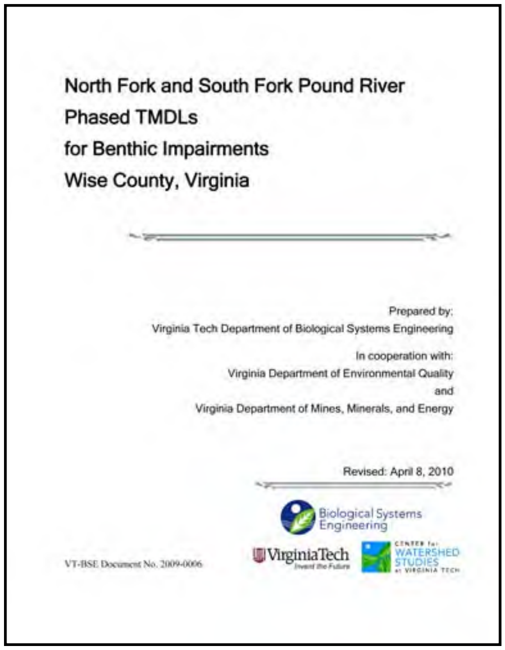
Phase II Benthic TMDL Development for North Fork and South Fork Pound River in Wise County, Virginia


North Fork and South Fork Pound River
Phased TMDLs
for Benthic Impairments
Wise County, Virginia

Prepared by:
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In cooperation with:
Virginia Department of Environmental Quality
and
Virginia Department of Mines, Minerals, and Energy

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1. INTRODUCTION

In order to meet the U. S. Environmental Protection Agency's (EPA) May 1, 2010 deadline, Virginia agencies produced Total Maximum Daily Load (TMDL) studies for the Levisa Fork River, Bull Creek, North/South Fork of the Pound River, and Powell River. During development, uncertainties regarding data and predictive tools were identified and help with the TMDL was solicited. The U. S. Office of Surface Mining, U.S. EPA, and private contractors provided assistance, but some concerns regarding the sufficiency of the available data's ability to determine pollution load reductions and the adequacy of the predictive tools being utilized remained. Therefore, the TMDL reports were submitted to EPA as "Phased" TMDLs in accordance with EPA guidance with the understanding that the Commonwealth of Virginia would utilize an adaptive management approach to complete the TMDLs.

Revised TMDL documents were planned for submittal to EPA two years from the date that both the U.S. EPA Region III approved and the Virginia State Water Control Board (SWCB) adopted the "phased" TMDLs. The Virginia Department of Mines, Minerals, and Energy's Division of Mined Land Reclamation (DMLR) took the lead role with the revisions. The issuance of the phased TMDLs was intended to provide time to address uncertainties with the individual TMDLs and to make any necessary revisions while interim water quality improvements were initiated.

To support TMDL completion, a monitoring plan and experimentation for model refinement was implemented by the Virginia Department of Environmental Quality (DEQ) and DMLR during the period of time beginning with the submittal to EPA of the DRAFT Phased TMDLs.

Although additional monitoring data, modeling refinements, allocations for pollutants, and long-term implementation actions were expected in the revised TMDLs, on-going, long-term efforts to improve the watershed continued. In the interim, DMLR utilized its existing TMDL processes and software to maintain or decrease existing pollution waste loads from active mining for TSS and TDS. DMLR also restricted additional mining, through the use of offset requirements.

A number of questions have been identified regarding data needs for these Phased TMDLs. These questions were the basis for the monitoring plan design.

Addenda (Phase II TMDLs) for the Bull Creek, Levisa Fork, Pound River, and Powell River Phased TMDLs have been developed to complete work on all four TMDLs.

1.1 Phased TMDLs in the North and South Fork Pound River Watershed

In addressing provisions of the Clean Water Act and agreements with the United States Environmental Protection Agency, Virginia's Department of Environmental Quality initiated the TMDL development process for aquatic life impaired segments in the North and South Fork Pound River watersheds in Virginia. The Department of Biological Systems Engineering (BSE) at Virginia Tech provided contract assistance by performing the analyses, modeling, and report preparation.

The benthic TMDLs for the Lower North Fork Pound River, South Fork Pound River, and Phillips Creek were initially submitted to the U.S. EPA as phased TMDLs in April of 2010, then resubmitted in February of 2011 after addressing comments. The TMDL evaluation determined that sediment (TSS) and Total Dissolved Solids (TDS) were the most probable cause of Aquatic life use (benthic) impairments in South Fork Pound River, and Phillips Creek, while sediment was the most probable cause of impairments in Lower North Fork Pound River. Sediment and TDS originating from surface runoff, streambank erosion, Abandoned Mine Land (AML), and point sources were taken into account.

During TMDL development, uncertainties and differences of interpretation regarding report narrative, report format, data, and predictive tools were identified. Specific concerns about sediment focused on the estimated load from control ponds at active mines during storm events, and the estimated load from ancillary active mining areas. Ancillary areas are active mining areas that are not controlled by ponds, Abandoned Mine Lands (AML), as well as reclaimed and released areas. With regard to TDS, concerns focused on the distribution of loads between sources. In particular, there are several discharges from abandoned underground mine workings that are of concern. It was thought that these discharges might have been under-represented in the model.

2. MONITORING TO SUPPORT PHASE II TMDLS

A monitoring plan was developed and executed to support Phase II TMDL development. For the Pound River TMDLs, the pollutants of concern were TSS (sediment) and TDS.

2.1 TSS (Sediment) Monitoring

The goal of the TSS monitoring project, was to better quantify sediment contributions to the watershed from active mining operations during larger storm events. More specifically, the questions addressed were:

- What is the best approach for representing existing contributions from permitted mining discharges?
- What is the best approach for representing allocated loads (*i.e.*, waste load allocations – WLAs) from permitted mining discharges?

The full report on the sediment monitoring effort and analyses is included in Appendix A (Representation of TSS Loads in Coalfield TMDLs). The results indicated that existing TSS loading from actively mined areas may have been moderately underestimated in the Phase I TMDL, however, the modeling of the TMDL was validated.

The recommended approach for estimating both existing and allocated loads from permitted surface mine discharges is to use the maximum permitted concentration (70 mg/L) applied to the runoff volume from active mine (disturbed) areas.

2.2 TDS Monitoring

A study was conducted by MapTech, Inc. of Blacksburg, VA to uncover any relationships between mining activities and in-stream TDS concentrations for use in other watersheds (*Phased TMDL: Bull Creek Watershed Total Dissolved Solids Evaluation, September 17, 2013* - Included in Appendix B). Monitoring data was collected by REI Consultants, Inc. on a semi-monthly basis over a six-month period from September 2012 to February 2013. Parameters measured were TDS, temperature, pH, dissolved oxygen, conductivity and flow. Nine springs in total were sampled in the Bull Creek watershed. In the Bull Creek mine springs the TDS concentrations varied from 300 to 1,400 mg/L. The lower concentrations were found in springs in the headwaters of Bull Creek. **Figure 2.1** shows the sampling locations in the Bull Creek watershed. **Table 2.1** shows the results of the flow TDS monitoring at the nine sites in the Bull Creek watershed.

