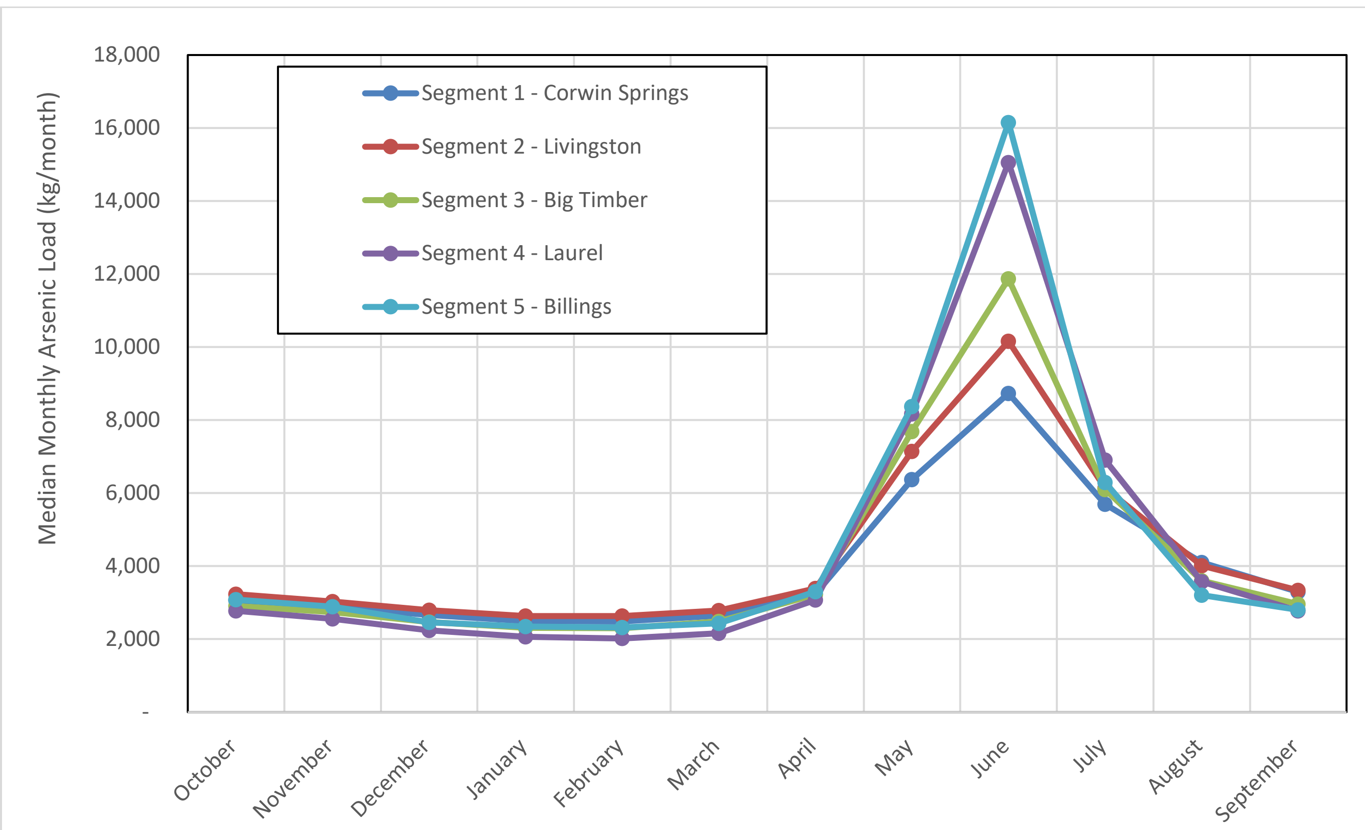

Figure 4-3. LOADEST Output of Median Monthly Arsenic Load for the Yellowstone River

In addition, the total arsenic loads are presented as monthly and annual loads for each hydrologic segment in **Table 4-3**. These loads are expressed as the median of the model estimated loads and include both anthropogenic and nonanthropogenic sources of arsenic.

Table 4-3. LOADEST Estimated Median Monthly Arsenic Load (TAL) for each Yellowstone River Segment

Segment		1 – MT/WY Border to Mill Creek	2 – Mill Creek to Boulder River	3 – Boulder River to Stillwater River	4 – Stillwater River to Clarks Fork Yellowstone River	5 – Clarks Fork Yellowstone River to Bighorn River
Monitoring Location		**Corwin Springs**	**Livingston**	**Big Timber**	**Laurel**	**Billings**
October	kg/month	3,069	3,234	2,907	2,776	3,079
November	kg/month	2,892	3,033	2,744	2,554	2,886
December	kg/month	2,666	2,791	2,473	2,237	2,464
January	kg/month	2,498	2,633	2,309	2,063	2,347
February	kg/month	2,488	2,633	2,300	2,019	2,321
March	kg/month	2,642	2,783	2,487	2,166	2,436
April	kg/month	3,243	3,389	3,220	3,072	3,305
May	kg/month	6,370	7,144	7,684	8,174	8,370
June	kg/month	8,733	10,161	11,869	15,058	16,153
July	kg/month	5,698	6,134	6,102	6,908	6,292
August	kg/month	4,097	4,016	3,599	3,571	3,203
September	kg/month	3,293	3,334	2,960	2,776	2,800
Annual	**kg/year**	**47,689**	**51,285**	**50,654**	**53,373**	**55,656**

4.3 Yellowstone National Park (YNP) Loads

The arsenic load in the Yellowstone River at the Montana/Wyoming border is almost entirely nonanthropogenic from geothermal sources at YNP. DEQ back-calculated the YNP arsenic load contribution based on the total arsenic load at the downstream Corwin Springs monitoring location in Segment 1, minus any arsenic contribution between the state line and Corwin Springs. The Gardner River joins the Yellowstone River just downstream of the MT/WY border, but is included as part of the YNP load since the river is almost entirely in the park.

YNP Nonanthropogenic Arsenic Load: 46,720 kg/yr

= Yellowstone River @ Corwin Springs **47,689 kg/yr** – [Bear Creek **922 kg/yr** (= TXV Mineral Hill + Jardine Tailings) – Gardiner WWTF **39 kg/yr** – total surface runoff **8 kg/yr** (Montana/Wyoming border to Corwin Springs)]

Note in the computation above that some anthropogenic sources (2% of the park's total arsenic) are near the park, including a point source load; these were removed accordingly. Point source loads across the entire Yellowstone River Basin are discussed next.

4.4 Point Source Loads (PSL)

Point source contribution of arsenic loading to the Yellowstone River Basin potentially includes: MPDES and MGWPCS - permitted point sources and "other" anthropogenic/ground water loads (active mines, abandoned mines, remediation response sites, underground storage tanks, and hazardous waste sites).

4.4.1 Permitted Discharges

DEQ found 98 MPDES and/or MGWPCS - permitted dischargers in the project area. These permitted discharges, as shown on **Figure 4-4**, are broken down into 22 individual MPDES permits, 22 storm water permits, 47 general permit authorizations, and seven ground water permits.

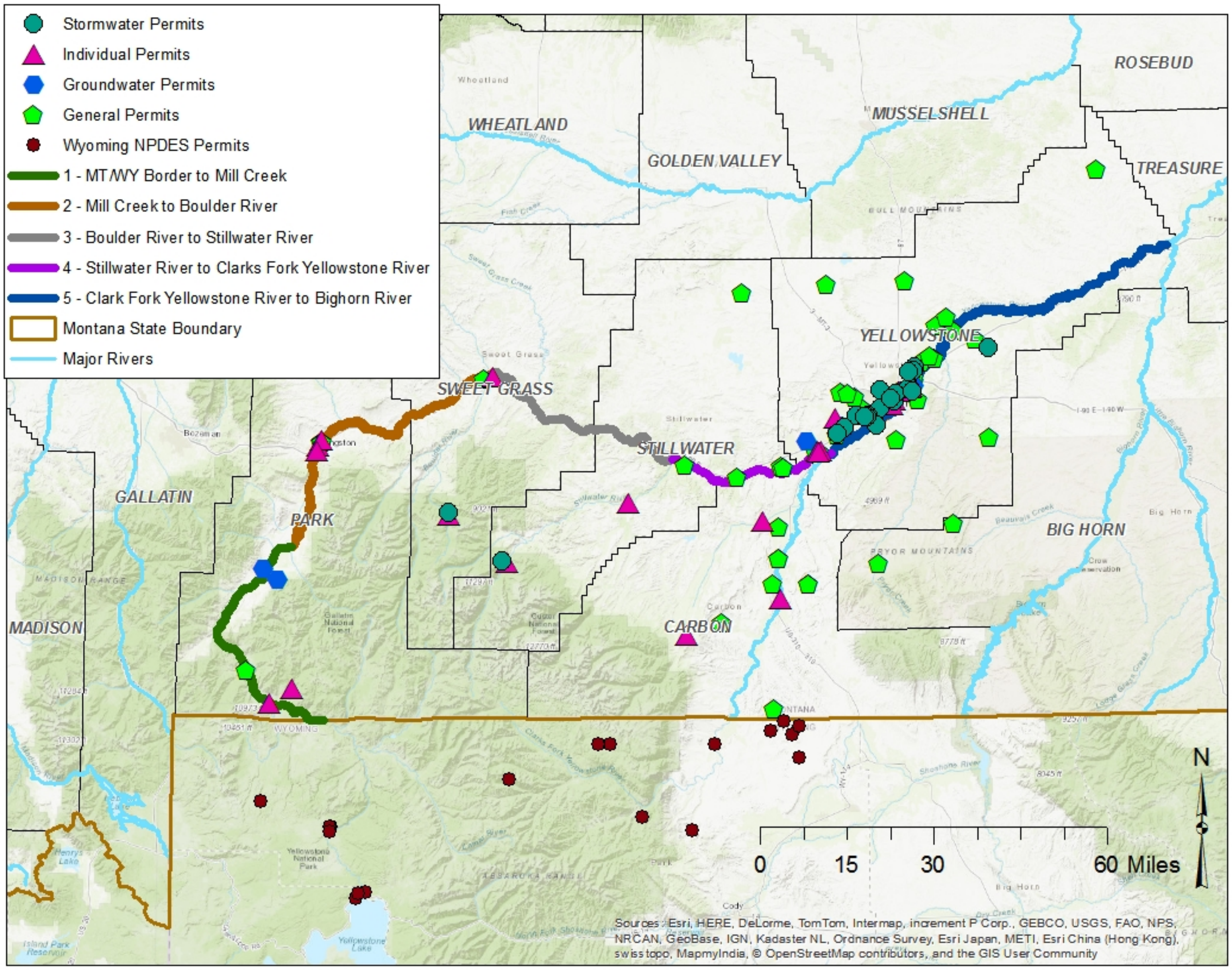

Figure 4-4. Permitted Point Sources in the Yellowstone River Basin

Due diligence was completed to assess whether any permitted discharges, whether monitoring for arsenic or not, have potential to contribute anthropogenic arsenic to the Yellowstone River Basin. Of the 98 Montana permits, only eight permitted dischargers had effluent monitoring for arsenic. These dischargers have quantifiable arsenic loads to the Yellowstone Basin (**Appendix E-2**). For comparison purposes, the high flow (May through July) and low flow (August through April) permitted arsenic loads are presented in **Table 4-4**.

Table 4-4. Permitted Discharges with Quantifiable Anthropogenic Arsenic Loads, by Hydrologic Segment

MPDES No.	Facility	Receiving Body	Facility Load *High Flow* (kg/ month)	Facility Load *Low Flow* (kg/month)	Annual Load (kg/year)
Segment 1					
MT0030252	JARDINE LAND & LIVESTOCK (TVX) MINERAL HILL MINE [1]	BEAR CREEK	0.16	0.25	2.7
MT0022705	GARDINER WWTF	YELLOWSTONE RIVER	4.4	2.9	39.3
		Subtotal Segment 1	***4.6***	***3.1***	***42.0***
Segment 2					
MT0020435	CITY OF LIVINGSTON WWTP	YELLOWSTONE RIVER	0.48	0.36	4.7
Segment 3					
None	NA	NA	NA	NA	NA
Segment 4					
MT0000264	CHS - LAUREL REFINERY (NET)	YELLOWSTONE RIVER	4.2	5.5	62.3
Segment 5					
MT0000281	WESTERN SUGAR COOPERATIVE (NET) [2]	YEGEN DRAIN	0	0	0
MT0000256	PHILLIPS 66 - BILLINGS REFINERY STORMWATER	YEGEN DRAIN	0.01	0	0.01
MT0022586	CITY OF BILLINGS WWTP (NET)	YELLOWSTONE RIVER	(8.0)	(11.0)	(123)
MT0000477	EXXONMOBIL - BILLINGS REFINERY (NET) [2,3]	YELLOWSTONE RIVER	0	0	0
		Subtotal Segment 5	***(8.0)***	***(11.0)***	***(123)***
Total from All Permittees [4]			**1.25**	**(2.0)**	**(14.0)**

[1] The Mineral Hill Mine has a permitted discharge to Bear Creek, which is a tributary to the Yellowstone River near the Yellowstone Park Boundary. Bear Creek is assumed to be entirely anthropogenic, comprised of the permitted Mineral Hill Mine and the remediation site Jardine Tailings (see **Section 4.4.3**).
[2] These facilities NET discharge loads were set to zero because they were small negative values and considered to be within the range of error of the estimated and extrapolated data used in the calculations (see **Appendix E** for calculations).
[3] ExxonMobil ceased direct discharge as of January 1, 2019, and is currently discharging to the Billings WWTP, where the wastewater undergoes additional treatment. A portion of the original arsenic load contained in ExxonMobil's discharge is now discharged from the Billings WWTP.
[4] Totals may be slightly off due to rounding.

For this mass balance, discharges into the Yegen Drain are characterized as discharging into the Yellowstone River rather than a tributary.

For facilities with untreated source water originating from the Yellowstone River, the initial arsenic load of the Yellowstone River is subtracted from the discharge load to avoid duplicate accounting in the mass balance. Sources that meet this scenario are indicated in **Table 4-4** and **Appendix E** as "NET," and include

CHS - Laurel Refinery, Western Sugar, City of Billings Wastewater Treatment Plant (WWTP) and ExxonMobil - Billings Refinery. As a result, the net loading attributed to two of these facilities (Western Sugar Cooperative and ExxonMobil) was a negative load (i.e. arsenic load appears to be removed by the facility). However, because neither of those facilities have arsenic treatment capabilities, for purposes of the DON it was assumed that they have zero arsenic loading to the Yellowstone River instead of assuming they provide some treatment capabilities (the calculated negative loading may be due to errors associated with averaging and extrapolating data to determine a relatively small load value). The City of Billings WWTP negative values were much higher and accounted for in **Table 4-4** because of the arsenic reduction that does occur as a result of their treatment processes.

The net arsenic load discharge data is captured by month and year in **Appendices E-1** and **E-2**. These anthropogenic arsenic loads from the permitted discharges account for less than 1% percent of the total arsenic load in the Yellowstone River for both the high flow and low flow seasons. In fact, in total the permitted sources do not contribute any arsenic load.

For potential anthropogenic sources of arsenic from Wyoming permitted sources, DEQ reviewed the databases described in **Section 2.4.3.1** and found that within the watershed there are 23 WDEQ permits; of these, 21 are either oil and gas production or construction storm water general permits that are not potential sources of arsenic. There are two individual WDEQ permits, one is a fish hatchery and the other is a wastewater treatment facility. Neither permit has permit limits for arsenic nor are they required to monitor for arsenic. Therefore, Wyoming permitted discharges are not considered potential sources of arsenic to the Yellowstone River Basin.

4.4.2 Mining (Active & Abandoned)

The only active mine in the Yellowstone River Basin is the Jardine Land & Livestock, LLC (formerly TVX) Mineral Hill Mine, which is identified as a point source and its' discharge is included under the permitted point source loads in **Section 4.4.1**. In addition, review of Enviro Mapper for permitted sites in Wyoming identified three sand & gravel mines and one granite mine. However, these Wyoming mines are all under 10 acres in size and based on the type of mining operations they are not potential sources of arsenic.

There are 421 abandoned mines in Montana identified in the Yellowstone River Basin. Of these, 17 mines are considered high priority sites and have limited data regarding pollutant concentrations for surface water and sediment. Using the DEQ abandoned mine data, USGS sediment data, USFS data, and MBMG GWIC data, the potential for arsenic loading to the watershed is discussed in this section.

Sediment

Sediment arsenic concentrations for the Yellowstone watershed, which is limited to 17 high priority abandoned mines, are shown on **Figure 4-5**. The sources for this data included a USGS geochemical database (USGS, 2008), the online USGS NWIS database, and the DEQ abandoned mines program.

Nine of the 17 abandoned mines are located within and around the New World Mining district near the northeast corner of YNP, which is an area of naturally elevated metals due to the local geology. The highest concentrations in the Yellowstone River Basin occur in the upper section of the watershed near YNP. There are two significantly elevated sediment arsenic concentrations (207 and 300 mg/kg) collected from Bear Creek below the Jardine Arsenic Tailings site and the TVX Mineral Hill Mine. The instream arsenic concentrations near the mouth of Bear Creek are also elevated most likely due to those two sources. Thus, the entire arsenic load from Bear Creek is assumed to be from anthropogenic sources.