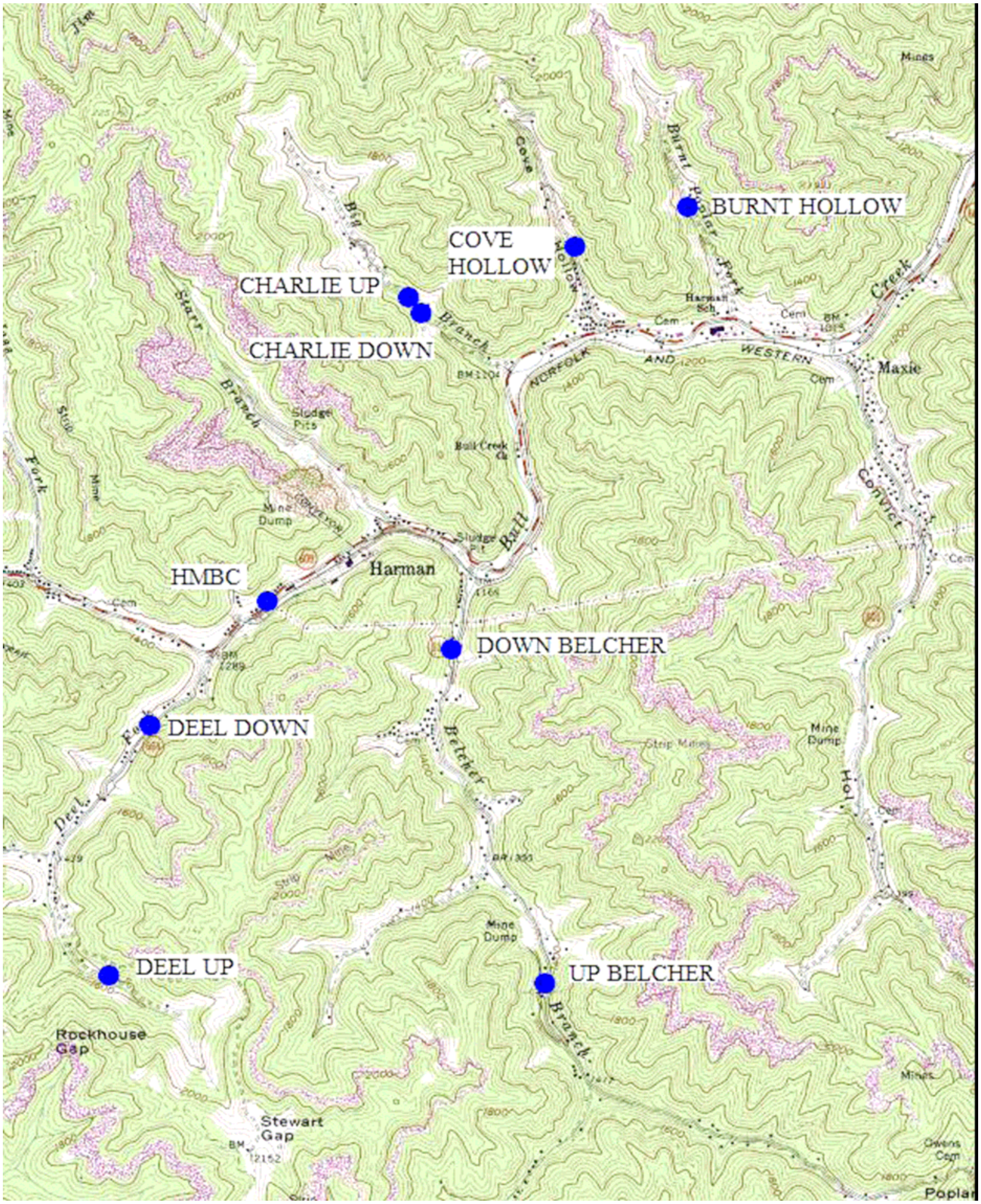


Figure 2.1 Sample locations for TDS in the Bull Creek watershed.

Table 2.1 Mine spring flow, and spring-TDS over the study period in the Bull Creek watershed.

Site	Ave. Flow (cfs)	Median Flow (cfs)	Mean TDS mg/L	Median TDS mg/L	Mean TDS Mg/yr	Median TDS Load Mg/yr	Load Ratio[a]	Elevation (feet)
Down Belcher	1.49	0.85	999	1,035	1,239	790	118	1,232
Up Belcher	1.21	0.83	997	1,010	1,039	741	111	1,377
Burnt Hollow	0.74	0.61	1,050	1,065	684	569	85	1,305
HMBC	1.18	1.04	627	625	636	607	91	1,261
Cove Hollow	0.12	0.10	1,054	1,065	112	101	15	1,260
Charlie Up	0.20	0.10	990	1,004	165	93	14	1,309
Charlie Down	0.12	0.08	1,217	1,210	129	87	13	1,293
Deel Down	0.05	0.02	447	475	17	8	1	1,383
Deel Up	0.02	0.02	559	581	11	7	1	1,567
maximum:	1.49	1.04	1,217	1,210	1,239	790	118	1,567
minimum:	0.02	0.02	447	475	11	7	1	1,232
median:		0.10		1,010		101		1,332

[1] Median TDS Load divided by 7, the minimum Median TDS Load measured.

The results indicated the following:

- There is a seasonal trend in mine spring flow: low in autumn, moderate in early winter, and highest in late winter.
- The TDS concentration in mine springs decreases with flow increase.
- The volume of a spring primarily controls its TDS load.
- Large-volume springs provide the majority of the TDS load.
- The dominant TDS load springs in the Bull Creek watershed are Up and Down Belcher, Burnt Hollow and HMBC.
- Spring elevation has a minor impact on flow volume and TDS load.
- Recent precipitation tends to increase TDS load at low flows. At high spring flows the relationship disappears.
- The volume of a spring tends to be larger from functional hydrologic islands with large footprints and volumes.
- Prominent abandoned mine scars above a mine spring dilute the TDS in springs but add substantially to the volume of the spring. Thus AML features lead to high TDS load.
- In the Bull Creek watershed, there is not a clear relationship between the mine parameters assessed and TDS load and flow volume as there is for hydrologic island footprint.

2.2.1 Implications for Pound River Impairments

The underground mine spring TDS results described above are directly applicable to the Bull Creek watershed, but they can also be applied to the extensively-mined Upper South Fork Pound River and Phillips Creek watersheds where TDS is a contributor to the benthic impairments.

No significant relationship could be detected between mine spring TDS and precipitation or features representing underground mine extent. However, there is a significant relationship between median TDS load and the footprint of the hydrologic island from which mine springs issue. A hydrologic island is a steep-sided hill system that is isolated from others by deep, intervening stream valleys and which, therefore, has its own source of water from underground mines. The groundwater accumulates mainly through precipitation and is released through springs such as the mine springs that were sampled. Where underground mining has undercut valleys two or more hill systems compose a functional hydrologic island, which yields higher TDS loads than the components.

The relationship established for hydrologic island footprint and TDS load has the potential to apply generally to other intensively mined watersheds such as the upper portion of the South Fork Pound River watershed. While the hydrologic island relationship does not directly relate to mining, it does indicate that mining can alter the local hydrology, especially of the hydrology within hills.

Water quality data collected since about 1995 in the South Fork Pound watershed were provided by DMME. Samples have been collected in-stream (**Figure 2.2**) as well at National Pollutant Discharge Elimination System (NPDES) outfalls associated with mining. In-stream flow values for the mainstem appear to be only estimates. Because they were the basis for determining TDS loads, in-stream TDS loads are estimates as well.

The South Fork Pound River watershed can be usefully divided into upper and lower components (**Figure 2.2**). The upper watershed is hydrologically upstream and topographically higher. From an underground mining extent perspective, the major difference is that the upper watershed is extensively mined while the lower watershed is mined very little. Mining in the lower watershed is principally along the watershed boundary and then mainly one level deep.

Below-ground mining in the upper watershed is up to four levels deep, and the area has been extensively surface-mined as well.

2.2.1.1 In-stream Water Quality, S. F. Pound

The TDS load at the final South Fork Pound watershed outlet originates primarily in the upper watershed. It can be traced up the mainstem of the river in which the load remains approximately constant from the outlet across the lower watershed and into the upper watershed (**Figure 2.2**). Thus, although the outlet has a TDS load of 13.2*10^6 Mg/yr (station #12), near the outlet of the upper watershed it is 12.7*10^6 Mg/yr (station #37); about the same (**Table 2.2**). Over that distance the stream volume decreases by one third, however the TDS concentration correspondingly increases upstream.

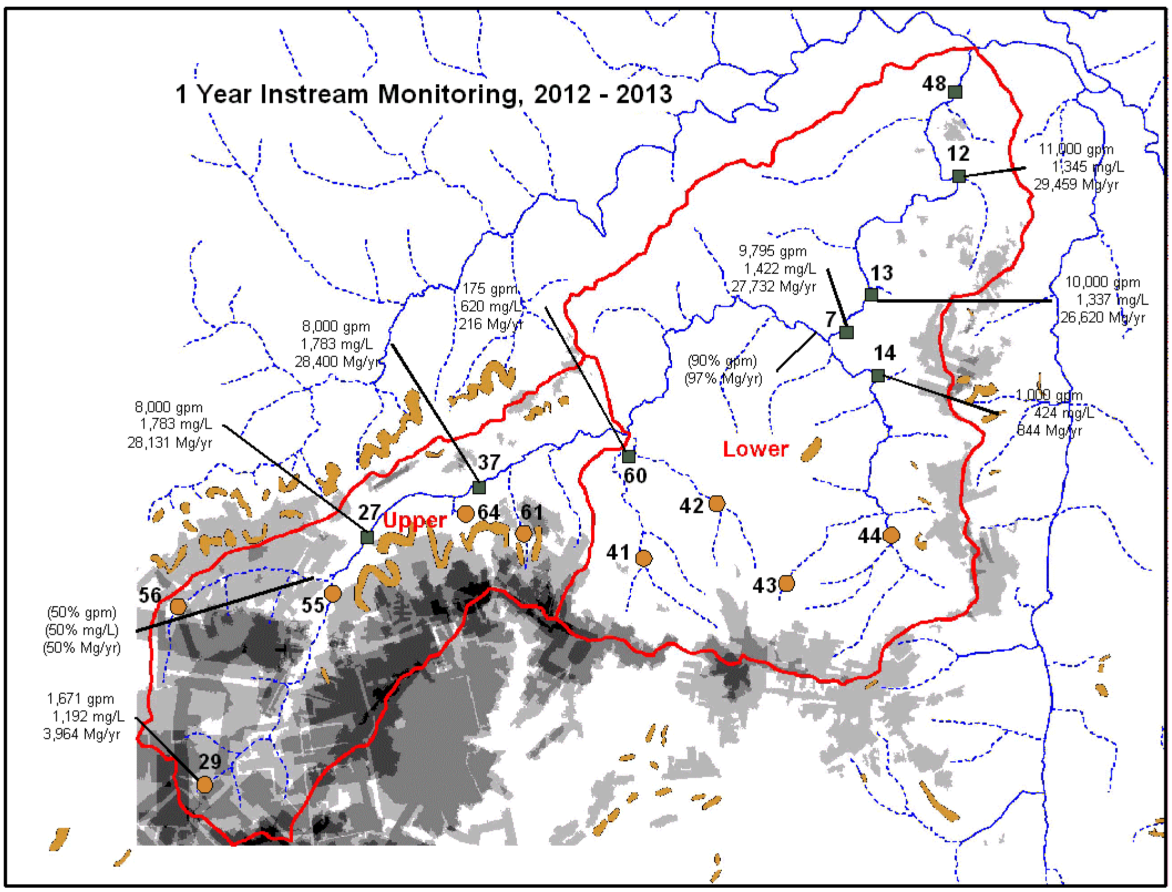


Figure 2.2 Current in-stream median flow, TDS concentration, and TDS load (Mg/yr) in the South Fork Pound River watershed. Squares mark perennial streams and circles mark intermittent stream stations.

That the major source of TDS is not in the lower watershed is supported by noting that the TDS concentration at station #14, which drains the southeast quarter of the lower watershed, is 424 mg/L, closer to the freshwater concentration range. When the TDS load medians for mainstems and tributaries are normalized to the same flow, the normalized loads in the upper mainstem and tributaries are well above those in the lower watershed emphasizing that the principal TDS source is the upper watershed (**Table 2.2**).

Table 2.2 In-stream water quality over the recent 12 months for representative stations in the South Fork Pound watershed. Station Map No. is from Figure 2.2.

Watershed	Map No.	DMME MPID	Median Flow (gpm)	Median TDS conc. (mg/L)	Median TDS Load (10^6 kg/yr)	TDS Load Normalized to 11,000 gpm (10^6 kg/yr)	Sample Period
Perennial							
Lower Mainstem[1]	**12**	0007245	11,000	1,345	29.394	29.4	2012-13
Lower, Tributary	**14**	0007696	1,000	424	0.842	9.3	2012-13
Upper Mainstem[2]	**37**	3420109	8,000	1,783	28.339	39.0	2012-13
Intermittent							
Lower, Tributary	**60**	3420267	175	620	0.216	13.5	2012-13
Lower, Tributary	**44**	3420178	450	498	0.445	10.9	2012-13
Lower, Tributary	**42**	3420176	5	236	0.002	5.2	2012-13
Upper, Tributary	**61**	3420268	43	2,843	0.243	62.1	2012-13
Upper, Tributary	**29**	3420085	1,671	1,192	3.957	26.1	2012-13

1 Near the outlet of the South Fork Pound watershed.
2 Near the outlet of the extensively mined upper South Fork Pound watershed.

From a seasonal perspective, in the South Fork Pound watershed, stream flow volume tends to be somewhat lower and, therefore, TDS concentrations tend to be somewhat higher in the growing season. As expected, flow and TDS load are more variable in tributaries than in the mainstem (**Figure 2.3**).In both the lower and upper South Fork Pound watersheds, TDS concentrations appear to have been low during the 1990s. Around the end of the 1990s, stream flow and TDS concentration increased abruptly in the lower watershed and gradually in the upper watershed (**Figure 2.4**).

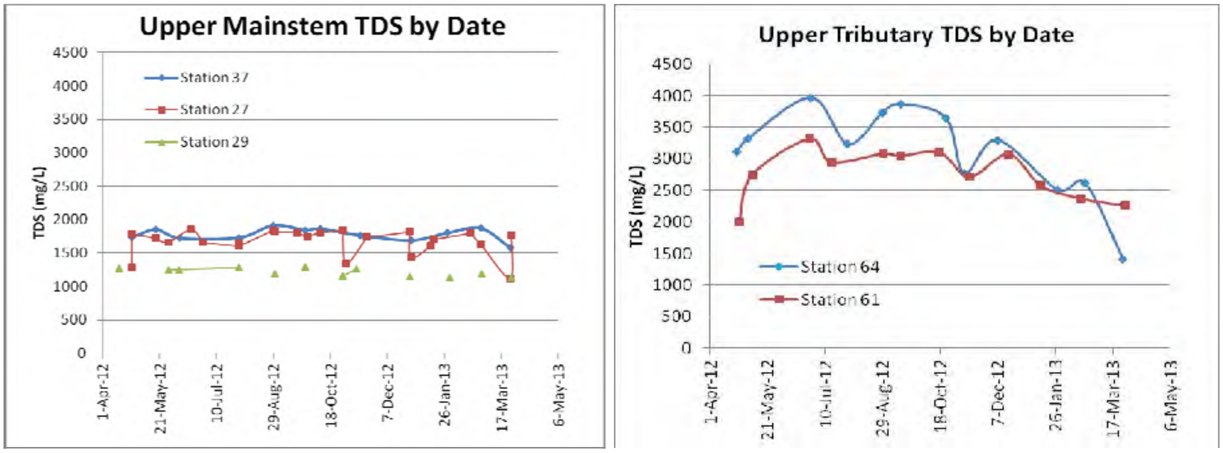


Figure 2.3 Mainstem and tributary TDS concentration (mg/L) in the upper South Fork Pound River watershed over the current year.

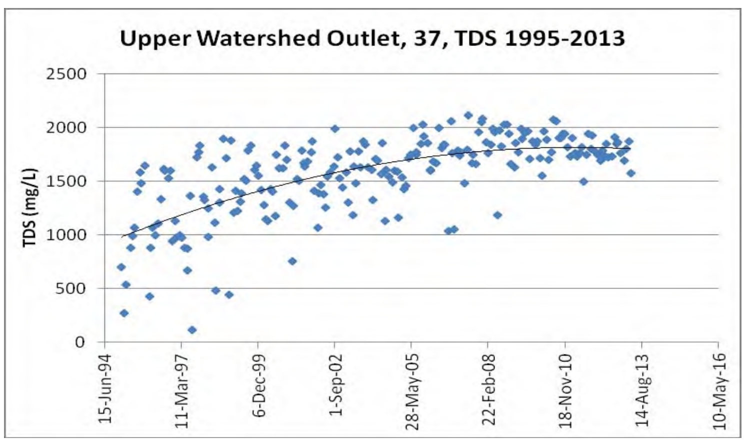


Figure 2.4 In-stream TDS (mg/L) near the outlet of the upper South Fork Pound River watershed.