There is no comparable data on abandoned mines available in the Wyoming portion of the watershed. The four Wyoming mines shown on **Figure 4-5** consist of three sand and gravel mines and one granite mine. Based on the type of mining, the Wyoming mines have a low potential for contributing arsenic to the basin.

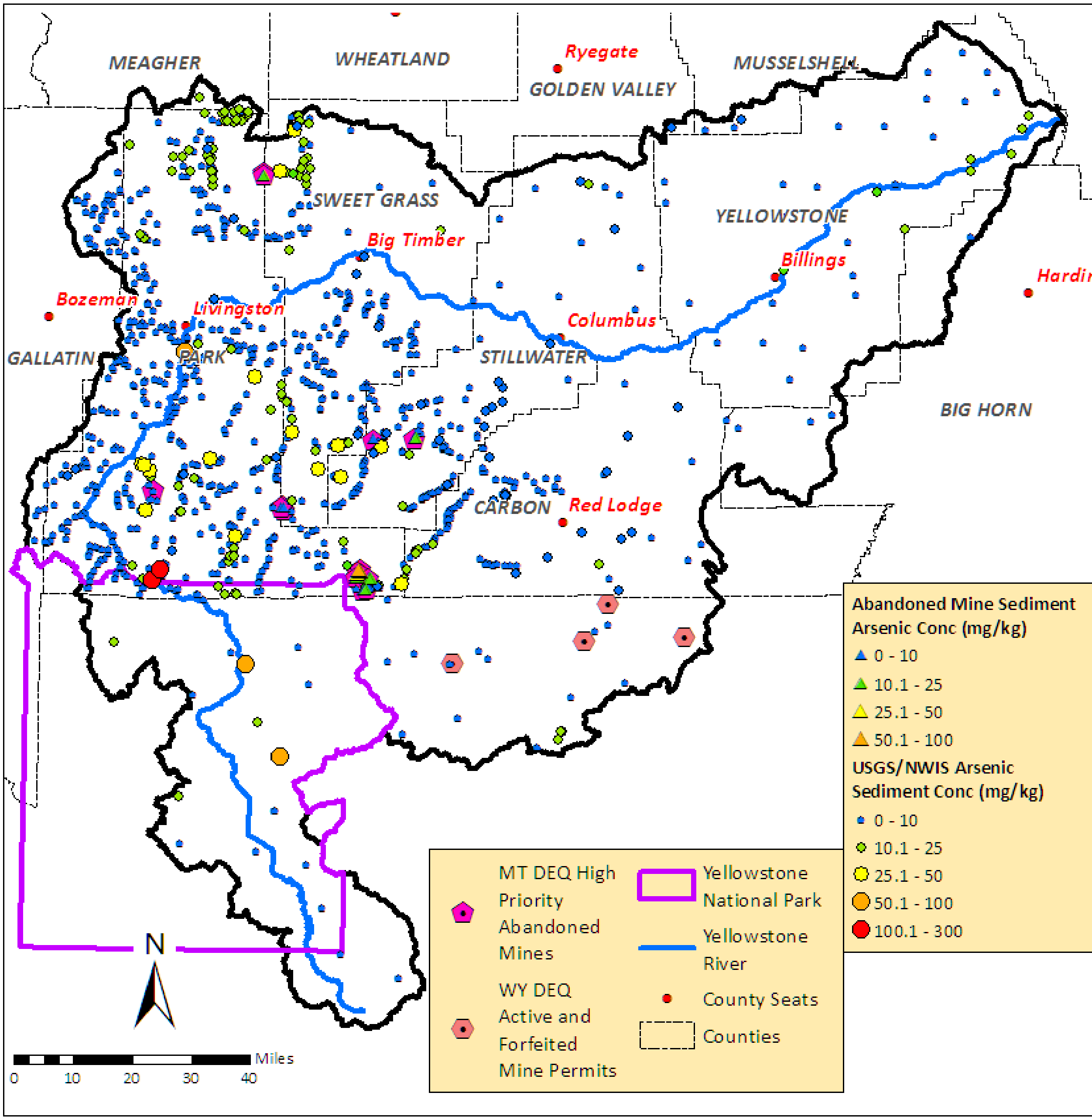

Figure 4-5. Sediment Arsenic Concentrations for Yellowstone Watershed

Surface Water

Figure 4-6 presents the surface water arsenic concentrations from DEQ's Abandoned Mines program database, collected downstream of the mine workings at 12 of the 17 high-priority abandoned mines, and sites listed as "mine drainage" the MBMG GWIC database**.** Only the western and central portions of the watershed are shown in **Figure 4-6** as there were no surface water samples related to mining in the far eastern portion of the project watershed.

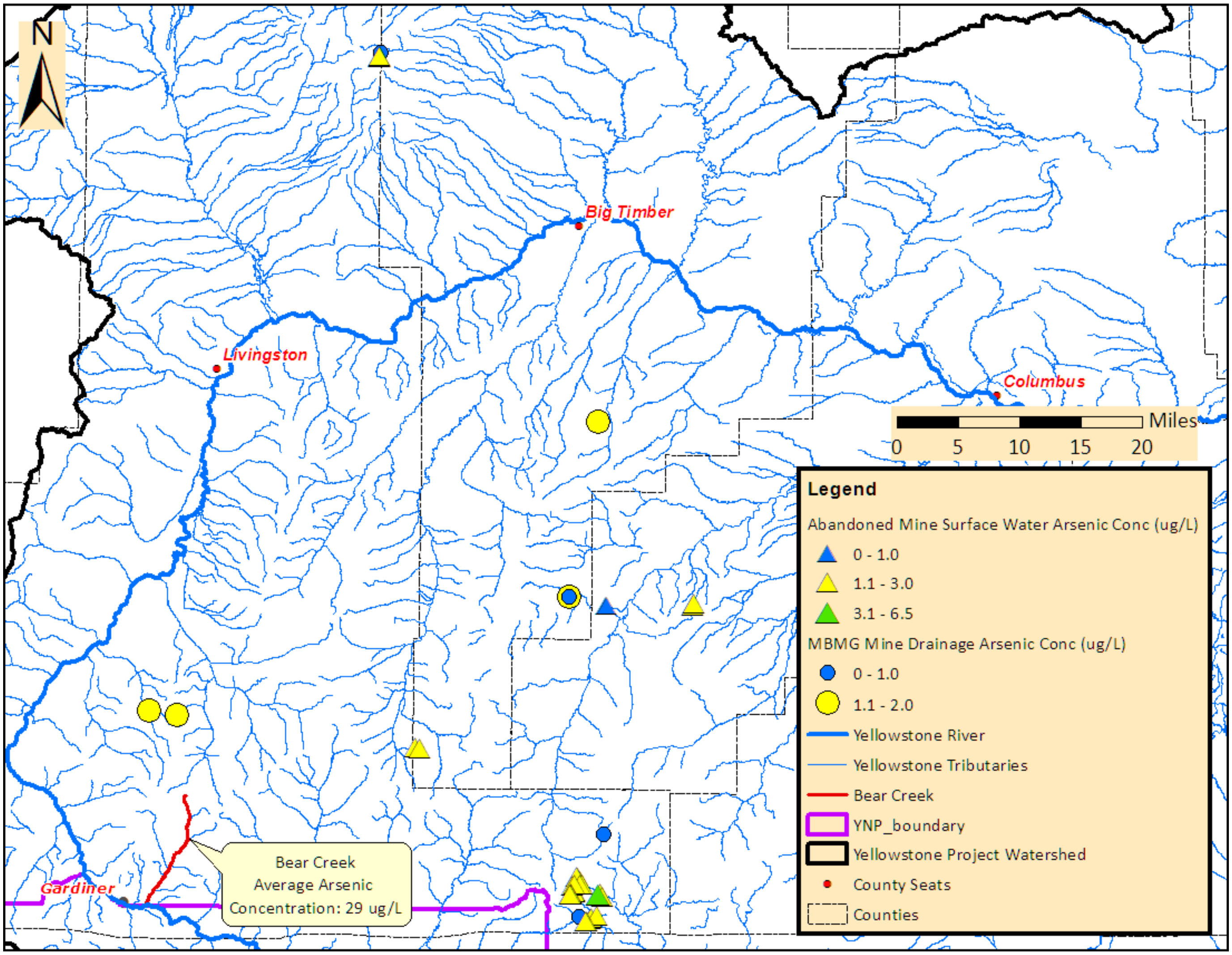

Figure 4-6. Mine Drainage Arsenic Concentrations in the Yellowstone Watershed

Review of the mining surface water data showed:

- Bear Creek - The highest arsenic concentrations occur in the upper section of the watershed near YNP, including Bear Creek. The elevated arsenic concentration in Bear Creek is attributed mainly to an abandoned mine -- the Jardine Tailings remediation site (see **Section 4.3**, **Section 4.4.3,** and **Section 4.5**).
- New World Mine District - Between 1989 and 1997, 116 total arsenic samples were collected on the four main streams (Daisy Creek, Stillwater River, Fisher Creek and Clarks Fork Yellowstone) draining the New World Mine district. These samples are not included in **Figure 4-6** because all the samples were below the laboratory detection limits of 10, 5 or 1 µg/L (except for four samples that had detects at 2 µg/L or less) and the points are too condensed to display on the Figure. The low and non-detectable arsenic concentrations indicate that the New World Mining District is not a significant source of arsenic to the Yellowstone River Basin.

In conclusion, DEQ has determined there are no Yellowstone River Basin anthropogenic arsenic loads attributable to discharges from active or abandoned mines, other than discharges to Bear Creek which are accounted for under Permitted Sources (Mineral Hill Mine) and “Other” Anthropogenic Point Sources (Jardine Tailings).

4.4.3 Remediation Response Sites, Underground Storage Tanks, and Hazardous Waste Sites

Other anthropogenic point sources of contaminants to the Yellowstone River Basin are shown in **Figure 4-7**, which potentially include remediation response sites (RRS), underground storage tanks, and hazardous waste sites. Most of the RRS are small and based on a review of the available site investigation summaries these sites have a low potential to contribute arsenic to the watershed.

In addition, DEQ considered chromated copper arsenate. It is still in use as a wood preservative in industry, but there is no evidence of industrial wood treatment facilities in the Yellowstone River Basin. Other common commercial uses of chromated copper arsenate have been discontinued for over 50 years and residuals are not expected to be present in the watershed.

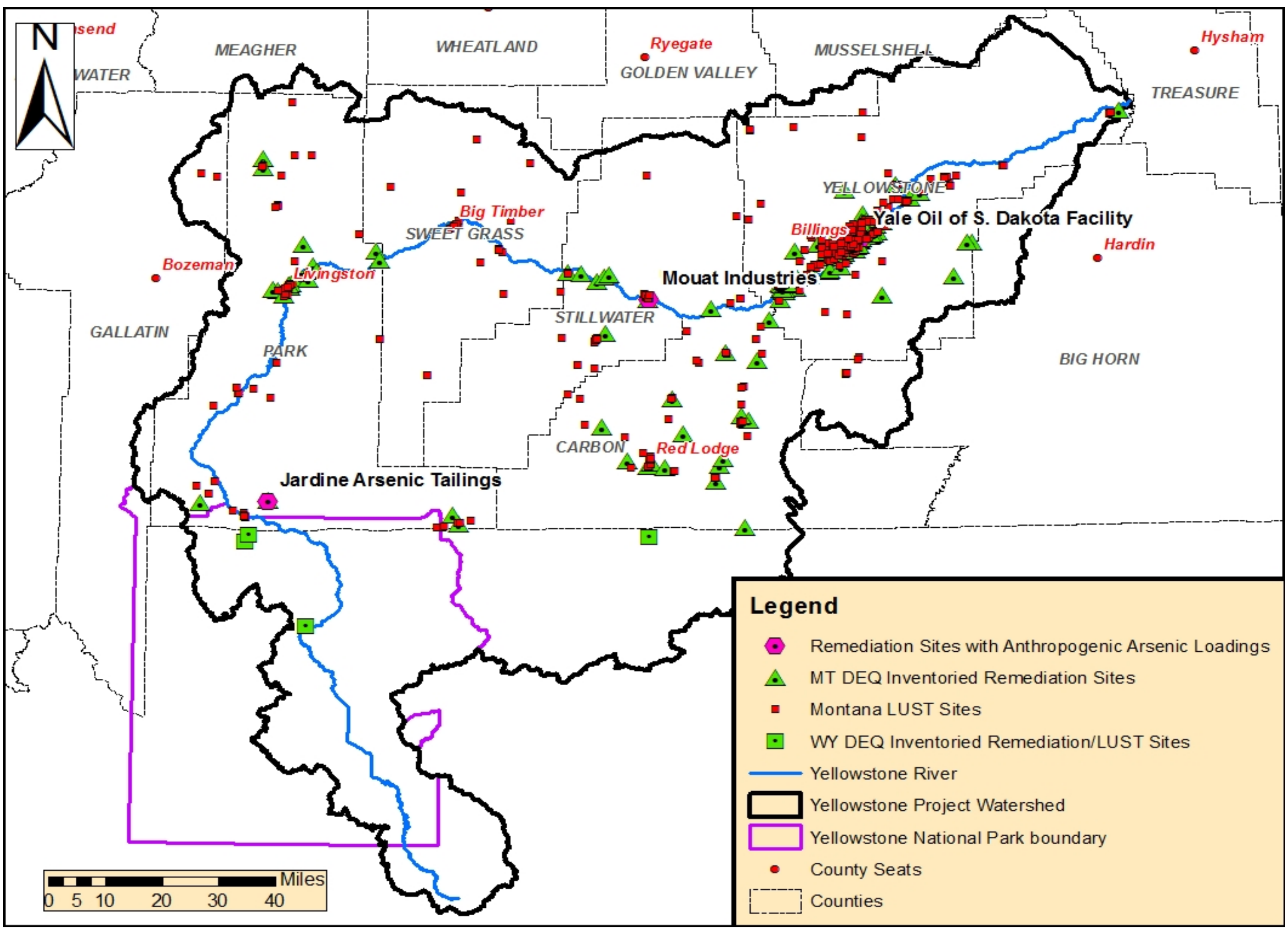

Figure 4-7. DEQ Remediation Response Sites in Yellowstone Watershed

There are six larger RRS sites in the watershed; three are not suspected sources of arsenic and three are. The three larger RRS sites that are not arsenic sources are:

- Lockwood solvent site, a federal Superfund site located east of Billings;
- Burlington Northern Livingston Complex, a state Comprehensive Environmental Cleanup and Responsibility Act (CECRA) site in Livingston; and
- 2011 Silvertip Pipeline Oil spill, a CECRA site near Laurel.

The three RRS sites identified as sources of arsenic are shown on **Figure 4-7**. They include:

- Jardine Tailings (Segment 1). The runoff and ground water from the tailings flow into Bear Creek which enters the Yellowstone River immediately north of YNP (see **Section 4.3**, **Sections 4.4.2, and 4.5**). DEQ estimated the monthly arsenic load in Bear Creek from measured stream discharge rates and instream arsenic concentrations. There was very little available flow data for Bear Creek; one value during high flow and four values during low flow. However, there were 40 data points for total recoverable arsenic concentrations, which varied from < 0.5 to 300 µg/L. The Bear Creek arsenic load estimate varied from 82 kg/month during low flow months to 63 kg/month during high flow months (**Appendix E-3**). The Jardine Tailings arsenic load was assumed to contribute all the arsenic load in Bear Creek --other than the minimal Mineral Hill Mine (also referred to as the TVX permit) contribution that is already included in the Permitted Sources estimates -- which resulted in 81 kg/month during low flow and 63 kg/month during high flow for an annual total load of 919 kg/yr.
- Mouat Industries of Columbus, Montana (Segment 4). This RRS was a chromite ore processing site that operated from 1957 to 1962. Remediation efforts were completed in 2008, but residual arsenic exists in the ground water beneath and downgradient of the site that eventually enters the Yellowstone River. The estimated ground water flow volume was combined with the available ground water arsenic concentration data to estimate the "Other" Anthropogenic arsenic load to the Yellowstone River (0.11 kg/month) in the Stillwater River to Clarks Fork Yellowstone River segment.
- Yale Oil of South Dakota Facility (Segment 5). This is an oil refinery that operated until 1949 in the City of Billings. The site remediation is ongoing and arsenic concentrations in the ground water beneath the site exceeds the water quality standard of 10 µg/L. The estimated ground water flow volume was combined with the available ground water arsenic concentration data to estimate the arsenic load to the Yellowstone River (0.0035 kg/month).

The ground water arsenic load for these three RRS sites (**Table 4-5**) are included as 'Other' anthropogenic point source loads in the mass balance calculations in **Section 4.8** and **Appendices E-1** and **E-3.**

Table 4-5. Other/Groundwater Anthropogenic Arsenic Loads, by Hydrologic Segment

Segment	Facility/Site	Receiving Body	Annual Load (kg/year)[3]
1	Jardine Tailings	Groundwater	919
4	Mouat Industries	Groundwater	1.3
5	Yale Oil of South Dakota	Groundwater	0.04

In addition to the RRS sites, there are 722 inventoried LUST sites in the Yellowstone River Basin in Montana **(Figure 4-7)**. Arsenic is not typically a contaminant of concern at petroleum sites and DEQ finds these sites have a low potential to contribute arsenic to the watershed. However, petroleum spills can in some cases alter the chemistry in the soil and allow previously immobile arsenic that occurs naturally in the soil to become mobile and migrate to ground water. One site where this may have occurred is the Phillips 66 refinery in Billings, which has a Montana Hazardous Waste Permit for on-going corrective actions. There are elevated ground water arsenic concentrations beneath this property, however due to corrective actions the arsenic plume has been maintained on-site and is not impacting the adjacent Yellowstone River. Therefore, there are no known arsenic loads to the Yellowstone River from LUST sites.