The increased flow and TDS concentration led to increased TDS load at the South Fork Pound watershed outlet as represented in **Figure 2.5**. This figure combines flow and TDS load records from two stations in the lower watershed (48 and 7) in order to trace changes over the entire period of record. While station 48 is near the watershed outlet, station 7 is several miles upstream of the outlet for which no adjustment has been made to its graphed flow or TDS to account for its smaller catchment. The records argue there has been an increase in flow and TDS load from 1995 to the present.

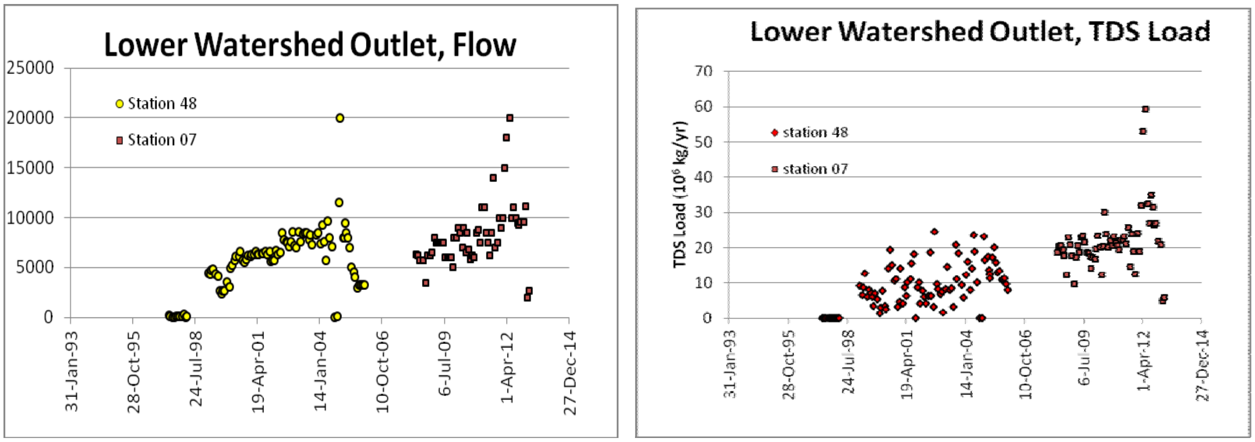


Figure 2.5 In-stream flow (gpm) and TDS load (10^6 kg/yr) at the South Fork Pound River watershed outlet.

Because TDS has been on the increase in the South Fork Pound watershed, the TDS data for the most recent 12 months presented in **Table 2.2** for upper and lower mainstem and tributaries may be the most relevant values for the benthic TMDL.

2.2.1.2 NPDES Water Quality, S. F. Pound

In the South Fork Pound watershed, samples have been collected at National Pollutant Discharge Elimination System (NPDES) outfalls associated with mining. Water quality records have been collected for many discharges but only twelve have been monitored for flow and TDS. The data for these discharges for the most recent 12 months are presented in **Table 2.3** and **Figure 2.6**.

Based on recent monitoring, NPDES discharges in the lower watershed exhibit a range of TDS concentration from near freshwater to mine water quality. Meanwhile, discharges in the upper watershed exhibit TDS in the mine water range; all exceed a median of 1,700 mg/L. The individual TDS loads are small, 6.0 x 10^6 kg/yr, compared to the load at the South Fork Pound outlet, 29.4 x 10^6 kg/yr, because the flows are relatively small. However, when normalized to the flow at the outlet, especially the discharges in the upper watershed exhibit larger TDS strength than the mainstem outlet.

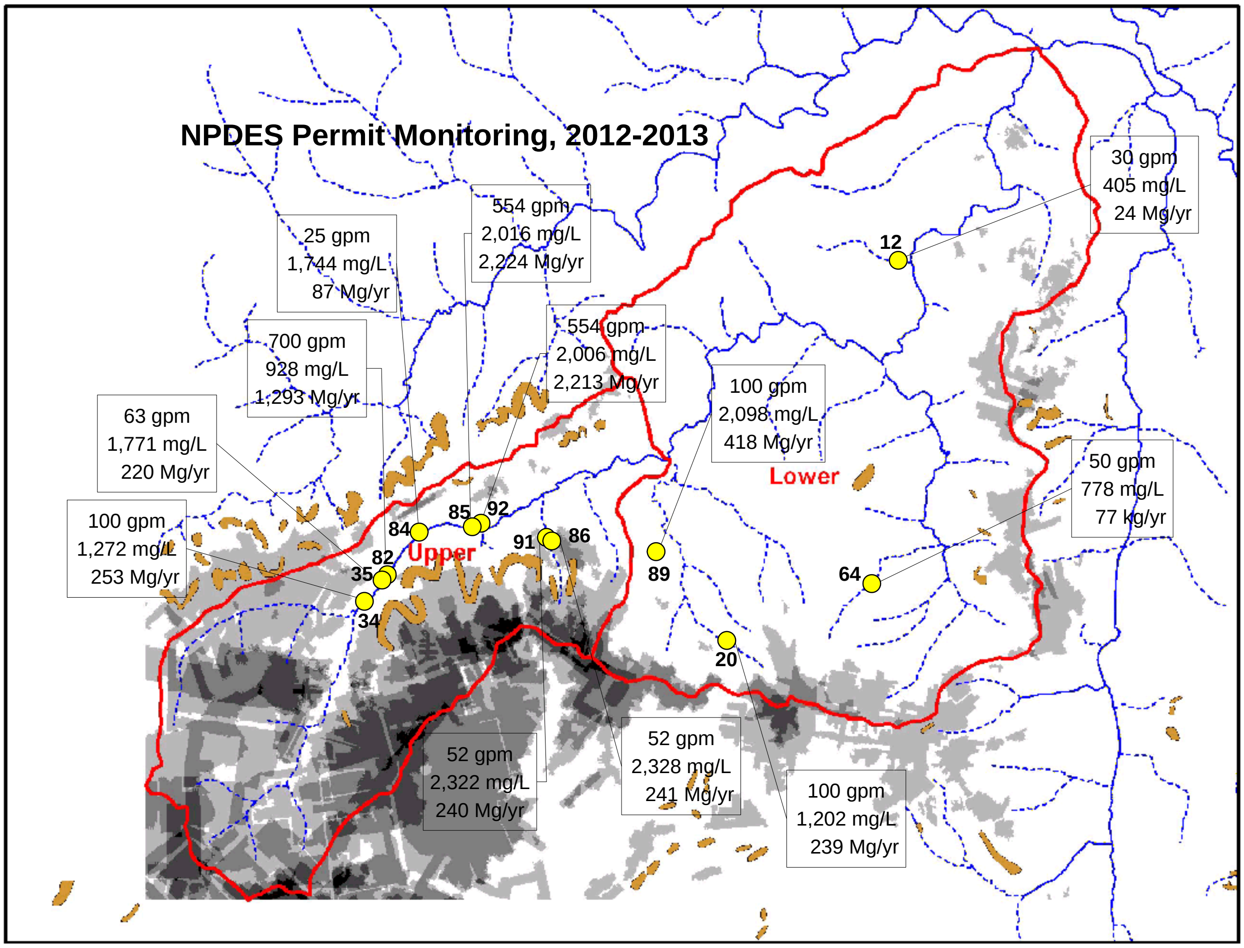


Figure 2.6 NPDES discharge median flow (gpm), TDS (mg/L), and TDS load (Mg/yr) for the current year in the South Fork Pound River watershed.