For Wyoming, the voluntary remediation program inventory showed four sites within the Yellowstone River Basin. Three of the sites were petroleum hydrocarbon leaks, remediated prior to 2012, and not potential sources of arsenic. The fourth site was a natural gas well blowout, not considered a potential source of arsenic to the Yellowstone watershed.

4.5 Ground Water (GWA) Loads

Ground water concentrations are shown in **Figure 4-8**.

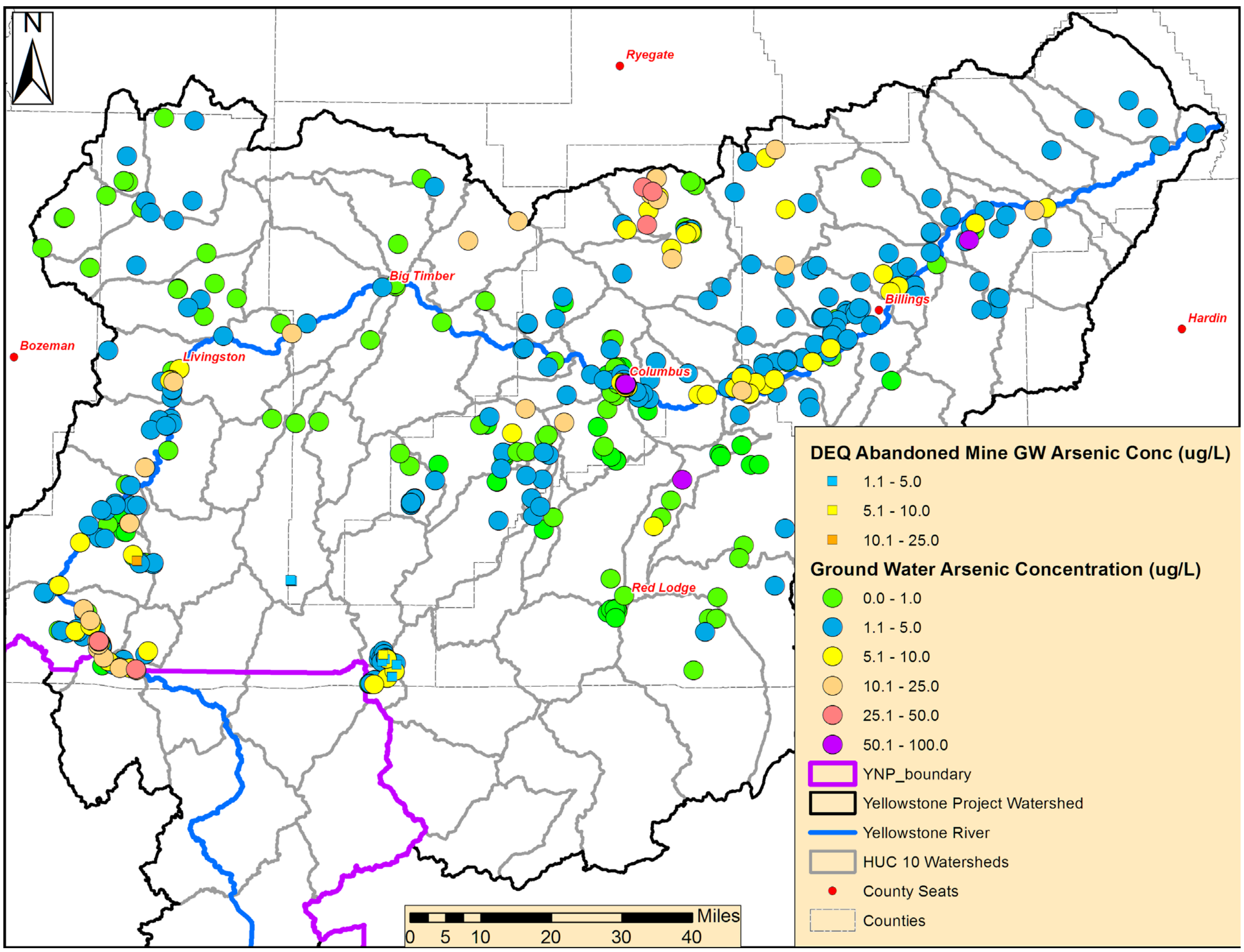

Figure 4-8. Ground Water (1971-2018) Arsenic Concentrations in Yellowstone Watershed

Concentrations of arsenic in ground water varied locally primarily due to geologic conditions. The ground water data shows most samples are below the arsenic water quality standard (10 µg/L). However, there are several areas of noticeably higher ground water arsenic concentrations, including:

- Two areas near the northern border of YNP located near Bear Creek and LaDuke Hot Springs.
  - Bear Creek - the Jardine mining tailings pile that has high arsenic concentrations contributing arsenic to Bear Creek is likely also contributing to high ground water arsenic concentrations. All of Bear Creek's arsenic loading is assumed to be anthropogenic, and is already accounted for under the Mineral Hill Mine permitted source and under "Other" for the Jardine Tailings.
  - The elevated arsenic in the ground water near LaDuke hot springs is a naturally occurring geothermal spring with total arsenic concentrations measured as high as 23 µg/L. The nonanthropogenic arsenic load from this ground water is discharged directly into the Yellowstone River near Gardiner, and is captured as part of the nonanthropogenic load from the TAL at Corwin Springs.
- The ground water in the Hailstone basin area north of Columbus also had numerous elevated arsenic concentrations. The Hailstone area has naturally high heavy metal concentrations due to evaporation in this hydrologically closed basin. Because it is a closed basin it does not contribute ground water to the Yellowstone River and therefore was not accounted for in this project.
- Another cluster of elevated ground water arsenic concentrations near Columbus are related to the Mouat Industries federal superfund site which was evaluated and included as an "Other" anthropogenic source of arsenic to the Yellowstone River (**Section 4.4.3 and Appendix E-3**).
- Two other isolated wells contained elevated arsenic concentrations were noted but not considered to be sources of arsenic loading to the Yellowstone River.
  - The first is a domestic well near Red Lodge, MT that is completed in the Lance formation known to contain trace metals including arsenic (USGS, 1999).
  - The second is a shallow monitoring well on the Montana State University Agricultural Research Center near Huntley, MT. The arsenic concentration in the well increased from less than 10 µg/L in 2002 to 62 µg/L in 2011; however, many other parameter concentrations increased between 2002 and 2011 including nitrate from 0.8 to 4.5 mg/L. Although the increase of nitrate and other parameters may indicate the elevated arsenic concentration is due to land management practices at the center, the extent of the elevated arsenic is likely minimal and not a significant source of arsenic to the Yellowstone River since a similar monitoring well 2,500 feet to the west of this well had an arsenic concentration of 6.9 µg/L on the same date in 2011.

Based on the available data, the average arsenic ground water concentrations in the Upper Yellowstone Basin is 4.9 mg/L, which is similar to the statewide average of 4.4 mg/L. However, the median value in the Upper Yellowstone River Basin is 2.5 mg/L, which is over double the statewide median ground water concentration of 1.1 mg/L. The higher median values are likely due to the naturally higher ground water concentrations north of YNP and in the Hailstone basin area.

In summary, the only identified anthropogenic ground water (GWA) arsenic load contributions to the Yellowstone River are the Bear Creek, Mouat Industries, and Yale Oil arsenic loads that were discussed in **Section 4.4.3** and are included under "Other" Anthropogenic Loads in **Appendix E-3**.

4.6 Surface Water Runoff (ROA) Loads

This section evaluates the anthropogenic land use changes and their effects on the arsenic load associated with surface water runoff.

4.6.1 Agriculture

DEQ evaluated whether agricultural practices in the Yellowstone River Basin may result in an increased anthropogenic load of arsenic to the Yellowstone River from water diversion practices in addition to increased sediment loading.

Water that is diverted from one surface water source may be used in a location that drains to a different surface water source thereby potentially migrating contaminants to different basins. The Yellowstone River has higher arsenic concentrations than most of its tributaries and the ground water in the basin:

- The Yellowstone River median arsenic concentration in the project area ranges from 30 µg/L above the confluence with the Lamar River inside YNP to 10 µg/L at Billings (**Appendix C**).
- The tributaries median arsenic concentration ranges from < 1 µg/L to 6 µg/L (DEQ, 2017b), with two notable exceptions that are accounted for within other variables:
    - Gardner River which has an elevated median arsenic concentration of 85 µg/L; and
    - Bear Creek, which has an elevated median arsenic concentration of 9 µg/L.

The ground water median arsenic concentration in the Yellowstone River Basin is 2.5 µg/L. Based on the tributary and ground water information, return flow to the Yellowstone River from irrigated lands through water diversions or ground water percolation will likely dilute the arsenic concentration in the Yellowstone River. However, there is no accurate method to determine the ground water load contribution to the Yellowstone River. Therefore, that load is assumed to be included with the tributary load and some of the ground water load is likely contributing to the watershed loading errors (**Table 4-10**).

4.6.2 HAWQS Sediment Runoff Modeling

The amount of arsenic associated with sediment runoff from anthropogenic land uses in the Yellowstone River Basin was estimated using measured and interpolated soil arsenic concentrations and simulated sediment runoff from the HAWQS watershed model (**Section 2.2.2** and **Appendix A**; electronic version of the HAWQS model parameters and results are available upon request).

Figure 4-9 shows the estimated soil arsenic concentrations for each HUC10 in the Yellowstone River Basin that were interpolated from the 25 USGS soil sample locations in the watershed (Smith et al., 2014). The soil arsenic concentrations were used with the monthly sediment loading estimates from the HAWQS model to estimate monthly and annual arsenic load runoff in the individual HUC10s.

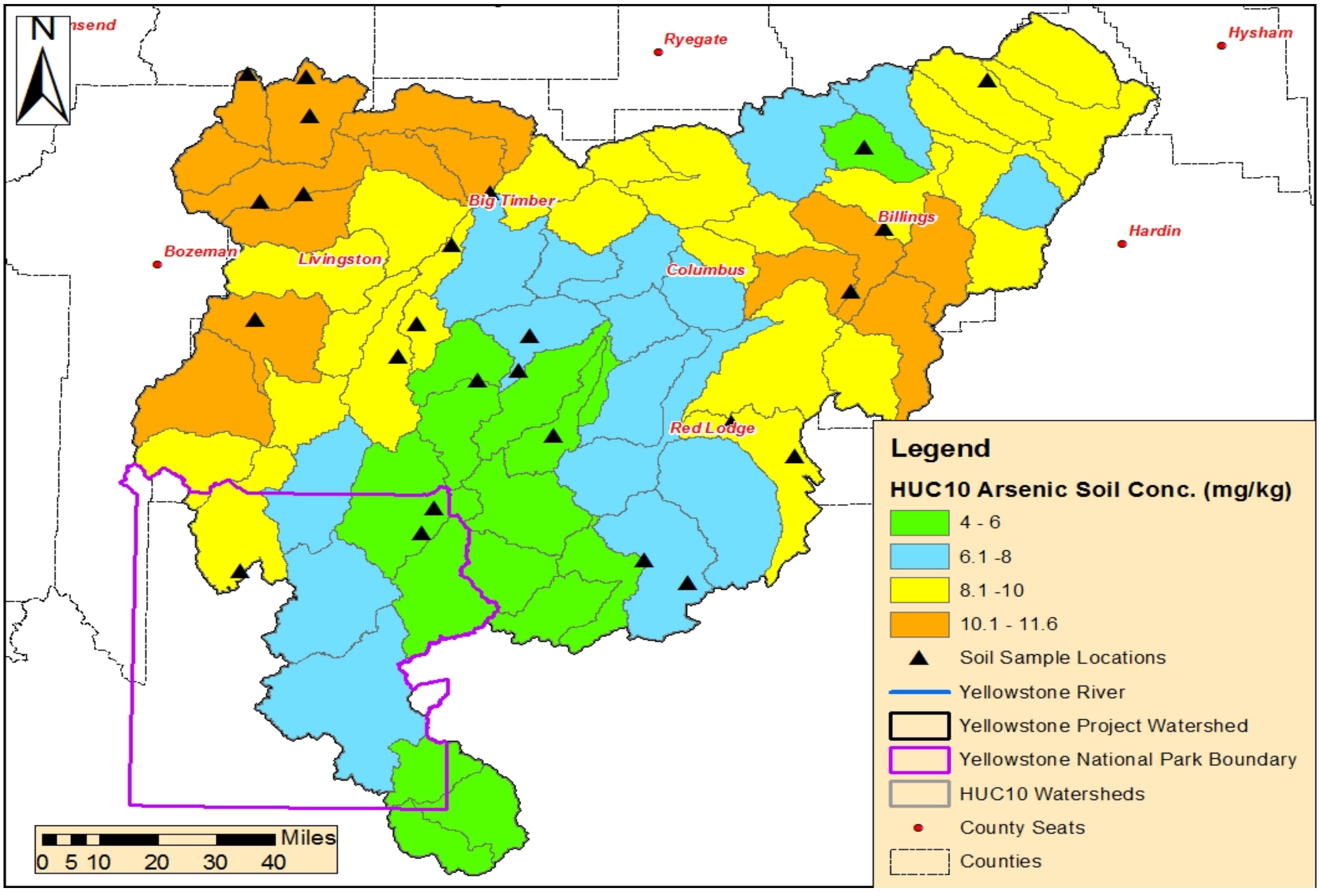

Figure 4-9. Soil Arsenic Concentrations for the Yellowstone Watershed

Table 4-6 shows the difference in estimated annual sediment load (tons/year) between the existing condition and the natural (nonanthropogenic) condition. The difference is the calculated anthropogenic sediment load that includes the mainstem of the Yellowstone River and its' tributaries. DEQ calculated the anthropogenic arsenic load from the anthropogenic sediment load for each HUC10 by multiplying this calculated sediment load by the interpolated arsenic concentration in that HUC. The anthropogenic arsenic load is the annual ROA component of the modified mass balance equation, by hydrologic segment. The annual ROA is less than one percent of the total arsenic in the Yellowstone River for all five hydrologic segments, and will be used in the modified mass balance equation to calculate the nonanthropogenic load in **Section 4.8**.

Table 4-6. HAWQS Annual Estimate of Arsenic Runoff to the Yellowstone River from Anthropogenic Land Use

Hydrologic Segment	Sediment Load			HUC10 Soil Arsenic Conc. Range (mg/kg)[2]	ROA Anthropogenic Arsenic Load (kg/yr)[3]
	Existing Condition (tons/yr)	Natural Condition / Nonanthropogenic (tons/yr)	Anthropogenic Land Uses (tons/yr)[1]		
1 -Montana/Wyoming border to Mill Creek	13,906	13,050	856	8.9 -10.6	8
2 - Mill Creek to Boulder River	38,708	24,876	13,832	8.3-11.6	134
3 - Boulder River to Stillwater River	22,585	19,445	3,140	5.1-10.4	25
4 - Stillwater River to Clarks Fork Yellowstone	40,398	23,095	17,303	4.1-11.3	118
5 - Clarks Fork Yellowstone to Bighorn River	53,240	11,608	41,633	5.4-10.6	364
TOTAL	**168,836**	**92,073**	**76,764**		**649**

[1]Calculated by subtracting the natural (nonanthropogenic) condition load from existing condition load. This includes anthropogenic tributary contributions.
[2] Values shown are the range in each segment. The value used for each HUC10 sub-watershed are listed in **Appendix A**.
[3]See **Appendix A**. ROA calculated for each HUC10 in the region, using the HUC10 average soil arsenic concentration multiplied by the sediment load due to anthropogenic land uses times a conversion factor.

The Yellowstone Basin overland sediment runoff estimated using the HAWQS model was not calibrated to measured concentrations. However, the sediment load rate was compared to a calibrated SWAT model run on the Flint Creek Basin that discharges to the Clark Fork River near Drummond, MT. Comparing just those land uses that the two basins have in common (alfalfa/hay, rangeland, evergreen forest, barley, spring wheat, and urban development) the sediment loading rates were within 15% between the two simulations. The average sediment load rates for the common land uses in the Yellowstone Basin and Flint Creek Basin indicates the Yellowstone sediment loading rates are reasonable and consistent with the calibrated model and therefore provide a good tool for estimating anthropogenic contributions of sediment to the Yellowstone River.

The ROA is broken down by each HUC10 and displayed in **Figure 4-10.**

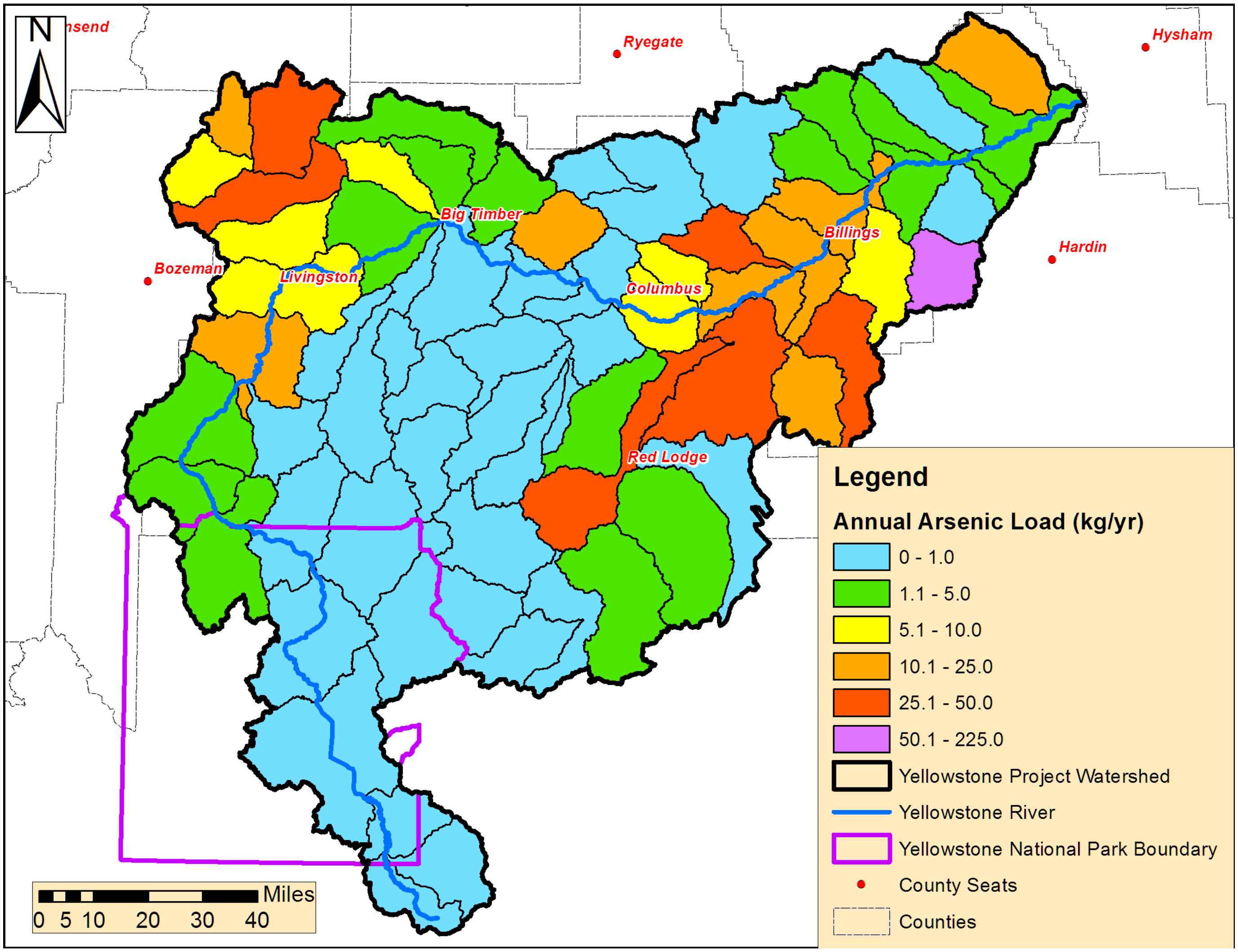

Figure 4-10. Anthropogenic Arsenic Runoff Loads from HAWQS Model for the Yellowstone River Basin

4.7 Tributary Loads

The tributary arsenic load contribution includes both anthropogenic and nonanthropogenic sources. The anthropogenic contribution from tributaries is already included as part of the previously quantified anthropogenic loads (point sources through permitting data, ground water data, Bear Creek data, and anthropogenic surface runoff through HAWQS).

In this section, DEQ calculated the nonanthropogenic tributary contribution from the difference between the total tributary arsenic loads developed in this section and the calculated anthropogenic runoff developed in **Section 4.6**. The tributary nonanthropogenic load developed in this section compared to the nonanthropogenic load calculated using the Yellowstone mainstem LOADEST calculations (see **Section 4.2**) at the end of the DON in **Section 4.8** to determine the difference in loads and as a check on the accuracy of the modified mass balance method.

4.7.1 Tributary Arsenic Loads - Paired Flow and Arsenic Measurement

DEQ used a mix of modeling using LOADEST, paired monitoring data, monitoring data, and extrapolation to determine the total arsenic load (and the nonanthropogenic load) contributed from the tributaries in the project area. **Figure 4-11** provides a spatial overview of the methods used. The confluence of the Yellowstone River with the Bighorn River signifies the end of the project area; therefore, the arsenic load from Bighorn River is not included. The calculation of the tributary loads is presented in **Appendix D-1**.

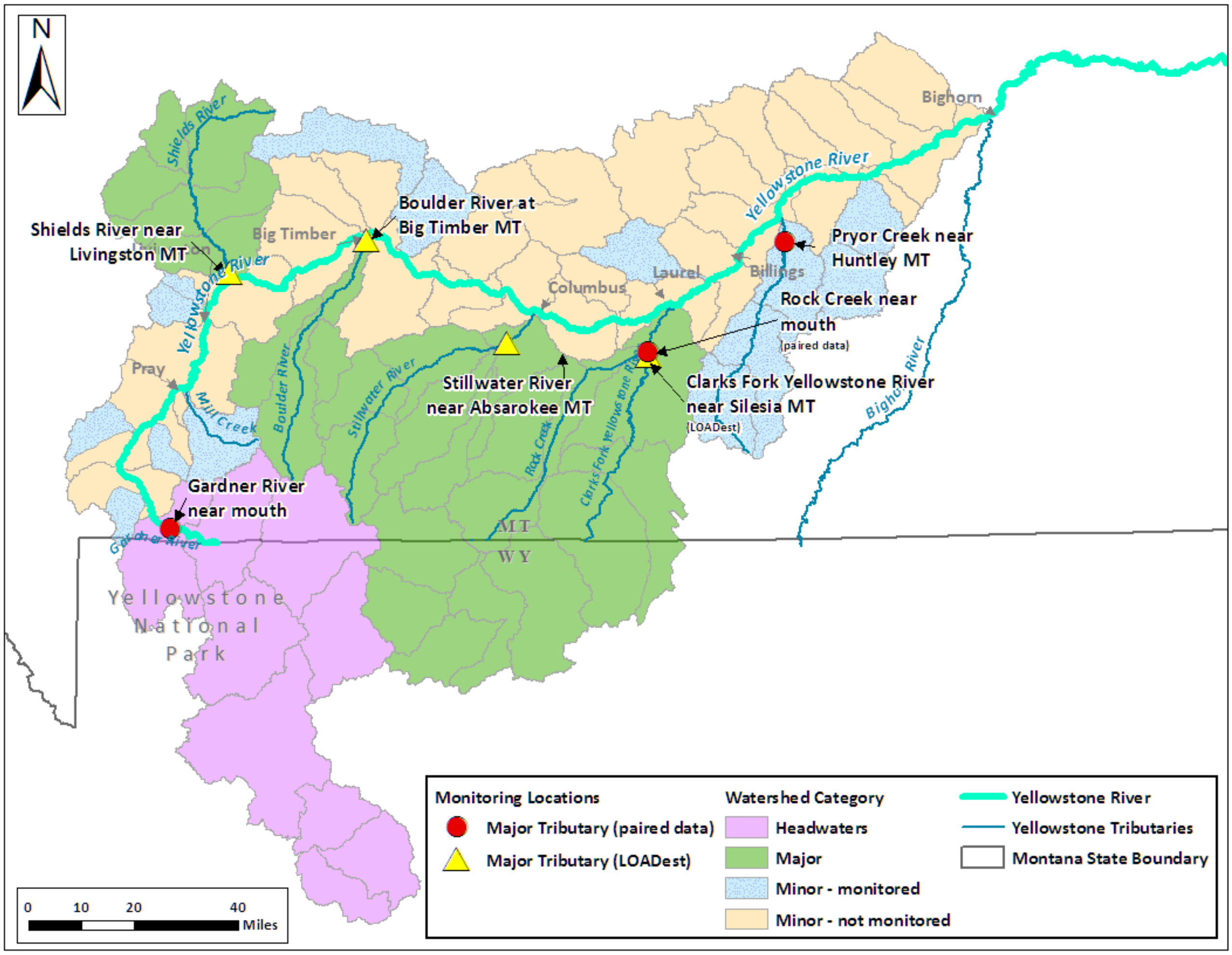

Figure 4-11. Tributaries to the Yellowstone River and Their Associated Drainage Areas

DEQ used the following methods for those tributaries with monitoring data:

- Major Rivers modeled with LOADEST - Shields, Boulder, Stillwater, and Clarks Fork of the Yellowstone had USGS gages with daily flow measurements and at least 19 pairs of flow and arsenic data using the ten-year period of 2008-2017.
- Major Rivers using paired data - Rock Creek and Pryor Creek had at least 10 paired flow and concentration samples collected by DEQ near the mouth of the tributaries. (Gardner River was also
- calculated in this manner, but the arsenic load is attributed to YNP). From this data DEQ calculated the total daily mass arsenic load for each tributary, using the mass load methodologies described in **Section**

2.2.1. Tributary load calculations were based on presumed high and low flow conditions and the median arsenic concentrations of those flow conditions (**Appendix D-1**). High flow conditions were defined as those occurring from May through July, and low flow conditions as those occurring from August through April.

- Minor Rivers monitored - the eight rivers with minimal available data (three to seven monitoring events with paired data and additional unpaired data) were counted as part of the measured tributaries. Tributary load calculations were conducted as with the major rivers using paired data (**Appendix D-1**).

4.7.2 Remaining Minor Tributary Arsenic Loads - Extrapolation

Not all minor tributaries were monitored for flow or arsenic concentration. The tributaries without monitoring data either (1) had no historical record and there was no evidence to suggest they had a potential anthropogenic source; (2) may not have been sampled due to private land access issues; or (3) their contributing area was so small that it was impractical to sample them. Although there is no direct monitoring data for these minor tributaries, unaccounted for drainages still contribute arsenic load to the Yellowstone River and need to be included in the mass balance.

For each of the hydrologic segments on the Yellowstone River, a ratio of unaccounted for (no monitoring data) and accounted for (monitoring data) drainage areas was developed by segment (**Table 4-7** and **Appendix D-2**). This ratio was then multiplied by the total arsenic load contribution of the "accounted for" drainages within the segment to provide an arsenic load estimate for the "unaccounted for" drainages.

Table 4-7. Accounted and Unaccounted for Drainage Area in the Yellowstone Watershed[1]

Drainage Area within Each Hydrologic Segment	Total Area (km)[2]	Monitored Area (km)[2]	Unmonitored Area (km)[2]	% of Segment unmonitored[2]	% of DON Watershed Unmonitored[3]
Montana/Wyoming Border[4]	6,718	6,718	--	--	--
1 - Montana/Wyoming border to Mill Creek	1,817	861	956	53%	11%
2 - Mill Creek to Boulder River	5,978	3,777	2,202	37%	22%
3 - Boulder River to Stillwater River	5,996	3,778	2,218	37%	26%
4 - Stillwater River to Clarks Fork Yellowstone	9,675	7,233	2,442	25%	26%
5 - Clarks Fork Yellowstone to Bighorn River	7,233	2,319	4,914	68%	34%
TOTAL	**37,417**	**24,685**	**12,732**	**--**	**34%**

[1]Tributary area drainage HUC10s presented in **Appendix D.**
[2] Each segment's ratio of monitored vs. not monitored is used to interpolate the arsenic load expected from the unmonitored areas.
[3]Percent of area unaccounted for is the rolling total of unaccounted for area/total land area.
[4]Area upstream of the Montana/Wyoming Border (6,718 sq. km) is assumed to be 100% nonanthropogenic.

The total arsenic load from the "non-Yellowstone National Park" tributaries in the Yellowstone River Basin project area is 3,841 kg/year (**Appendix D-2**). This is less than 7% of the total arsenic load of the Yellowstone River as monitored at the Billings monitoring station. The method of estimating arsenic tributary loads of unaccounted for minor drainages is acceptable for the Yellowstone Basin because it is unlikely that any one minor tributary would contribute a significant arsenic load to the Yellowstone River. Furthermore, the accounted for and unaccounted-for area within the Yellowstone have similar physiographic, land use, and geologic conditions, this ratio method can provide a reliable estimate for the total arsenic load from the tributaries that have no arsenic data.

4.7.3 Tributary Summary

The total non-YNP tributary arsenic load is 3,841 kg/yr; 17 percent of that load (649 kg/yr) is estimated as ROA. The remainder, 3,193 kg/yr, is nonanthropogenic. **Table 4-8** provides a summary of the annual anthropogenic and nonanthropogenic tributary loads by segment.

Table 4-8. Annual Tributary Contribution (Anthropogenic vs. Nonanthropogenic)

Hydrologic Segment	Total Tributary Arsenic Load (kg/yr)	Anthropogenic Tributary (ROA) (kg/yr)[2]	Nonanthropogenic Tributary (RON) (kg/yr)
1 - Montana/Wyoming border to Mill Creek[1]	352	**8**	344
2 - Mill Creek to Boulder River	722	**134**	588
3 - Boulder River to Stillwater River	623	**25**	598
4 - Stillwater River to Clarks Fork Yellowstone	1,051	**118**	933
5 - Clarks Fork Yellowstone to Bighorn River	1,094	**364**	730
TOTAL	**3,841**	**649**	**3,193**

[1] Does not include Gardner River, which is attributed to nonanthropogenic sources in the YNP.
[2] From surface water runoff modeling with HAWQS (see **Table 4-6**).

4.8 MODIFIED MASS BALANCE RESULTS

The modeling results and calculated anthropogenic and nonanthropogenic loads were used in the modified mass balance equation to calculate the final nonanthropogenic arsenic condition of the Yellowstone River (**Appendix E**). The modified mass balance equation used to calculate the Nonanthropogenic Arsenic Load (NAL) shown in Equation 5 (**Section 2.3**) is:

Nonanthropogenic = TAL - [PSL + GWA + ROA]

The monthly arsenic loads for each hydrologic segment is presented in **Appendix E-1**. An annual summary for the five segments is presented in **Table 4-9**.

Table 4-9. Median Annual Arsenic Load Summary for Yellowstone River, by Segment

	SEGMENT VALUES			**CUMULATIVE ANNUAL VALUES**			
Description	***LOADEST Total Arsenic Load***	***Total Anthropogenic Load***	***Non-Anthropogenic Load***	**LOADEST Total Arsenic Load**	**Total Anthropogenic Load**	**Non-Anthropogenic Load**	**Non-anthropogenic Load as a % of TAL**
Data source	*Calculated from Table 4-3* [1]	*Calculated from Tables 4-4, 4-5 and 4-6*	*(see footnote 1)*	Cumulative from Monitoring	Cumulative from segment values	Cumulative from segment values	Calculation from Cumulative values
Variable (see Section 2.3)	*TAL*	*AAL (PSL+GWA+ ROA)*	*NAL*	TAL	AAL (PSL+GWA+ ROA)	NAL	NAL/TAL
Units	***kg/yr***	***kg/yr***	***kg/yr***	**kg/yr**	***kg/yr***	***kg/yr***	***%***
1 - MT/WY Border to Mill Creek	***47,689***	*969*	*46,720*	**47,689**	969	46,720	**98.0%**
2 - Mill Creek to Boulder River	***3,595***	*138*	*3,457*	**51,285**	1,107	50,178	**97.8%**
3 - Boulder River to Stillwater River	***(631)***	*25*	*(656)*	**50,654**	1,132	49,522	**97.8%**
4 - Stillwater River to Clarks Fork Yellowstone River	***2,719***	*182*	*2,537*	**53,373**	1,314	52,060	**97.5%**
5 - Clarks Fork Yellowstone River to Bighorn River	***2,283***	*241*	*2,042*	**55,656**	1,555	54,101	**97.2%**
			Total	**55,656**	**1,555**	**54,101**	**97.2%**

[1] The nonanthropogenic load by segment is calculated by the segment-specific TAL (difference between the segments' and the previous segments' TAL), minus the anthropogenic load for that segment. For segment 1, this is equivalent to the nonanthropogenic contribution from YNP.

Table 4-9 shows that approximately 97 percent of the arsenic load in the Yellowstone watershed above the Bighorn River is nonanthropogenic (DEQ, 2019).

Mass Balance Error

DEQ used a variety of methods to measure, model, or approximate the amounts of arsenic loading from various sources at various locations. To estimate the total error in this modeling work, DEQ compared the modified mass balance load at the end of Segment 5 against the LOADEST-derived loads (TAL) at the Billings monitoring station (**Table 4-10**).