Over the 1995 – 2012 period of record, in the upper watershed the flow from NPDES sources increased and the TDS load increased (**Figure 2.7**). Meanwhile, at an example NPDES source in the lower watershed where the record covers only the last three years of the upstream station, flow and TDS load increased through the first two years and then dropped low. However, in both discharges TDS concentration exhibited a gradual increase over the period of record. Much of the irregularity in the flow and load at station 12 in the lower watershed can be explained by the relatively low flow, which tends to be characterized by high flow variability, and therefore high load variability, when compared to station 92. Yet, when the median loads for the most recent year of record are normalized to a flow of 11,000 gpm, the load from NPDES 92 is much stronger than that from NPDES 12 (**Table 2.3**). In fact, most of the NPDES discharges in the lower South Fork Pound watershed are weaker in TDS than those in the upper watershed.

Table 2.3 NPDES discharge over the recent 12 months in the South Fork Pound River watershed.

Map No.	DMME MpNo	Median Flow (cfs)	Median TDS (mg/L)	Median TDS Load (10^6 kg/yr)	TDS Load Normalized to 11,000 cfs (10^6 kg/yr)	Sample Period
Lower Watershed:						
12	0006925	30	405	0.024	8.9	2012-2013
64	3470158	50	778	0.077	17.0	2012-2013
20	2670086	100	1,202	0.239	26.3	2012-2013
89	3470291	100	2,098	0.417	45.9	2012-2013
Upper Watershed:						
92	3470294	554	2,006	2.208	43.8	2012-2013
85	3470287	554	2,016	2.219	44.1	2012-2013
84	3470286	25	1,744	0.087	38.1	2012-2013
86	3470288	52	2,328	0.241	50.9	2012-2013
91	3470293	52	2,322	0.240	50.7	2012-2013
35	3470069	63	1,771	0.222	38.7	2012-2013

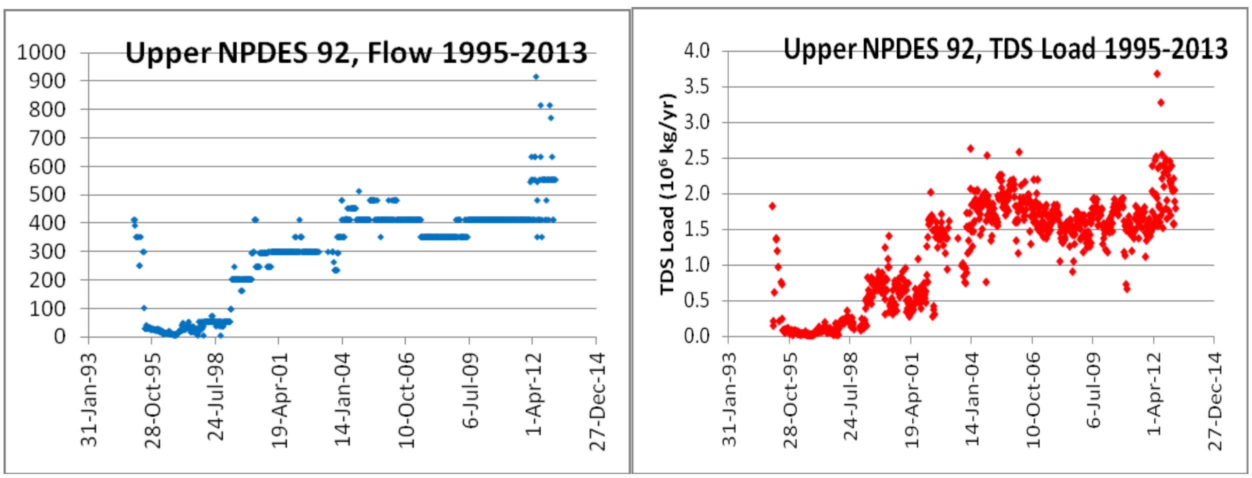
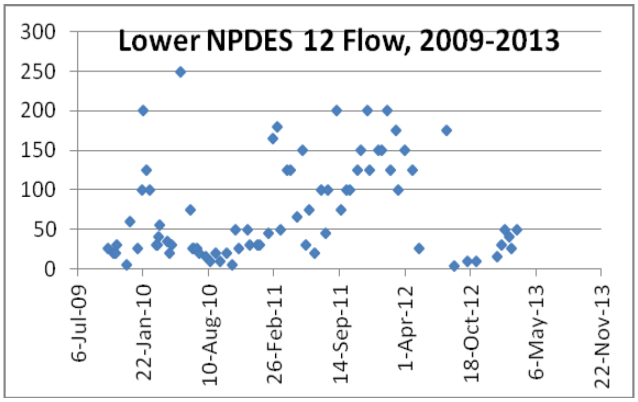


Figure 2.7 NPDES #92 flow volume (gpm, left) and TDS load (10^6 kg/yr, right) in the upper watershed.



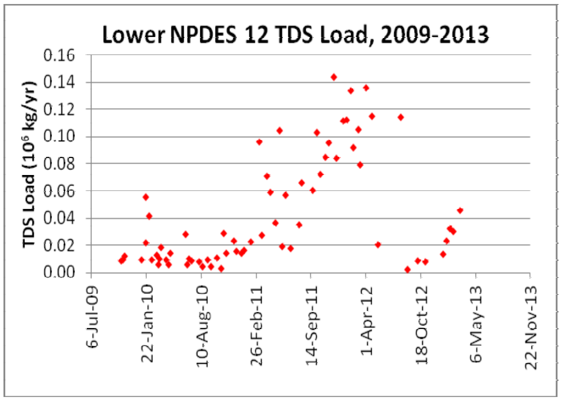


Figure 2.8 NPDES #12 flow volume (gpm, left) and TDS load (10^6 kg/yr, right) in the lower watershed.

2.2.1.3 TDS Modeling Implications

It was mentioned previously that the upper watershed of the South Fork Pound is extensively mined while the lower watershed is mined considerably less. The small amount of underground mining in the lower watershed is principally along the watershed boundary, and one level deep. The upper watershed has been mined up to four levels deep, and it has been surface-mined as well. Because mining characteristics in the upper watershed in the South Fork Pound are very similar to those in the Bull Creek watershed, relationships found in the Bull Creek watershed may apply to the upper watershed as well.

In the Bull Creek watershed underground mine springs yield median flows from 0.02 to 1.04 cfs, with an overall median of 0.10 cfs over the study period (**Table 2.4**). Because the study period captured both low- and high-flow seasons, the summary data are considered representative of the year. Individual springs exhibit a range of TDS concentrations from values near the freshwater range (475 mg/L) to the mine-spring range (1,210 mg/L). However, flow was by far the controlling variable in the production of TDS load (**Figure 2.9**). Annual TDS loads ranged from 7 Mg/yr to 790 Mg/yr. That is, compared to the smallest loads, top-producing springs from underground mines yield one hundred times as much TDS load.

Table 2.4 Mine spring flow, and spring-TDS over the study period in the Bull Creek watershed.

Site	Ave. Flow (cfs)	Median Flow (cfs)	Mean TDS mg/L	Median TDS mg/L	Mean TDS Mg/yr	Median TDS Load Mg/yr	Load Ratio[1]	Elevation (feet)
maximum:	1.49	1.04	1,217	1,210	1,239	790	118	1,567
minimum:	0.02	0.02	447	475	11	7	1	1,232
median:		0.10		1,010		101		1,332

[1] Median TDS Load divided by 7, the minimum Median TDS Load.