Table 4-10. Comparison of Mass Balance and LOADEST Results at the end of the Project Reach (Bighorn River)

Arsenic Load Source	Percent of Arsenic Load at Bighorn based on Modified Mass Balance [1]	Percent of Arsenic Load at Bighorn based on LOADEST [2]
Modified Mass Balance Load[1]	100%	92.5%

[1] Total Arsenic Load at end of project reach (mouth of Bighorn River) based on the Modified Mass Balance is calculated as 51,468 kg/yr. This is equivalent to sum of AAL (1,555 kg/year from **Table 4-9**) + NAL (46,720 kg/yr YNP + 3,193 kg/yr TribN from **Table 4-8**).
[2] Total Arsenic Load (LOADEST) at end of project reach based on monitoring data at Billings is 55,656 kg/yr (**Table 4-3**).

The modified mass balance total arsenic load for the watershed (51,468 kg/yr) is 7.5% less than the total arsenic load based on LOADEST at Billings (55,656 kg/yr; **Table 4-3**). This unaccounted mass load is likely a combination of several sources of error in the mass balance calculations in either model and includes, but is not limited to: estimated tributary loads based on limited data; extrapolation of measured tributary loads to unmeasured tributaries; unaccounted for anthropogenic loads from point and non-point sources; unaccounted for ground water loads; and in-stream chemical and physical processes not accounted for.

Given the range of potential errors in estimating the arsenic load over the large Yellowstone watershed, the 7.5% error is acceptable. There is no indication that the error is biased towards the nonanthropogenic load or the anthropogenic load. Therefore, the relative percentages of nonanthropogenic load and anthropogenic load compared to the river's total arsenic load should be valid for deriving nonanthropogenic standards for each of the five Yellowstone River segments addressed in this document.

5.0 CONCLUSIONS

In this document, DEQ has demonstrated that the nonanthropogenic arsenic load in the Yellowstone River Basin from the Montana/Wyoming border to the confluence with the Bighorn River is approximately 97 percent of the total arsenic load.

Of the total Yellowstone River arsenic load above the Bighorn River, Yellowstone National Park's nonanthropogenic arsenic load accounts for approximately 91 percent of that load, and nonanthropogenic tributary arsenic loads downstream of YNP account for an additional 6 percent.

The remaining arsenic load, 3 percent, is composed of anthropogenic sources of arsenic.

DEQ evaluated Yellowstone River hydrograph information and determined that the Yellowstone River has a high flow season from May 1st to July 31st and a low flow season from August 1st to April 30th; the monitoring data shows that the Yellowstone River arsenic concentrations vary by high and low flow season. In conclusion, **Table 5-1** provides the proportion of the total arsenic load that is nonanthropogenic for each segment, by season.

Table 5-1: Nonanthropogenic Seasonal Arsenic Load Percentages, by Segment

Yellowstone River Segment				**Yellowstone River Sampling Location**	**Proportion of Arsenic Load that is Nonanthropogenic [1]**	
#	Beginning	End [2]	Length (miles)		High Flow Season [3]	Low Flow Season [3]
1	Montana/Wyoming Border	Mill Creek near Pray	45	Corwin Springs	99.0%	97.0%
2	Mill Creek	Boulder River at Big Timber	54	Livingston	98.9%	96.9%
3	Boulder River	Stillwater River near Columbus	37	Big Timber	98.9%	96.5%
4	Stillwater River	Clarks Fork of the Yellowstone River at Laurel	27	Laurel	98.9%	95.6%
5	Clarks Fork of the Yellowstone River	Bighorn River at Bighorn	73	Billings	98.7%	95.6%

[1] Based on the median of the LOADEST-modeled daily loads (See Appendix C).
[2] Each segment ends immediately before the confluence with the referenced tributary.
[3] High Flow season for the Yellowstone River was determined to be May – July, and the Low Flow Season was determined to be August - April.

DEQ will derive seasonal arsenic criteria in the NAS document based on the above percentages.

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APPENDICES

1. Appendix A-1 HAWQS
2. Appendix A-2 HAWQS
3. Appendix B-1 Seasonality for Segment 1
4. Appendix B-2 Seasonality for Segment 2
5. Appendix B-3 Seasonality for Segment 3
6. Appendix B-4 Seasonality for Segment 4
7. Appendix B-5 Seasonality for Segment 5
8. Appendix B-6 - Mann-Whitney Test
9. Appendix C-1 LOADEST Arsenic Concentration Summary
10. Appendix C-2 LOADEST Arsenic Load Summary
11. Appendix C-3 LOADEST Nonanthropogenic Arsenic Load
12. Appendix D-1 – Tributary Loads from Monitoring Data
13. Appendix D-2 – Tributary Loads
14. Appendix E-1 – Modified Mass Balance
15. Appendix E-2 – Permitted Source Loads
16. Appendix E-3 – Other Arsenic Source Loads
17. Appendix E-4 – Anthropogenic Runoff
18. Appendix E-5 – Tributary Arsenic Loads

Appendix A-1: DERIVATION OF ANNUAL ANTHROPOGENIC ARSENIC RUNOFF LOADS (ROA)

HAWQS Results by HUC - Land Use Annual Sediment & Arsenic Loading

Hydrologic Segment / HUC 10	SEDIMENT EXISTING CONDITIONS (tons/yr)[1]	SEDIMENT NATURAL CONDITIONS (tons/yr)[1]	SEDIMENT ANTHROPOGENIC EFFECTS (tons/yr)[2]	USGS SOIL ARSENIC CONC (mg/kg)	ROA ESTIMATED ANNUAL ANTHROPOGENIC ARSENIC LOAD (kg/yr)[3]
YNP - YELLOWSTONE FROM HEADWATERS TO MT/WY BORDER					
1007000101	2	2	0	4.3	**0.00**
1007000102	0	0	0	4.1	**0.00**
1007000103	0	0	0	4.8	**0.00**
1007000104	749	743	5	6.7	**0.03**
1007000105	610	574	36	6.8	**0.22**
1007000106	44	44	0	4.2	**0.00**
1007000107	458	446	12	4.3	**0.05**
1007000108	1,288	1,281	7	7.0	**0.04**
TOTAL YNP	**3,150**	**3,091**	**59**		**0.3**
YELLOWSTONE RIVER SEGMENTS					
1. YELLOWSTONE FROM MT/WY BORDER TO MILL CREEK					
Non-YNP					
1007000109	3,499	3,163	337	9.3	**2.8**
1007000201	2,635	2,427	208	9.3	**1.8**
1007000202	7,084	6,758	326	10.6	**3.1**
1007000203	687	702	-15	8.9	**-0.1**
SUB-TOTAL	**13,906**	**13,050**	**856**		**7.6**
2. YELLOWSTONE FROM MILL CREEK TO BOULDER RIVER					
1007000204	5,112	3,811	1,301	11.4	**13.5**
1007000205	4,249	3,393	855	10.0	**7.8**
1007000206	2,274	1,653	620	10.2	**5.7**
1007000207	290	283	7	8.9	**0.1**
1007000208	404	380	24	9.7	**0.2**
1007000209	1,050	962	88	8.3	**0.7**
1007000211	3,347	3,134	212	8.5	**1.6**
1007000301	2,198	614	1,584	10.4	**14.9**
1007000302	1,779	1,071	708	10.4	**6.7**
1007000303	7,694	4,072	3,621	11.6	**38.1**
1007000304	7,747	3,515	4,232	10.2	**39.2**
1007000305	2,566	1,987	579	10.1	**5.3**
SUB-TOTAL	**38,708**	**24,876**	**13,832**		**134**
3. YELLOWSTONE FROM BOULDER RIVER TO STILLWATER RIVER					
1007000212	3,569	3,219	351	10.4	**3.3**
1007000213	2,153	1,930	223	9.7	**2.0**
1007000214	1,048	1,042	7	7.5	**0.0**
1007000401	4,577	2,144	2,433	8.4	**18.5**
1007000402	931	886	46	7.3	**0.3**
1007000403	1,709	1,609	100	7.5	**0.7**
1007000501	75	76	0	5.1	**0.0**
1007000502	1,357	1,363	-6	6.0	**0.0**
1007000503	1,178	1,201	-22	5.5	**-0.1**
1007000504	1,497	1,542	-45	5.6	**-0.2**
1007000505	3,809	3,814	-5	6.3	**0.0**
1007000506	681	621	60	7.1	**0.4**
SUB-TOTAL	**22,585**	**19,445**	**3,140**		**25**
4. YELLOWSTONE FROM STILLWATER TO CLARKS FORK YELLOWSTONE					
1007000210	1,334	1,235	99	11.3	**1.0**
1007000404	1,729	923	806	8.0	**5.8**
1007000405	1,587	941	646	8.6	**5.0**
1007000406	2,473	543	1,930	10.2	**17.9**
1007000601	112	98	13	4.8	**0.1**
1007000602	275	275	1	4.3	**0.0**
1007000603	133	122	11	4.1	**0.0**
1007000604	264	262	3	4.6	**0.0**
1007000605	4,570	4,340	231	7.1	**1.5**
1007000606	4,614	4,389	225	7.6	**1.6**
1007000607	2,037	1,942	96	8.5	**0.7**
1007000608	7,277	3,176	4,101	8.8	**32.7**
1007000609	11,965	3,209	8,756	6.2	**49.2**
1007000610	2,027	1,641	386	6.6	**2.3**
SUB-TOTAL	**40,398**	**23,095**	**17,303**		**118**
5. YELLOWSTONE FROM CLARKS FORK YELLOWSTONE TO BIGHORN					
1007000409	3,958	816	3,143	9.3	**26.5**
1007000410	2,934	644	2,290	10.6	**22.0**
1007000702	690	407	283	5.4	**1.4**
1007000703	994	663	332	7.3	**2.2**
1007000704	1,897	646	1,251	9.3	**10.6**
1007000705	951	298	653	8.4	**5.0**
1007000706	27,554	2,249	25,305	9.7	**222.6**
1007000707	885	807	78	8.0	**0.6**
1007000708	730	292	439	8.5	**3.4**
1007000709	431	396	35	8.8	**0.3**
1007000710	1,998	441	1,556	9.0	**12.7**
1007000711	525	376	149	8.4	**1.1**
1007000801	2,527	867	1,660	9.7	**14.6**
1007000802	5,679	1,929	3,750	10.3	**35.0**
1007000803	1,487	778	710	10.1	**6.5**
SUB-TOTAL	**53,240**	**11,608**	**41,632**		**364**
TOTAL YELLOWSTONE (Segments 1 - 5)	**168,836**	**92,073**	**76,764**		**649**

[1] Sediment Loads calculated by HAWQS

[2] Sediment-loading Anthropogenic Effects = Existing Conditions minus Natural Conditions. Negative value indicates more sediment runoff under natural conditions than anthropogenic influenced conditions.

[3] Estimated Annual Anthropogenic Arsenic Load is the value for Anthropogenic Runoff (ROA) in Appendix D Mass Balance.

Appendix A-2: HAWQS Results- Monthly Anthropogenic Arsenic Loading by Segment

YNP - ARSENIC LOADING INTO YELLOWSTONE RIVER FROM HEADWATERS TO MT/WY BORDER

	MONTH												
PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
SWAT percent sediment runoff by month for Anthropogenic Scenario	0.00%	0.62%	15.84%	44.10%	27.64%	7.45%	0.00%	0.00%	0.00%	1.55%	2.80%	0.00%	
SWAT sediment runoff load for Anthropogenic Scenario (tons)	0.0	19.6	499.0	1,389.2	870.7	234.8	0.0	0.0	0.0	48.9	88.1	0.0	**3,150**
SWAT percent sediment runoff by month for Natural Scenario	0.00%	0.63%	16.19%	44.13%	27.62%	6.98%	0.00%	0.00%	0.00%	1.59%	2.86%	0.00%	
SWAT sediment runoff load for Natural Scenario (tons)	0.0	19.6	500.5	1,364.0	853.7	215.9	0.0	0.0	0.0	49.1	88.3	0.0	**3,091**
SWAT sediment runoff load due to anthropogenic activities [Anthropogenic load minus Natural Load] (tons)	0.0	-0.1	-1.5	25.2	17.0	18.9	0.0	0.0	0.0	-0.1	-0.3	0.0	**59**
Monthly anthropogenic arsenic loading associated with SWAT sediment runoff (kg)	**0.00**	**0.00**	**-0.01**	**0.14**	**0.10**	**0.11**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.3**

SEGMENT 1. ARSENIC LOADING INTO YELLOWSTONE RIVER FROM MT/WY BORDER TO MILL CREEK

	MONTH												
PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
SWAT percent sediment runoff by month for Anthropogenic Scenario	0.46%	1.61%	19.23%	41.85%	18.03%	12.23%	0.00%	0.00%	0.00%	1.21%	3.21%	2.18%	
SWAT sediment runoff load for Anthropogenic Scenario (tons)	63.9	223.5	2,674.2	5,819.3	2,506.5	1,700.3	0.0	0.0	0.0	167.6	447.0	303.3	**13,906**
SWAT percent sediment runoff by month for Natural Scenario	0.54%	1.69%	19.92%	42.55%	17.43%	11.08%	0.00%	0.00%	0.00%	1.15%	3.33%	2.30%	
SWAT sediment runoff load for Natural Scenario (tons)	71.1	221.2	2,598.9	5,553.2	2,275.0	1,445.6	0.0	0.0	0.0	150.1	434.5	300.2	**13,050**
SWAT sediment runoff load due to anthropogenic activities [Anthropogenic load minus Natural Load] (tons)	-7.2	2.3	75.3	266.2	231.6	254.7	0.0	0.0	0.0	17.5	12.6	3.2	**856**
Monthly anthropogenic arsenic loading associated with SWAT sediment runoff (kg)	**-0.06**	**0.02**	**0.67**	**2.37**	**2.06**	**2.26**	**0.00**	**0.00**	**0.00**	**0.16**	**0.11**	**0.03**	**7.6**

SEGMENT 2. ARSENIC LOADING INTO YELLOWSTONE RIVER FROM MILL CREEK TO BOULDER RIVER

	MONTH												
PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
SWAT percent sediment runoff by month for Anthropogenic Scenario	6.45%	4.65%	16.08%	23.56%	12.27%	21.94%	0.40%	0.60%	1.22%	1.77%	3.74%	7.33%	
SWAT sediment runoff load for Anthropogenic Scenario (tons)	2,497	1,799	6,224	9,118	4,749	8,494	153	233	471	687	1,447	2,837	**38,708**
SWAT percent sediment runoff by month for Natural Scenario	6.50%	4.72%	17.28%	23.90%	11.84%	21.97%	0.24%	0.24%	0.52%	1.90%	3.35%	7.55%	
SWAT sediment runoff load for Natural Scenario (tons)	1,617	1,175	4,297	5,944	2,946	5,466	59	59	130	472	832	1,877	**24,876**
SWAT sediment runoff load due to anthropogenic activities [Anthropogenic load minus Natural Load] (tons)	879	624	1,927	3,174	1,804	3,028	94	174	341	214	615	960	**13,832**
Monthly anthropogenic arsenic loading associated with SWAT sediment runoff (kg)	**8.5**	**6.0**	**18.6**	**30.7**	**17.4**	**29.3**	**0.9**	**1.7**	**3.3**	**2.1**	**5.9**	**9.3**	**134**

SEGMENT 3. ARSENIC LOADING INTO YELLOWSTONE RIVER FROM BOULDER RIVER TO STILLWATER RIVER

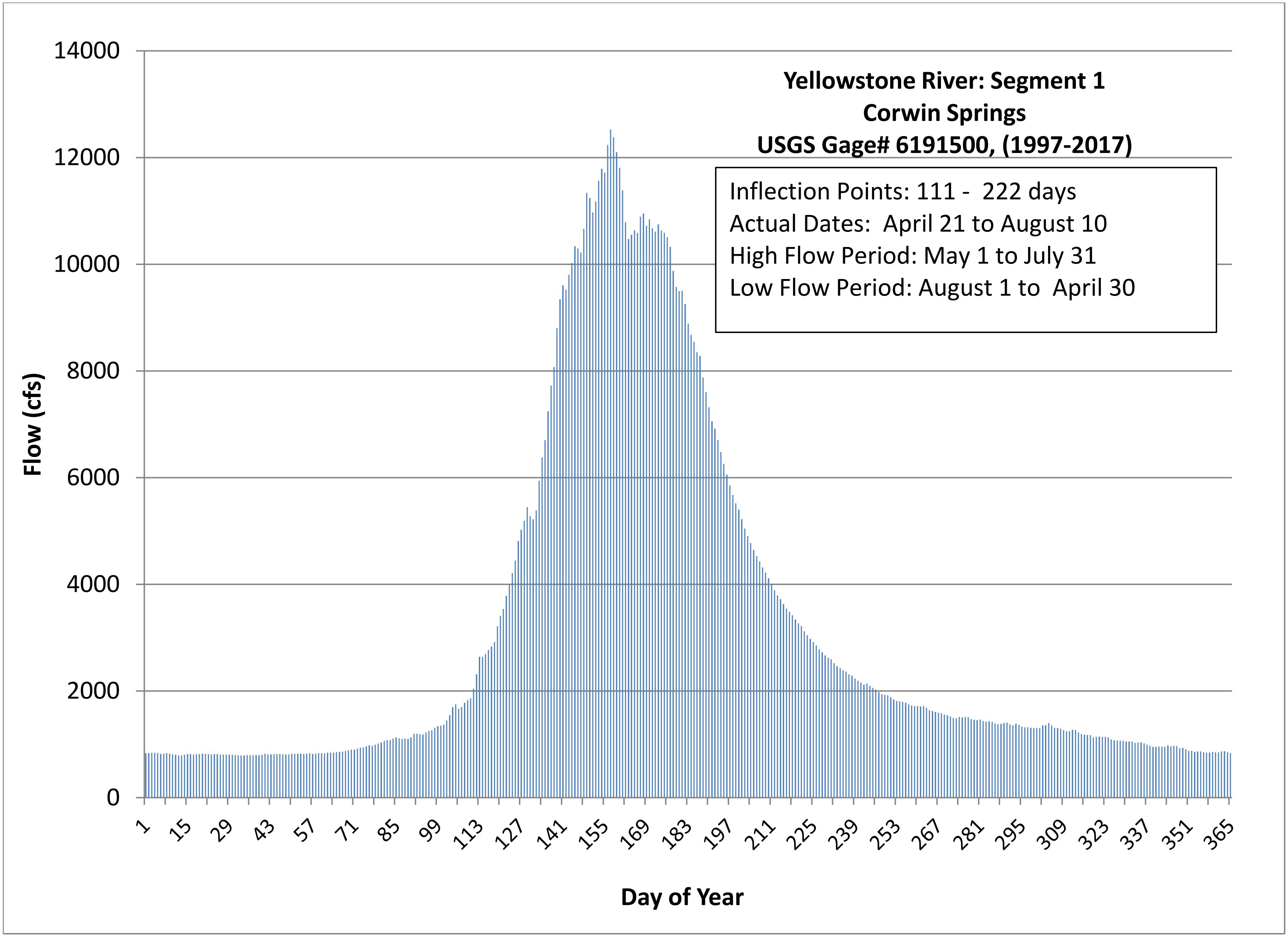
	MONTH												
PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
SWAT percent sediment runoff by month for Anthropogenic Scenario	4.50%	3.25%	12.17%	11.94%	26.84%	23.34%	1.36%	0.30%	3.09%	4.54%	3.47%	5.20%	
SWAT sediment runoff load for Anthropogenic Scenario (tons)	1,015	733	2,749	2,697	6,062	5,272	308	67	697	1,026	785	1,174	**22,585**
SWAT percent sediment runoff by month for Natural Scenario	4.75%	3.26%	13.27%	13.35%	27.59%	22.12%	0.83%	0.16%	0.99%	4.49%	3.71%	5.48%	
SWAT sediment runoff load for Natural Scenario (tons)	924	634	2,581	2,597	5,365	4,300	161	31	192	873	722	1,065	**19,445**
SWAT sediment runoff load due to anthropogenic activities [Anthropogenic load minus Natural Load] (tons)	91	100	168	101	697	972	147	36	505	153	63	110	**3,140**
Monthly anthropogenic arsenic loading associated with SWAT sediment runoff (kg)	**0.7**	**0.8**	**1.3**	**0.8**	**5.5**	**7.7**	**1.2**	**0.3**	**4.0**	**1.2**	**0.5**	**0.9**	**24.8**

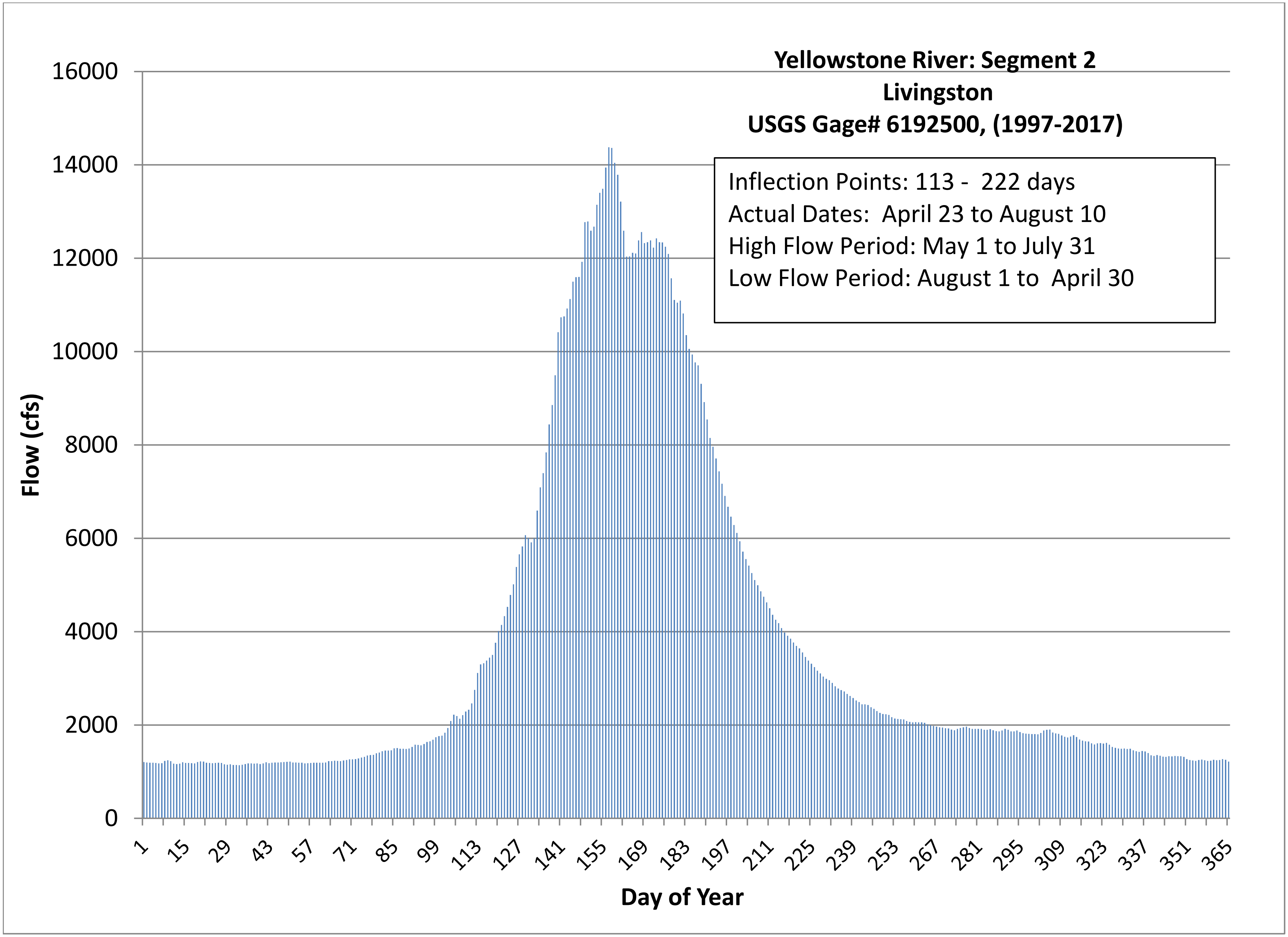
SEGMENT 4. ARSENIC LOADING INTO YELLOWSTONE RIVER FROM STILLWATER RIVER TO CLARKS FORK YELLOWSTONE

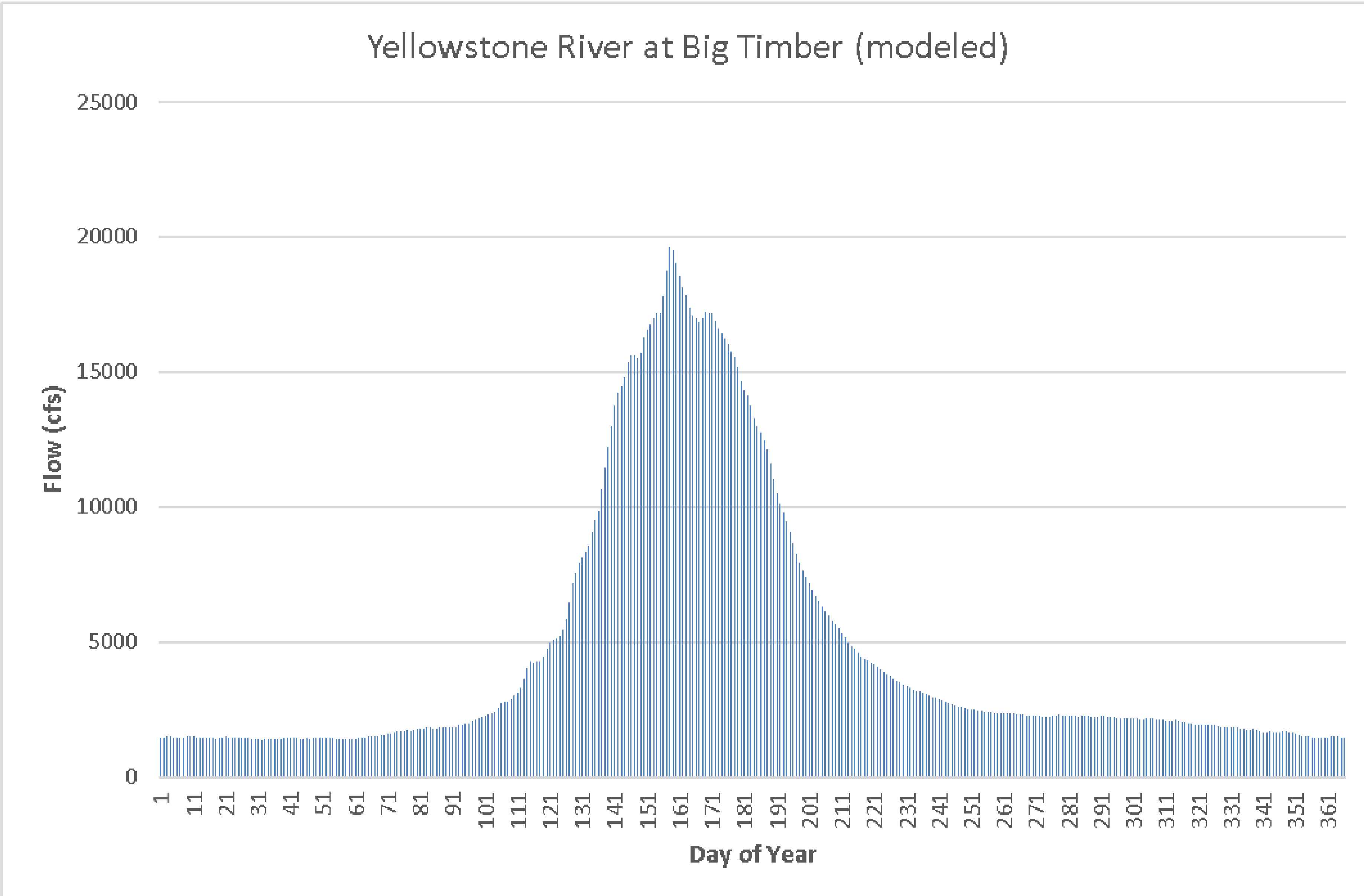
	MONTH												
PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
SWAT percent sediment runoff by month for Anthropogenic Scenario	3.72%	4.13%	17.41%	15.67%	21.10%	21.60%	0.46%	0.24%	4.35%	3.08%	2.76%	5.46%	
SWAT sediment runoff load for Anthropogenic Scenario (tons)	1,504	1,669	7,035	6,331	8,524	8,726	187	97	1,759	1,242	1,115	2,208	**40,398**
SWAT percent sediment runoff by month for Natural Scenario	4.27%	4.59%	18.54%	14.59%	20.76%	25.22%	0.22%	0.09%	0.76%	2.75%	2.56%	5.63%	
SWAT sediment runoff load for Natural Scenario (tons)	987	1,060	4,283	3,369	4,794	5,825	51	22	175	636	592	1,301	**23,095**
SWAT sediment runoff load due to anthropogenic activities [Anthropogenic load minus Natural Load] (tons)	518	609	2,752	2,962	3,730	2,901	136	75	1,583	606	523	907	**17,303**
Monthly anthropogenic arsenic loading associated with SWAT sediment runoff (kg)	**3.5**	**4.2**	**18.8**	**20.2**	**25.4**	**19.8**	**0.9**	**0.5**	**10.8**	**4.1**	**3.6**	**6.2**	**118**

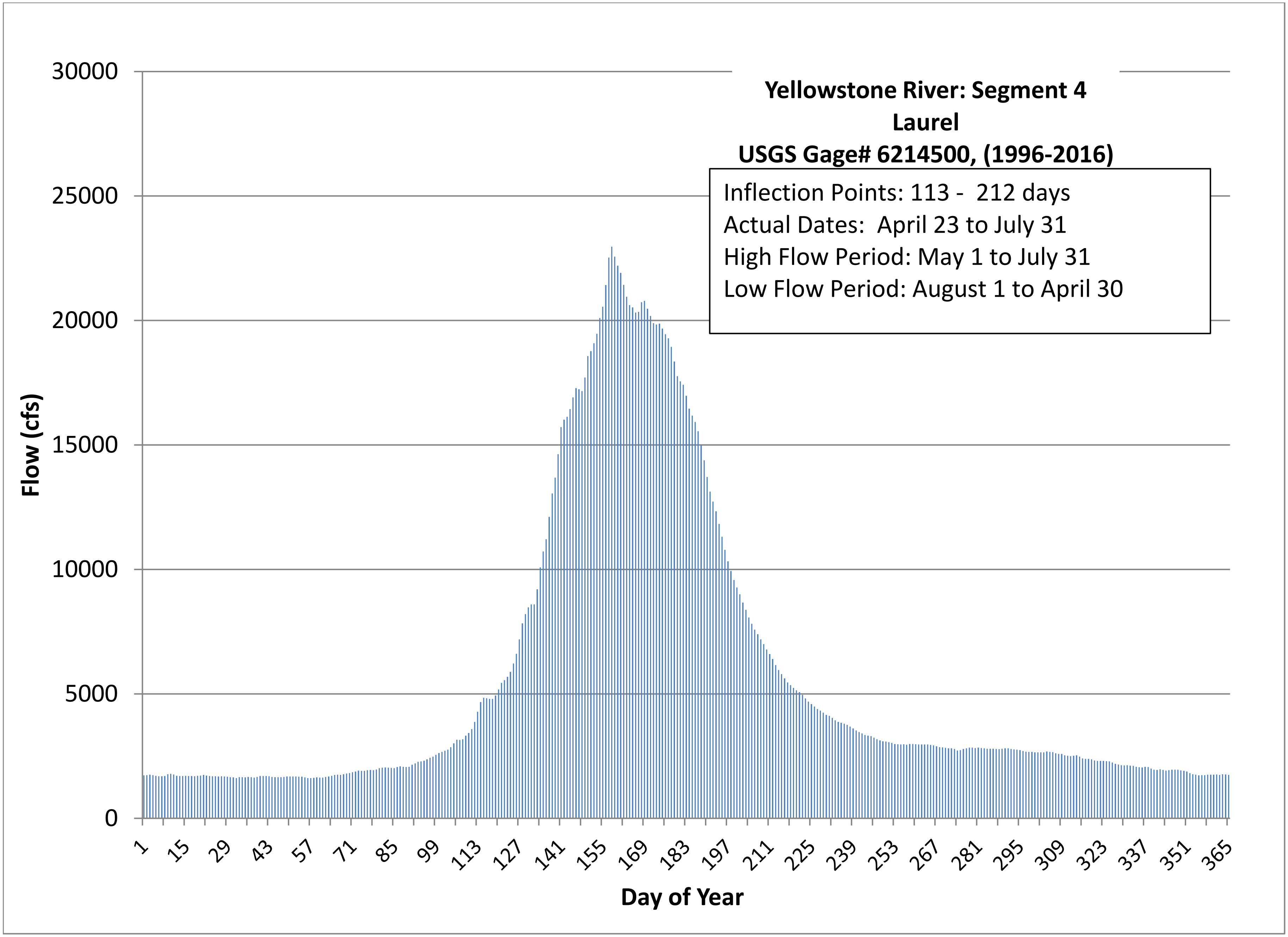
SEGMENT 5. ARSENIC LOADING INTO YELLOWSTONE RIVER FROM CLARKS FORK YELLOWSTONE TO BIGHORN RIVER