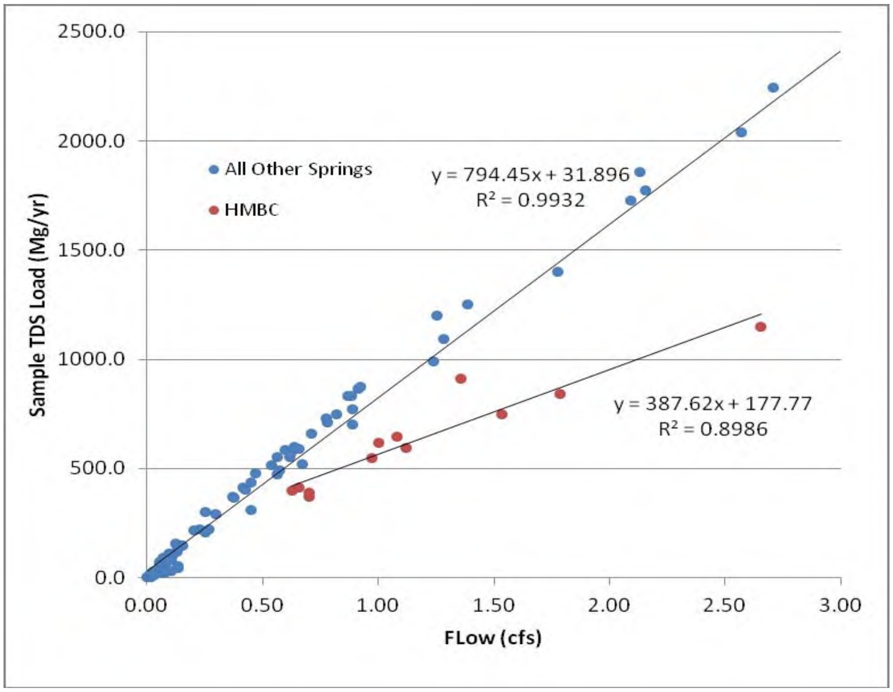


Figure 2.9 TDS load and flow for spring HMBC compared to all other mine springs.

As stated earlier, in the Bull Creek watershed, no relationship could be detected between mine spring TDS and precipitation or features representing underground mine extent. However, a significant relationship was found between median TDS load and the footprint of the hydrologic island from which the mine spring issues. Where underground mining has undercut valleys two or more hill systems compose a functional hydrologic island, which yields higher TDS loads than the components. The relationship established for hydrologic island footprint and TDS load in presented in **Table 2.5**.

Table 2.5 Regression of spring flow and TDS load against island footprint.

Parameter	Estimate	Standard Error	p-value
Median Flow, Intercept	-0.3248	0.3553	0.412
Median Flow, Slope	0.0016	0.0005	0.040
Sum Raw Median Load, Intercept	-243.5	354.5	0.530
Sum Raw Median Load, Slope	1.268	0.530	0.075

While the hydrologic island relationship does not relate to a mining parameter, the springs issuing below the Bull Creek hydrologic islands originate from the mines in the islands. Thus, it provides a means of estimating the TDS from mined hydrologic islands in the upper South Fork Pound. Also, the functional hydrologic island concept embodies the idea that mining can alter the local hydrology, especially of the subsurface water within hills.

Before applying the hydrologic island footprint:TDS load relationship, it is admitted that there is a difference in scale between the two watersheds. The South Fork Pound River watershed totals 11,189 acres, which is 31% larger than the 7,731 acres in the Bull Creek watershed. Meanwhile, the upper South Fork Pound watershed has a footprint of 3,849 acres; half the size of the Bull Creek watershed. Nevertheless, because the island footprint:TDS load relationship is area based, the results for the upper South Fork Pound watershed should be comprehensive; they should express the TDS load for the entire area.

The upper watershed of the South Fork Pound watershed appears to consist of five hydrologic islands (**Figure 2.10**). As in the Bull Creek watershed, the hill units were divided based on suspected contiguity of mine drainage. For example, the South Fork Pound mainstem has not been undermined for most of its length and so divides the area into two parts. Island #8 is essentially un-mined. Island #9 has been thoroughly mined at one level. Islands #10, 11 and 12 have been extensively mined underground, but islands #11 and #12 also contain prominent abandoned surface mines.

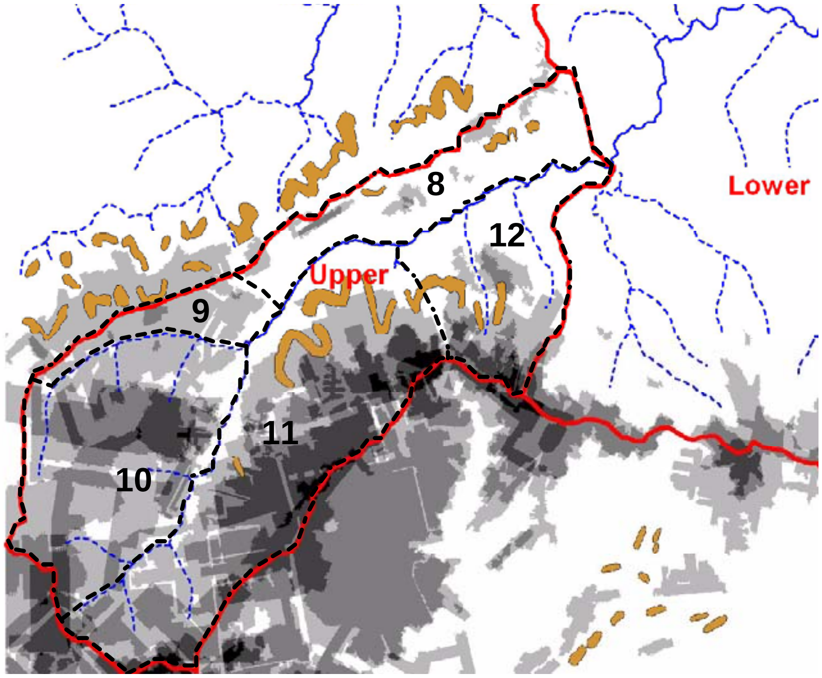


Figure 2.10 Hydrologic islands in the upper South Fork Pound River watershed.

In the South Fork Pound, island #8 has very little mining and should produce low-TDS springs. The spring discharge in Bull Creek island #7 with similar island parameters approximates its load and flow (**Table 2.6**).

Table 2.6 Summary of TDS results for hydrologic islands in Bull Creek and South Fork Pound watersheds.

Watershed and Island	Foot-print (acre)	Relief (ft)	Island Volume ($x10^9$ ft^3)	Mining [2]	Median Spring Flow (cfs)	Median TDS conc. (mg/L)	Median TDS Load (Mg/yr)	*Load x Flow* Median TDS Load (Mg/yr)
S.F. Pound #8	571	400	10	minimal	**0.02**	*475*	**8**	
Bull Cr. #1+2	1,154	1,007	51	UG	1.70	1,017	1,538[1]	1,382[e]
S.F. Pound #9	213	600	6	UG	**0.02±0.53**[3]	*(1,511)*[5]	**27**[4]	*45* [6]
S.F. Pound #10	1,013	1,600	71	UG	**1.30±0.54**[3]	*(897)*[5]	**1,042**[4]	*1,062*[6]
Bull Cr. #3	874	1,022	39	UG+Surf.	1.04	625	607[1]	858 [6]
S.F. Pound #11	1,438	1,750	110	UG+Surf.	**1.98±0.69**[3]	*(893)*[5]	**1,580**[4]	*944*[7]
S.F. Pound #12	613	950	25	UG+Surf.	**0.66±0.49**[3]	*(905)*[5]	**534**[4]	*432*[7]

1 Sum of Raw Median TDS load, based on monitored data.
2 "UG" = underground mining, , "UG+Surf." = underground plus surface mining.
3 Estimated Median Flow (cfs) = 0.0016*(footprint acres) – 0.3248, 95% C.I..
4 Estimated Median TDS Load (Mg/yr) = 1.2681*(footprint acres) – 243.52.
5 Back-calculated: Median TDS concentration (mg/L) = footprint est. Median TDS Load (Mg/yr) / (footprint est. flow*0.8935911).
6 Estimated using non-HMBC *Load x Flow* relationship: Median Load (Mg/yr) = 794.45*(Footprint est. flow, cfs*0.8935911).
7 Estimated using HMBC *Load x Flow* relationship: Median Load (Mg/yr) = 387.62*(Footprint est. flow, cfs*0.8935911).
8 Load x Flow Median TDS Load .. The TDS load based on the basic flow-dependent load relationship for all non-HMBC springs.