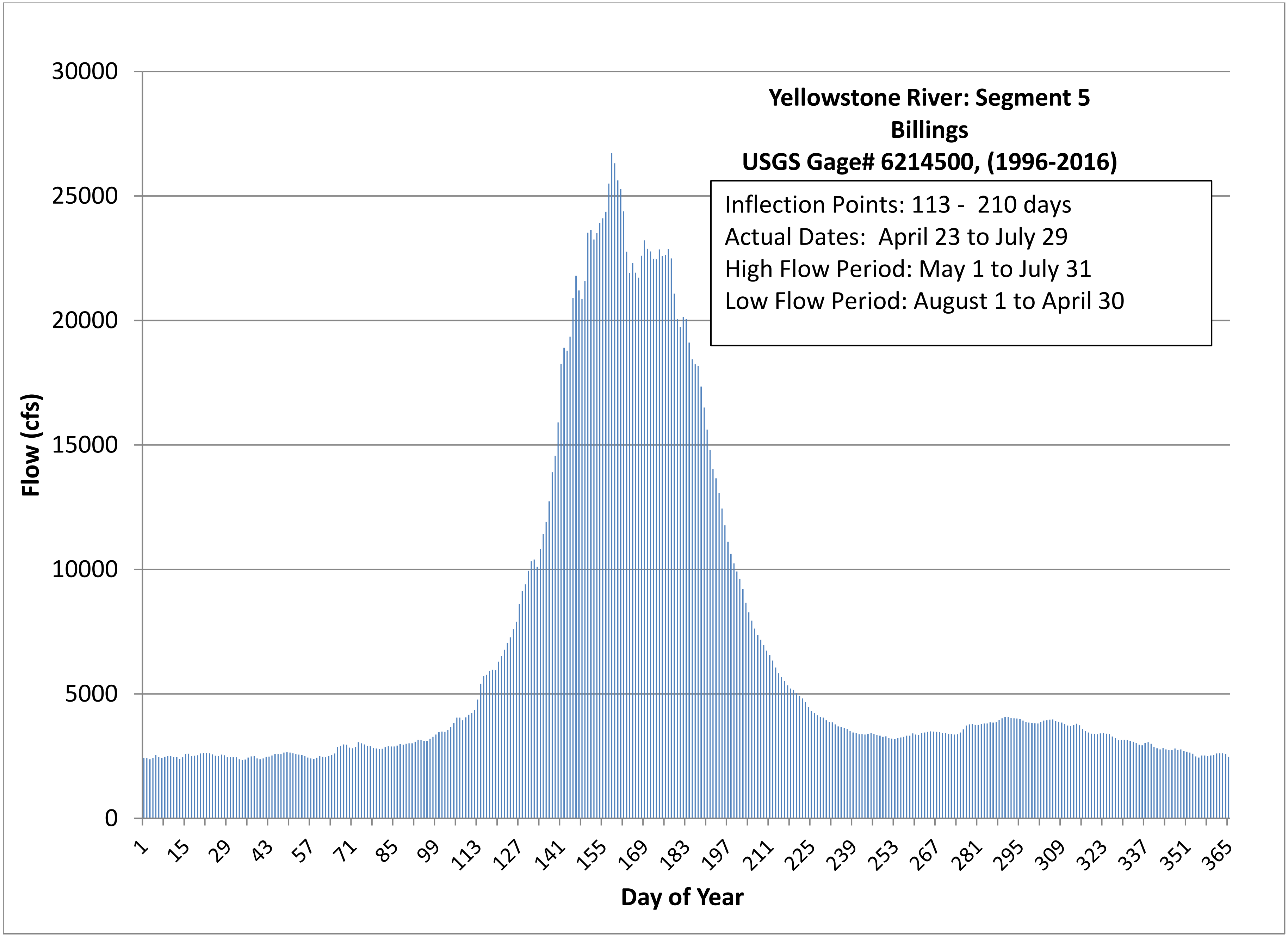
	MONTH												
PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
SWAT percent sediment runoff by month for Anthropogenic Scenario	3.69%	3.25%	13.99%	5.67%	24.41%	13.12%	0.87%	2.93%	19.86%	1.67%	2.47%	8.06%	
SWAT sediment runoff load for Anthropogenic Scenario (tons)	1,964	1,731	7,449	3,020	12,998	6,988	462	1,561	10,571	890	1,313	4,294	**53,240**
SWAT percent sediment runoff by month for Natural Scenario	4.92%	4.92%	15.57%	14.15%	23.19%	15.74%	0.04%	0.04%	1.55%	2.66%	3.68%	13.53%	
SWAT sediment runoff load for Natural Scenario (tons)	571	571	1,807	1,642	2,692	1,827	5	5	180	309	427	1,570	**11,608**
SWAT sediment runoff load due to anthropogenic activities [Anthropogenic load minus Natural Load] (tons)	1,393	1,160	5,643	1,378	10,305	5,160	457	1,556	10,391	581	886	2,724	**41,632**
Monthly anthropogenic arsenic loading associated with SWAT sediment runoff (kg)	**12.2**	**10.2**	**49.4**	**12.1**	**90.2**	**45.2**	**4.0**	**13.6**	**91.0**	**5.1**	**7.8**	**23.8**	**364**


Yellowstone River: Segment 1
Corwin Springs
USGS Gage# 6191500, (1997-2017)
Inflection Points: 111 - 222 days
Actual Dates: April 21 to August 10
High Flow Period: May 1 to July 31
Low Flow Period: August 1 to April 30
Flow (cfs)
14000
12000
10000
8000
6000
4000
2000
0
1
15
29
43
57
71
85
99
113
127
141
155
169
183
197
211
225
239
253
267
281
295
309
323
337
351
365
Day of Year


Yellowstone River: Segment 2
Livingston
USGS Gage# 6192500, (1997-2017)
Inflection Points: 113 - 222 days
Actual Dates: April 23 to August 10
High Flow Period: May 1 to July 31
Low Flow Period: August 1 to April 30
Flow (cfs)
16000
14000
12000
10000
8000
6000
4000
2000
0
1 15 29 43 57 71 85 99 113 127 141 155 169 183 197 211 225 239 253 267 281 295 309 323 337 351 365
Day of Year


Yellowstone River at Big Timber (modeled)
25000
20000
15000
10000
5000
0
Flow (cfs)
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181
191
201
211
221
231
241
251
261
271
281
291
301
311
321
331
341
351
361
Day of Year


Yellowstone River: Segment 4
Laurel
USGS Gage# 6214500, (1996-2016)
Inflection Points: 113 - 212 days
Actual Dates: April 23 to July 31
High Flow Period: May 1 to July 31
Low Flow Period: August 1 to April 30
Flow (cfs)
Day of Year
30000
25000
20000
15000
10000
5000
0
1
15
29
43
57
71
85
99
113
127
141
155
169
183
197
211
225
239
253
267
281
295
309
323
337
351
365



Yellowstone River: Segment 5
Billings
USGS Gage# 6214500, (1996-2016)
Inflection Points: 113 - 210 days
Actual Dates: April 23 to July 29
High Flow Period: May 1 to July 31
Low Flow Period: August 1 to April 30
Flow (cfs)
30000
25000
20000
15000
10000
5000
0
1
15
29
43
57
71
85
99
113
127
141
155
169
183
197
211
225
239
253
267
281
295
309
323
337
351
365
Day of Year

Attachment B-6: Mann-Whitney Test Summary

Results for: Segment 1

Mann-Whitney Test and CI: C1, C2

	N	Median
C1	9	10.000
C2	16	29.500

Point estimate for η1 - η2 is -16.000
95.6 Percent CI for η1 - η2 is (-24.003,-10.003)
W = 50.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0002
The test is significant at 0.0002 (adjusted for ties)

alpha = .05

p-value = .0002
p<alpha; therefore, the data does support the hypothesis that there is a difference between the population medians.
Signifcant
Seasonality

Results for: Segment 2

Mann-Whitney Test and CI: C1, C2

	N	Median
C1	15	13.000
C2	22	22.500

Point estimate for η1 - η2 is -10.000
95.1 Percent CI for η1 - η2 is (-13.000,-7.000)
W = 136.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

alpha = .05

p-value = .0000
p<alpha; therefore, the data does support the hypothesis that there is a difference between the population medians.
Significant
Seasonality

Results for: Segment 3

Mann-Whitney Test and CI: C1, C2

	N	Median
C1	7	12.000
C2	11	14.000

Point estimate for η1 - η2 is -3.000
95.4 Percent CI for η1 - η2 is (-6.001,-1.000)
W = 40.0
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0185
The test is significant at 0.0170 (adjusted for ties)

alpha = .05

p-value = 0.0170
p<alpha; therefore, the data does support the hypothesis that there is a difference between the population medians.
Significant
Seasonality

Results for: Segment 4

Mann-Whitney Test and CI: C1, C2

	N	Median
C1	9	10.000
C2	13	12.000

Point estimate for η1 - η2 is -3.000
95.5 Percent CI for η1 - η2 is (-4.000,-0.002)
W = 71.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0354
The test is significant at 0.0331 (adjusted for ties)

alpha = .05

p-value = 0.0331
p<alpha; therefore, the data does support the hypothesis that there is a difference between the population medians.
Significant
Seasonality

Results for: Segment 5

Mann-Whitney Test and CI: C1, C2

	N	Median
C1	10	8.000
C2	18	10.000

Point estimate for η1 - η2 is -2.000
95.3 Percent CI for η1 - η2 is (-4.000,-0.999)
W = 95.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.0188
The test is significant at 0.0177 (adjusted for ties)

alpha = .05

p-value = 0.0177
p<alpha; therefore, the data does support the hypothesis that there is a difference between the population medians.
Significant
Seasonality

Appendix C-1 Yellowstone River Median Total Arsenic Concentration Calculated by LOADest (2008 - 2018)

	Median Daily Arsenic Concentration (µg/L)				
	Corwin Springs	Livingston	Big Timber	Laurel	Billings
January	42.9	29.5	21.5	15.9	11.4
February	43.2	29.5	21.6	16.2	11.5
March	38.3	27.1	19.8	15.4	11.1
April	26.8	21.0	15.5	12.8	9.3
May	12.1	11.7	10.0	10.1	7.8
June	9.4	9.9	9.1	9.9	7.9
July	13.4	12.7	10.8	10.3	7.9
August	19.3	17.6	14.2	12.0	9.4
September	26.1	21.4	16.6	13.4	10.1
October	29.3	22.2	16.9	13.4	9.6
November	32.4	24.1	17.9	14.0	9.9
December	37.6	27.0	19.9	15.1	11.0
Annual Median	**29**	**22**	**17**	**14**	**10**
Low Flow Season	33	24	18	14	10
High Flow Season	12	11	10	10	8

Appendix C-2 Yellowstone River Median Total Arsenic Loads Calculated by LOADest (2008 - 2018)

	Median Monthly Arsenic Load (kg/month)				
	Segment 1 - Corwin Springs	Segment 2 - Livingston	Segment 3 - Big Timber	Segment 4 - Laurel	Segment 5 - Billings
October	3,069	3,234	2,907	2,776	3,079
November	2,892	3,033	2,744	2,554	2,886
December	2,666	2,791	2,473	2,237	2,464
January	2,498	2,633	2,309	2,063	2,347
February	2,488	2,633	2,300	2,019	2,321
March	2,642	2,783	2,487	2,166	2,436
April	3,243	3,389	3,220	3,072	3,305
May	6,370	7,144	7,684	8,174	8,370
June	8,733	10,161	11,869	15,058	16,153
July	5,698	6,134	6,102	6,908	6,292
August	4,097	4,016	3,599	3,571	3,203
September	3,293	3,334	2,960	2,776	2,800
Annual	**47,689**	**51,285**	**50,654**	**53,373**	**55,656**

USGS LOADEST Model using daily hydrologic data (1997-2017) calibrated to discrete arsenic concentration data (2013-2017)

Appendix C-3 Yellowstone River Median Nonanthropogenic Arsenic Loads Calculated by LOADest (2008 - 2018)

Median Monthly Nonanthropogenic Arsenic Load (kg/mo)					
	Corwin Springs	Livingston	Big Timber	Laurel	Billings
October	2,984	3,147	2,819	2,679	2,987
November	2,808	2,943	2,653	2,453	2,787
December	2,582	2,698	2,379	2,131	2,345
January	2,414	2,540	2,215	1,959	2,242
February	2,404	2,543	2,209	1,915	2,218
March	2,557	2,679	2,382	2,037	2,269
April	3,157	3,271	3,102	2,929	3,159
May	6,301	7,057	7,592	8,051	8,164
June	8,664	10,062	11,762	14,928	15,986
July	5,631	6,065	6,032	6,833	6,221
August	4,011	3,928	3,511	3,479	3,109
September	3,208	3,245	2,867	2,667	2,612
Annual	**46,720**	**50,178**	**49,522**	**52,060**	**54,101**

Median Daily Percentage of Arsenic that is Nonanthropogenic					
	Corwin Springs	Livingston	Big Timber	Laurel	Billings
Low Flow Season	97.0%	96.9%	96.5%	95.6%	95.6%
High Flow Season	99.0%	98.9%	98.9%	98.9%	98.7%

Appendix D-1: Yellowstone River Daily Tributary Arsenic Contribution for Tribs with Monitoring Data [1]

Tributary	HUC	Yellowstone 7Q10 @ HUC	% of Yellowstone at Low Flow	Major [2]/Minor	*High Flow (cfs)*	High Flow [3] Arsenic Conc. (ug/L) [5]	**Arsenic Load (kg/day) [6]**	*Low Flow (cfs)*	Low Flow [4] Arsenic Conc. (ug/L) [5]	**Arsenic Load (kg/day) [6]**
Headwaters Nonanthropogenic										
Gardner River, Gardiner	10070001	504	22.7%	Major	*451*	50.9	**56.2**	*114*	114.6	**32.0**
1. MT/WY Border to Mill Creek (Except Tributaries Counted Elsewhere)										
Mulherin Creek	10070002	504	3.5%	Minor	*49*	0.50	**0.06**	*18*	0.50	**0.02**
Big Creek	10070002	504	4.9%	Minor	*104*	0.50	**0.13**	*25*	0.55	**0.03**
Six Mile Creek	10070002	504	2.5%	Minor	*98*	2.33	**0.56**	*13*	6.75	**0.21**
Mill Creek	10070002	766	2.9%	Minor	*171*	0.50	**0.21**	*22*	0.50	**0.03**
							57.13			**32.32**
2. Mill Creek to Boulder River										
Billman Creek	10070002	766	0.8%	Minor	*26*	1.17	**0.07**	*6*	1.50	**0.02**
Fleshman Creek	10070002	766	0.4%	Minor	*6*	4.17	**0.07**	*3*	17.00	**0.12**
Shields River [6,7]	10070003	766	12.4%	Major	*572*	1.04	**1.62**	*95*	0.81	**0.18**
Boulder River [6,7]	10070002	907	15.4%	Major	*814*	0.79	**1.48**	*140*	0.75	**0.26**
							3.24			**0.59**
3.Boulder River to Stillwater River										
Sweet Grass Creek	10070002	907	2.9%	Minor	*88*	0.50	**0.11**	*27*	1.17	**0.08**
Stillwater River [6,7]	10070005	1047	32.2%	Major	*1630*	0.66	**2.25**	*337*	0.76	**0.57**
							2.36			**0.65**
4. Stillwater River to Clarks Fork Yellowstone River										
Clarks Fork Yellowstone (@ Edgar) [6,7]	10070006	1197	29.2%	Major	*1570*	0.97	**3.76**	*350*	0.98	**0.90**
Rock Creek to Clarks Fork Yellowstone	10070006	1197	12.1%	Major	*397*	1.05	**1.02**	*145*	1.05	**0.37**
							4.78			**1.27**
5. Clarks Fork Yellowstone to Bighorn River										
Pryor Creek	10070008	1197	5.0%	Major	*62*	1.71	**0.26**	*60*	2.17	**0.32**
Fly Creek	10070007	1197	4.1%	Minor	*56*	6.25	**0.86**	*49*	5.00	**0.60**
							1.12			**0.92**

[1] This attachment summarizes tributaries' arsenic load for those tributaries that are "accounted for" (i.e. have flow & arsenic monitoring data).

[2] Major tribs defined as tribs with low flow >5% of Yellowstone River 7Q10.

[3] High Flow: May, June, July

[4] Low Flow: Aug, Sept, Oct, Nov, Dec, Jan, Feb, March, April

[5] Using Average Arsenic Concentrations; ND is equal to 1/2 detection limit (detection limit varies). If all results were ND, concentration is in red font.

[6] Except where noted, tributary asenic daily load based on paired data (kg/day) = flow (ft^3/sec) x concentration (µg/L) x 0.0024466* (*86,400 sec/day x 1/10-9 kg/ug x 28.3168 L/ ft^3).

[7] Arsenic Daily Load based on a 10-year LOADest model for four of the seven major tribs: Shields River, Boulder River, Stillwater River, and Clarks Fork Yellowstone River. The daily loads for the four major tributaries that were modeled by LOADEST were developed using median daily data.