Hydrologic island #1+2 from the Bull Creek watershed has been extensively mined underground matching the nature of mining in South Fork Pound islands #9 and #10. Island #10 is similar in footprint size to #1+2 while #9 is much smaller. But their footprints are in the Bull Creek range developed to predict flow and TDS load. The South Fork Pound hydrologic islands have greater relief and therefore have about 40% larger hill volume than the Bull Creek islands. This suggests they could have larger groundwater reservoirs although no significant relationship was found between hill volume and flow in Bull Creek. Still, spring volume and TDS load, which is proportional to flow, may be somewhat under-predicted in these taller islands.

Bull Creek island #3 is slightly larger than island #12, and about 60% the size of island #11. However, the flow and load predictions should be reasonable because the South Fork Pound islands are within the island footprint range used to develop the relationships. However, as was noted for the HMBC spring in Bull Creek, abandoned surface mine features tend to produce substantially lower TDS concentrations and higher flows than areas that have only been mined underground. Thus, although the predicted flow volume may be under estimated for any springs in islands #11 and #12, the TDS load yield is still expected to be reasonable.

The "Load x Flow" estimate of load presented in the last column of **Table 2.6** is a separate estimate of the loads. This is the predicted load based upon the Bull Creek spring volume dependence on TDS load. In the table, this separate estimate for Bull Creek #1+2 and South Fork Pound #9 and #10 is based on the load from all non-HMBC springs. For the remaining islands the HMBC spring relationship is used. Upon comparing the values, the island-estimated load for South Fork Pound #11 appears somewhat over-estimated.

In the following **Table 2.7**, water quality and quantity in the South Fork Pound mainstem and tributaries are presented for comparison to values in NPDES discharges and dominant Bull Creek watershed springs. While tributary loads tend to be one 100th the size of mainstem loads, NPDES loads can be as much as one 10th the size of mainstem loads. Meanwhile, mine spring loads fall somewhere between the two.

Table 2.7 Comparison of water quality and discharge over the recent 12 months.

Watershed	Map No. NPDES No., or Spring	Median Flow (gpm)	Median TDS (mg/L)	Median TDS Load (10^6 kg/yr)	TDS Load Normalized to 11,000 gpm (10^6 Mg/yr)	Sample Period
SFP, Lower, mainstem[1]	**12**	11,000	1,345	29.39	29.4	2012-13
SFP, Upper, mainstem[1]	**37**	8,000	1,783	28.34	39.0	2012-13
SFP, Lower, tributary[1]	**60**	175	620	0.22	13.5	2012-13
SFP, Upper, tributary[1]	**61**	43	2,843	0.24	62.1	2012-13
SFP., Lower[2]	NPDES **20**	100	1,202	0.24	26.3	2012-13
SFP., Upper[2]	NPDES **85**	554	2,016	2.22	44.1	2012-13
Bull Creek	DownBelcher	381	1,035	0.79	22.8	2012-13
Bull Creek	HMBC	467	625	0.61	14.4	2012-13

1 **Table 2.2** page **14**.
2 **Table 2.3** page **17**.

3. ADJUSTMENTS TO PHASE I MODEL

Adjustments were made to both the sediment and TDS models.

3.1 Sediment Modeling

Based on assessment of the existing model, available data, and an effort to maintain consistency across TMDL projects, some changes were made to the existing Bull Creek GWLF model. The land use distribution developed for the Phase I model was used for the Phase II GWLF. The model parameter changes are outlined in **Table 3.1** and **Table 3.2**, which correspond with *Tables 10.9 and 10.11* in the Phase I document.

Table 3.1 GWLF watershed parameters in the impaired and reference watersheds.

GWLF Watershed Parameter[1]	Units	Lower North Fork Pound River	Upper Dismal Creek	Phillips Creek	Upper Dismal Creek	South Fork Pound River[2]	Upper Dismal Creek
Recession Coefficient*	Day^{-1}	0.2726	0.2564	0.2564	0.2564	0.0697	0.0697
Seepage Coefficient*	Day^{-1}	0.508	0.074	0.23	0.074	0.37	0.074
Sediment Delivery Ratio	---	0.29	0.29	0.28	0.28	0.16	0.15
Unsaturated Water Capacity	(cm)	11.89	10.05	10.73	10.05	10.45	12.00
Erosivity Coefficient (May-Oct)*	---	0.28	0.28	0.28	0.28	0.28	0.28
Erosivity Coefficient (Sep-Apr)*	---	0.1	0.1	0.1	0.1	0.1	0.1
Evapotranspiration Cover Coefficient*	---	0.766 - 0.941	0.844 - 0.954	0.645 - 0.785	0.844 - 0.954	0.709 - 0.848	0.844 - 0.954
% Developed Land*	(%)	2.97	2.84	2.97	2.84	2.97	2.84
Livestock Density*	(AU/ac)	0.00129	0.00241	0.00129	0.00241	0.00129	0.00241
Area-weighted Soil Erodibility (K)	---	0.200	0.208	0.200	0.208	0.200	0.208
Area-weighted Runoff Curve Number (CN)	---	67.43	70.07	67.43	70.07	67.43	70.07
Total Stream Length	(m)	3441.70	3441.70	148.08	148.08	18237.79	18385.87
Mean Channel Depth	(m)	0.181	0.181	0.184	0.184	0.337	0.348

[1] Parameters identified with and asterisk (*), were maintained at the value set in the Phase I model.
[2] South Fork Pound River modeled excluding Phillips Creek. Loads from Phillips Creek included as separate source in allocation.

Table 3.2 GWLF curve numbers and KLSCP values for existing conditions in the impaired and reference watersheds.

Sediment Source	Lower North Forth Pound River		Upper Dismal Creek		Phillips Creek		Upper Dismal Creek		South Forth Pound River		Upper Dismal Creek	
	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP
Pervious Area:												
Row Crop - High Till	81.50	0.8072	81.50	0.6538	80.30	4.7652	81.50	0.6538	81.50	0.4349	81.50	0.6538
Row Crop - Low Till	78.90	0.1583	78.90	0.1282	77.21	0.9343	78.90	0.1282	78.90	0.0853	78.90	0.1282
Pasture	76.00	0.1187	75.85	0.1361	73.59	0.7008	75.85	0.1361	76.00	0.1247	75.85	0.1361
Hay	67.10	0.0063	66.91	0.0073	63.97	0.0374	66.91	0.0073	67.10	0.0067	66.91	0.0073
Forest	64.03	0.0034	65.10	0.0055	61.89	0.0093	65.10	0.0055	65.45	0.0040	65.10	0.0055
Barren	86.78	0.6578	86.56	1.2562	86.80	0.5830	86.56	1.2562	86.76	0.9481	86.56	1.2562
Low Density Residential	70.10	0.0326	69.20	0.0342	66.97	0.1215	69.20	0.0342	70.10	0.0339	69.20	0.0342
Medium Density Residential	70.10	0.0022	68.11	0.0518	66.97	0.1215	68.11	0.0518	70.10	0.0295	68.11	0.0518
High Density Residential	70.10	0.0221	68.80	0.0487	66.97	0.1215	68.80	0.0487	70.10	0.0285	68.80	0.0487
Transportation	87.80	0.0863	87.19	0.1057	86.84	0.2803	87.19	0.1057	87.80	0.0792	87.19	0.1057
AML	79.25	0.3256	78.97	0.3492	79.30	0.3795	78.97	0.3492	79.30	0.2573	78.97	0.3492
Mining Land Uses:												
Extractive/Active Mining	86.80	2.1664	86.25	1.5626	84.77	2.6005	86.25	1.5626	86.77	1.1224	86.25	1.5626
Reclaimed	74.00	0.3141	72.62	0.2266	74.00	0.4115	72.62	0.2266	73.92	0.3972	72.62	0.2266
Released	65.80	0.4062	63.87	0.2930	65.80	0.5321	63.87	0.2930	65.69	0.2105	63.87	0.2930
Impervious Area:												
Low Density Residential	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000
Medium Density Residential	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000
High Density Residential	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000
Transportation	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000	98.00	0.0000

The sediment loads were modeled for existing conditions in the impaired and reference watersheds. For domestic wastewater treatment permits, the design discharge was multiplied by the permitted TSS concentration and then converted to get a permit load in metric tons per year (t/yr). As discussed in Section 2.1 of this report, the existing TSS concentration from active mining and reclaimed areas within mining permits was assumed to be the permitted concentration of 70 mg/L. The remainder of the area in the mining permit areas consist of released lands and areas that have yet to be disturbed. Sediment loads from these areas are included with their respective land uses, while the disturbed areas are allocated as mining permit

The existing condition is the combined sediment load from both point and diffuse sources, shown in **Table 3.3** through **Table 3.5** for the impaired watershed and the area-adjusted reference watershed load. The Lower North Fork Pound River was modeled as only the area downstream of the North For Pound Lake. The reservoir was assumed to be a sediment trap, which is supported by TSS data frequently being below detection levels, and during allocation an additional 5% of the TMDL was set aside to account for any sediment load that may be attributed to the reservoir outflow. The reference watershed was scaled down to this size as well.