Appendix D-2: Total Tributary Arsenic Load to Yellowstone River

Tributary	Major/ Minor	Area (sq km) [1]	% Total Watershed Not Monitored [1]	High Flow [2] Median Arsenic Load (kg/day)	High Flow [2] Median Arsenic Load (kg/month)	Low Flow [2] Median Arsenic Load (kg/day)	Low Flow [2] Median Arsenic Load (kg/month)	ANNUAL [3] Annual Arsenic Load (kg/year)
Headwaters Nonanthropogenic								
Yellowstone River leaving YNP		5,941						
Gardner River, Gardiner	Major	777		56.2	1,725	32.0	973.6	**13,936**
Total from Headwaters		**6,718**						
1. MT/WY Border to Mill Creek (Except Tributaries Counted Elsewhere)								
Mulherin Creek	Minor	135		0.06	1.8	0.02	0.7	
Big Creek	Minor	181		0.13	3.9	0.03	1.0	
Six Mile Creek	Minor	123		0.56	17.2	0.21	6.4	
Mill Creek	Minor	422		0.21	6.4	0.03	0.8	
Monitored Area		***861***		*0.96*	*29.4*	*0.29*	*8.9*	
Area not Monitored		*956*		*1.06*	*31.9*	*0.33*	*9.8*	
Total from Tribs at Mill Creek		**1,817**	**11%**	2.02	61.2	0.6	18.7	**352**
2. Mill Creek to Boulder River								
Billman Creek	Minor	138		0.07	2.3	0.02	0.7	
Fleshman Creek	Minor	62		0.07	2.0	0.12	3.6	
Shields River [4]	Major	2,211		1.62	49.8	0.18	5.5	
Boulder River [4]	Major	1,366		1.48	45.5	0.26	8.0	
Monitored Area		***3,777***		*3.24*	*99.6*	*0.59*	*17.8*	
Area not Monitored		*2,202*		*1.89*	*56.7*	*0.34*	*10.3*	
Total from tribs at Boulder River		**5,978**	**15%**	5.14	156.3	0.93	28.1	**722**
3.Boulder River to Stillwater River								
Sweet Grass Creek	Minor	1,017		0.11	3.3	0.08	2.3	
Stillwater River [4]	Major	2,761		2.25	69.2	0.57	17.4	
Monitored Area		***3,778***		*2.36*	*72.5*	*0.65*	*19.7*	
Area not Monitored		*2,218*		*1.39*	*41.6*	*0.38*	*11.4*	
Total from tribs at Stillwater River		**5,996**	**11%**	3.7	114	1.0	31.1	**623**
4. Stillwater River to Clarks Fork Yellowstone River								
Clarks Fork Yellowstone (@Edgar) [4]	Major	5,775		3.76	115.5	0.90	27.4	
Rock Creek	Major	1,458		1.02	31.3	0.37	11.3	
Monitored Area		***7,233***		*4.78*	*146.8*	*1.27*	*38.7*	
Area not Monitored		*2,442*		*1.61*	*48.4*	*0.43*	*12.9*	
Total from tribs at CFY River		**9,675**	**8%**	6.4	195	1.7	51.6	**1,051**
5. Clarks Fork Yellowstone to Bighorn River								
Pryor Creek	Major	1,559		0.26	8.0	0.32	9.7	
Fly Creek	Minor	760		0.86	26.3	0.60	18.3	
Monitored Area		***2,319***		*1.12*	*34*	*0.92*	*28*	
Area not Monitored		*4,914*		*2.37*	*71.0*	*1.95*	*58.5*	
Total from Tribs at Bighorn River		**7,233**	**13%**	3.5	105	2.9	87	**1,094**
TOTAL TRIB ARSENIC LOADS (kg/year)								**17,777**
YNP TRIB ARSENIC LOADS (after MT/WY Border)								**13,936**
Non-YNP TRIB ARSENIC LOADS								**3,841**

[1] Total land area, including from WY: Sq KM: **37,417** "% Not monitored" = area not monitored /total drainage area at that location.

Unaccounted for (i.e.not monitored) Sq KM: 12,732

[2] High Flow months are May, June, and July. Low flow months are August through April.

[3] Annual Load calculated by the sum of (High flow monthly load x 3 months) + (Low flow monthly load x 9 months)

[4] Arsenic Load based on a 10-year LOADest model for four of the seven major tribs: Shields River, Boulder River, Stillwater River, and Clarks Fork Yellowstone River.

Appendix E-1: Yellowstone River Arsenic Load Mass Balance

		TOTAL LOAD	ANTHROPOGENIC ARSENIC LOADS					NONANTHROPOGENIC ARSENIC LOADS		
		TAL	PSL & GWA		ROA			Median Daily	Tributaries	
		Total Arsenic Load [1]	Permitted Point Source (see App E-2)	"Other" Point Source/GWA (see App E-3)	Anthropogenic Runoff (includes TribA) (see App E-4)	Sum of Anthropogenic Arsenic Loads	CUMULATIVE Anthropogenic	CUMULATIVE Calculated [2] Nonanthropogenic	Measured Trib (TribA + TribN)	Calculated TribN 3
1. MT/WY to Mill Creek										
TAL @ CORWIN SPRINGS										
October	kg/mo	3,069	3.4	81.3	0.2	84.9	**84.9**	**2,984**	19	19
November	kg/mo	2,892	2.5	81.3	0.1	83.9	**83.9**	**2,808**	19	19
December	kg/mo	2,666	2.7	81.1	0.0	83.9	**83.9**	**2,582**	19	19
January	kg/mo	2,498	2.6	81.3	(0.1)	83.9	**83.9**	**2,414**	19	19
February	kg/mo	2,488	2.5	81.4	0.0	83.9	**83.9**	**2,404**	19	19
March	kg/mo	2,642	2.9	81.3	0.7	84.8	**84.8**	**2,557**	19	18
April	kg/mo	3,243	3.0	81.3	2.4	86.7	**86.7**	**3,157**	19	16
May	kg/mo	6,370	4.0	62.7	2.1	68.7	**68.7**	**6,301**	61	59
June	kg/mo	8,733	4.6	62.6	2.3	69.5	**69.5**	**8,664**	61	59
July	kg/mo	5,698	5.1	62.6	-	67.8	**67.8**	**5,631**	61	61
August	kg/mo	4,097	4.5	81.3	-	85.8	**85.8**	**4,011**	19	19
September	kg/mo	3,293	4.2	81.1	-	85.3	**85.3**	**3,208**	19	19
Annual	**kg/yr**	**47,689**	**42.0**	**919**	**7.6**	969	**969**	**46,720**	**352**	**344**
2. Mill Creek to Boulder River										
TAL @ LIVINGSTON										
October	kg/mo	3,234	0.4		2.1	2.5	**87.3**	**3,147**	28	26
November	kg/mo	3,033	0.4		5.9	6.3	**90.2**	**2,943**	28	22
December	kg/mo	2,791	0.3		9.3	9.6	**93.5**	**2,698**	28	19
January	kg/mo	2,633	0.3		8.5	8.8	**92.7**	**2,540**	28	20
February	kg/mo	2,633	0.3		6.0	6.3	**90.2**	**2,543**	28	22
March	kg/mo	2,783	0.3		18.6	18.9	**103.8**	**2,679**	28	9
April	kg/mo	3,389	0.3		30.7	31.0	**117.7**	**3,271**	28	(3)
May	kg/mo	7,144	0.4		17.4	17.8	**86.6**	**7,057**	156	139
June	kg/mo	10,161	0.5		29.3	29.8	**99.3**	**10,062**	156	127
July	kg/mo	6,134	0.5		0.9	1.4	**69.1**	**6,065**	156	155
August	kg/mo	4,016	0.5		1.7	2.1	**87.9**	**3,928**	28	26
September	kg/mo	3,334	0.4		3.3	3.7	**89.0**	**3,245**	28	25
Annual	**kg/yr**	**51,285**	4.7	-	134	138	**1,107**	**50,178**	**722**	**588**
3. Boulder River to Stillwater River										
TAL @ BIG TIMBER										
October	kg/mo	2,907	-		1.2	1.2	**88.5**	**2,819**	31	30
November	kg/mo	2,744	-		0.5	0.5	**90.7**	**2,653**	31	31
December	kg/mo	2,473	-		0.9	0.9	**94.3**	**2,379**	31	30
January	kg/mo	2,309	-		0.7	0.7	**93.4**	**2,215**	31	30
February	kg/mo	2,300	-		0.8	0.8	**91.0**	**2,209**	31	30
March	kg/mo	2,487	-		1.3	1.3	**105.1**	**2,382**	31	30
April	kg/mo	3,220	-		0.8	0.8	**118.5**	**3,102**	31	30
May	kg/mo	7,684	-		5.5	5.5	**92.1**	**7,592**	114	109
June	kg/mo	11,869	-		7.7	7.7	**107.0**	**11,762**	114	106
July	kg/mo	6,102	-		1.2	1.2	**70.3**	**6,032**	114	113
August	kg/mo	3,599	-		0.3	0.3	**88.2**	**3,511**	31	31
September	kg/mo	2,960	-		4.0	4.0	**93.0**	**2,867**	31	27
Annual	**kg/yr**	**50,654**	-	-	**25**	25	**1,132**	**49,522**	**623**	**598**
4. Stillwater River to Clarks Fork Yellowstone River										
TAL @ LAUREL										
October	kg/mo	2,776	4.5	0.11	4.1	8.7	**97.3**	**2,679**	52	48
November	kg/mo	2,554	6.0	0.11	3.6	9.7	**100.4**	**2,453**	52	48
December	kg/mo	2,237	5.6	0.11	6.2	11.9	**106.3**	**2,131**	52	45
January	kg/mo	2,063	7.6	0.11	3.5	11.2	**104.7**	**1,959**	52	48
February	kg/mo	2,019	8.6	0.11	4.2	12.8	**103.8**	**1,915**	52	47
March	kg/mo	2,166	5.1	0.11	18.8	24.0	**129.1**	**2,037**	52	33
April	kg/mo	3,072	4.5	0.11	20.2	24.8	**143.3**	**2,929**	52	31
May	kg/mo	8,174	5.5	0.11	25.4	31.0	**123.1**	**8,051**	195	170
June	kg/mo	15,058	3.7	0.11	19.8	23.6	**130.6**	**14,928**	195	175
July	kg/mo	6,908	3.3	0.11	0.9	4.4	**74.7**	**6,833**	195	194
August	kg/mo	3,571	2.7	0.11	0.5	3.3	**91.5**	**3,479**	52	51
September	kg/mo	2,776	5.1	0.11	10.8	16.0	**109.0**	**2,667**	52	41
Annual	**kg/yr**	**53,373**	62	1.3	118	182	**1,314**	**52,060**	**1,051**	**933**
5. Clarks Fork Yellowstone River to Bighorn River										
TAL @ BILLINGS										
October	kg/mo	3,079	(11.0)	0.004	5.1	(5.9)	**91.4**	**2,987**	87	81
November	kg/mo	2,886	(9.7)	0.004	7.8	(1.9)	**98.5**	**2,787**	87	79
December	kg/mo	2,464	(10.9)	0.004	23.8	13.0	**119.2**	**2,345**	87	63
January	kg/mo	2,347	(11.9)	0.004	12.2	0.3	**105.0**	**2,242**	87	74
February	kg/mo	2,321	(11.3)	0.004	10.2	(1.2)	**102.6**	**2,218**	87	76
March	kg/mo	2,436	(12.0)	0.004	49.4	37.4	**166.5**	**2,269**	87	37
April	kg/mo	3,305	(9.3)	0.004	12.1	2.8	**146.1**	**3,159**	87	74
May	kg/mo	8,370	(7.8)	0.004	90.2	82.4	**205.5**	**8,164**	105	15
June	kg/mo	16,153	(8.3)	0.004	45.2	36.9	**167.5**	**15,986**	105	60
July	kg/mo	6,292	(8.0)	0.004	4.0	(4.0)	**70.7**	**6,221**	105	101
August	kg/mo	3,203	(11.1)	0.004	13.6	2.5	**94.0**	**3,109**	87	73
September	kg/mo	2,800	(12.1)	0.004	91.0	78.9	**187.9**	**2,612**	87	(4)
Annual	**kg/yr**	**55,656**	(123)	0.042	364	241	**1,555**	**54,101**	**1,094**	**730**
TOTAL[4]	**kg/yr**	**55,656**	**(14)**	**921**	**649**	**1,555**		**54,101**	**3,841**	**3,193**

Foototes:

[1] TAL based on 50th Percentile

[2] Calculated Nonanthropogenic Load = Total Arsenic Load - the Cumulative (Running Sum) of Anthropogenic Arsenic Loads from App C. Monthly is the median of the daily values as calculated in Appendix C. Annual is the sum of the monthly values. The nonanthropogenic load for Segment 1 is equivalent to the arsenic load from YNP.

[3] Calculated NonAnthro Trib (= Measured Trib - ROA)

[4] Total annual loads at Bighorn River:

* Total Arsenic Load from synoptic LOADest calculations @ Bighorn River	55,656	kg/yr
* Anthropogenic Loads = permitted + other point sources & groundwater + anthr runnoff	1,555	kg/yr
Mainstem Calculated Nonanthropogenic Arsenic Load (kg/year)	54,101	kg/yr
Tributary Nonanthropogenic Contrib (kg/year)	3,193	kg/yr

Appendix E-2: Summary of Monthly and Annual Arsenic Loads from Permitted Sources by Segment

Month	Units	1. MT/WY Border to Mill Creek	2. Mill Creek to Boulder River	3. Boulder River to Stillwater River	4.Stillwater River to Clark Fork Yellowstone	5. Clark Fork Yellowstone to Bighorn River	Sum of all Segments
Oct	kg/mo	3.4	0.40	0.0	4.5	(11.0)	**(2.7)**
Nov	kg/mo	2.5	0.35	0.0	6.0	(9.7)	**(0.8)**
Dec	kg/mo	2.7	0.33	0.0	5.6	(10.9)	**(2.2)**
Jan	kg/mo	2.6	0.33	0.0	7.6	(11.9)	**(1.3)**
Feb	kg/mo	2.5	0.29	0.0	8.6	(11.3)	**0.0**
Mar	kg/mo	2.9	0.32	0.0	5.1	(12.0)	**(3.7)**
Apr	kg/mo	3.0	0.32	0.0	4.5	(9.3)	**(1.5)**
May	kg/mo	4.0	0.41	0.0	5.5	(7.8)	**2.1**
Jun	kg/mo	4.6	0.54	0.0	3.7	(8.3)	**0.6**
Jul	kg/mo	5.1	0.49	0.0	3.3	(8.0)	**1.0**
Aug	kg/mo	4.5	0.45	0.0	2.7	(11.1)	**(3.5)**
Sep	kg/mo	4.2	0.44	0.0	5.1	(12.1)	**(2.4)**
Annual	**kg/yr**	**42.0**	**4.7**	**0.0**	**62.3**	**(123.3)**	**(14.3)**

Appendix E-3: "Other Anthropogenic Point Sources," by Segment

1. MT/WYBorder to MC

	Mouth of Bear Creek	TVX Permit	**Jardine Tailings Load**
		kg/month	
October	81.5	0.24	**81.3**
November	81.5	0.21	**81.3**
December	81.5	0.40	**81.1**
January	81.5	0.19	**81.3**
February	81.5	0.17	**81.4**
March	81.5	0.23	**81.3**
April	81.5	0.18	**81.3**
May	62.8	0.11	62.7
June	62.8	0.19	62.6
July	62.8	0.17	62.6
August	81.5	0.22	**81.3**
September	81.5	0.43	**81.1**
ANNUAL	**922**	**2.7**	**919** kg/yr

Jardine Tailings is calculated based on the load in Bear Creek minus the permitted contribution from TVX. (Bear Creek assumed all Anthropogenic.)

4. SW to CFR

	Mouat site GW kg/month
October	0.11
November	0.11
December	0.11
January	0.11
February	0.11
March	0.11
April	0.11
May	0.11
June	0.11
July	0.11
August	0.11
September	0.11
ANNUAL	**1.3** **kg/yr**

5. CFY to BHR

	Yale Oil of S. Dakota kg/month
October	0.0035
November	0.0035
December	0.0035
January	0.0035
February	0.0035
March	0.0035
April	0.0035
May	0.0035
June	0.0035
July	0.0035
August	0.0035
September	0.0035
ANNUAL	**0.042** **kg/yr**

Appendix E-4: Anthropogenic Runoff (ROA) Calculated Using HAWQS

Month	Segment:	1. MT/WY to MC	2. MC to BR	3. BR to SW	4. SW to CFR	5. CFY to BHR	TOTAL
Oct	kg/month	0.16	2.1	1.2	4.1	5.1	13
Nov	kg/month	0.11	5.9	0.5	3.6	7.8	18
Dec	kg/month	0.03	9.3	0.9	6.2	23.8	40
Jan	kg/month	-0.06	8.5	0.7	3.5	12.2	25
Feb	kg/month	0.02	6.0	0.8	4.2	10.2	21
Mar	kg/month	0.67	18.6	1.3	18.8	49.4	89
Apr	kg/month	2.37	30.7	0.8	20.2	12.1	66
May	kg/month	2.06	17.4	5.5	25.4	90.2	141
Jun	kg/month	2.26	29.3	7.7	19.8	45.2	104
Jul	kg/month	0.00	0.9	1.2	0.9	4.0	7
Aug	kg/month	0.00	1.7	0.3	0.5	13.6	16
Sep	kg/month	0.00	3.3	4.0	10.8	91.0	109
Annual	**kg/year**	**7.6**	**134**	**25**	**118**	**364**	**649**

Appendix E-5: Total Tributary Arsenic Load Contributions, by Month (*see Appendix D-2*)

		Total Tributary Arsenic Load, by Segment					
Month		1. MT/WY to MC	2. MC to BR	3. BR to SW	4. SW to CFY	5. CFY to BHR	TOTAL
October	kg/month	19	28	31	52	87	216
November	kg/month	19	28	31	52	87	216
December	kg/month	19	28	31	52	87	216
January	kg/month	19	28	31	52	87	216
February	kg/month	19	28	31	52	87	216
March	kg/month	19	28	31	52	87	216
April	kg/month	19	28	31	52	87	216
May	kg/month	61	156	114	195	105	632
June	kg/month	61	156	114	195	105	632
July	kg/month	61	156	114	195	105	632
August	kg/month	19	28	31	52	87	216
September	kg/month	19	28	31	52	87	216
Annual	**kg/year**	**352**	**722**	**623**	**1,051**	**1,094**	**3,841**