Table 3.3 Existing sediment loads from Lower North Fork Pound River and area-adjusted Dismal Creek.

Sediment Source	Lower North Fork River		Area-adjusted Dismal Creek	
	t/yr	**t/ha/yr**	**t/yr**	**t/ha/yr**
Pervious Area				
Row Crop - High Till	0.00	0.00	0.00	0.00
Row Crop - Low Till	0.00	0.00	0.38	7.80
Pasture	107.77	6.65	55.48	7.58
Hay	0.83	0.26	0.00	0.00
Forest	54.57	0.14	92.32	0.22
Barren	1076.57	51.53	364.68	98.27
Low Density Residential	8.55	1.51	11.92	1.49
Medium Density Residential	0.16	0.10	0.04	2.15
High Density Residential	3.44	1.02	0.71	2.13
Transportation	8.77	6.86	5.61	8.35
AML	0.00	0.00	474.15	21.34
Mining Land Uses				
Extractive	52.44	169.70	71.30	121.81
Reclaimed	0.00	0.00	4.46	11.05
Released	0.00	0.00	5.05	11.70
Impervious Area				
Low Density Residential	0.37	0.48	0.52	0.48
Medium Density Residential	0.80	1.18	0.01	1.23
High Density Residential	4.64	0.74	0.46	0.74
Transportation	2.56	0.53	1.34	0.53
Direct Sources				
Channel Erosion	0.12	0.00	0.11	0.00
Watershed Totals	**1321.58**	**2.84**	**1088.55**	**2.34**

Table 3.4 Existing sediment loads from Phillips Creek and area-adjusted Dismal Creek.

Sediment Source	Phillips Creek		Area-adjusted Dismal Creek	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious Area				
Row Crop - High Till	21.17	302.37	0.00	0.00
Row Crop - Low Till	1.04	52.18	0.40	7.51
Pasture	33.03	35.22	57.26	7.23
Hay	0.27	1.44	0.00	0.00
Forest	36.23	0.33	96.64	0.21
Barren	458.71	44.09	382.62	95.35
Low Density Residential	0.00	0.00	12.27	1.42
Medium Density Residential	0.00	0.00	0.05	2.07
High Density Residential	0.00	0.00	0.73	2.03
Transportation	0.00	0.00	5.89	8.11
AML	96.90	22.82	493.21	20.53
Mining Land Uses[1]				
Extractive	*	*	74.90	118.33
Reclaimed	*	*	4.62	10.58
Released	3.00	20.88	5.28	11.31
Impervious Area				
Low Density Residential	0.00	0.00	0.56	0.48
Medium Density Residential	0.00	0.00	0.01	1.18
High Density Residential	0.00	0.00	0.50	0.75
Transportation	0.00	0.00	1.46	0.54
Direct Sources				
Channel Erosion	0.00		0.01	
Permitted Sources				
Mining Permits	28.17	3.83		
Watershed Totals	**1552.68**	**52.53**	**1136.42**	**2.26**

[1] An asterisk (*) denotes extractive and reclaimed land uses covered by DMME permits in the impaired watershed.

Table 3.5 Existing sediment loads from the South Fork Pound River and area-adjusted Dismal Creek.

Sediment Source	South Fork Pound River		Area-adjusted Dismal Creek	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious Area				
Row Crop - High Till	246.37	16.35	0.00	0.00
Row Crop - Low Till	12.51	2.87	1.91	4.03
Pasture	1119.85	3.86	276.73	3.87
Hay	8.71	0.15	0.00	0.00
Forest	185.21	0.09	467.07	0.11
Barren	7999.92	40.98	1849.33	51.08
Low Density Residential	12.55	0.86	59.32	0.76
Medium Density Residential	0.19	0.75	0.22	1.12
High Density Residential	3.22	0.73	3.53	1.09
Transportation	4.47	3.48	28.47	4.35
AML	2643.58	8.84	2383.61	11.00
Mining Land Uses[1]				
Extractive	*	*	362.09	63.39
Reclaimed	*	*	22.36	5.67
Released	40.28	4.72	25.56	6.06
Impervious Area				
Low Density Residential	0.94	0.48	5.07	0.48
Medium Density Residential	0.13	1.18	0.10	1.19
High Density Residential	6.09	0.74	4.50	0.75
Transportation	2.58	0.53	13.19	0.54
Direct Sources				
Channel Erosion	1.22		3.35	
Upstream Inputs				
Phillips Creek[2]	1552.68			
Permitted Sources				
Mining Permits	64.46			
Individual Residences	0.17			
Watershed Totals	**12287.81**	**52.53**	**5506.40**	**1.21**

[1] An asterisk (*) denotes extractive and reclaimed land uses covered by DMME permits in the impaired watershed.
[2] Reflects the existing condition load from Phillips Creek watershed shown in **Table 3.4**.

3.2 TDS Modeling

TDS modeling was not adjusted based on the monitoring results. However, insights gained from the monitoring effort have been incorporated into the interpretation of the resulting allocations. Additionally, some changes were made in the categorization of loads. Specifically, groundwater loads were divided into those loads associated with natural conditions (background), and those that were not associated with natural conditions (non-background). Based on groundwater monitoring in non-impacted areas of the watershed, a concentration of 230 mg/L was used to establish “background” conditions. This concentration represents approximately 32% of the total groundwater load in the watershed. The remaining “groundwater” loads modeled represent human-impacted loads that enter through shallow groundwater, as well as persistent loads to the stream that are not dependent on active rainfall event (*e.g.*, unaccounted-for drainage from abandoned underground mine workings, and slow drainage from fill areas).

4. PHASE II TMDLS FOR THE POUND RIVER (BENTHIC)

Adjustments were made to both the sediment and TDS TMDL allocations.

4.1 Sediment TMDL Allocations

LOWER NORTH FORK POUND RIVER

The target TMDL load for the Lower North Fork Pound River watershed is the average annual load in metric tons per year (t/yr) from the area-adjusted Upper Dismal Creek watershed under existing conditions. In addition to the 10% MOS for the Lower North Fork Pound River allocation, an additional 5% was set aside as load allocation (LA) for loads that may come from the reservoir outflow. To reach the TMDL target goal (1088.55 t/yr), two different scenarios were run with GWLF (**Table 4.1**). Scenario 1 shows 32.2% reductions to residential, pasture, high-till cropland, barren areas, and mining land uses. Scenario 2 shows reductions limited to the land use contributing the greatest sediment load, barren or transitional areas (37.9%). Scenario 1 was chosen to use for the final TMDL because it has similar reductions on different land uses throughout the watershed. The final overall sediment load reduction required for the Lower North Fork Pound River is 17.7%.

The sediment TMDL for the Lower North Fork Pound River includes three components – WLA, LA, and the 10% MOS. As there were no permitted sources within the watershed, the WLA consisted of only the future load allocation of 1% of the TMDL. The average annual sediment TMDLs for the Lower North Fork Pound River are given in **Table 4.2**.

Table 4.1 Final TMDL allocation scenarios for the Lower North Fork Pound River watershed.

Sediment Source	Existing Lower North Fork Pound River Loads t/yr	Scenario 1 Reductions %	Scenario 1 Allocated Loads t/yr	Scenario 2 Reductions %	Scenario 2 Allocated Loads t/yr
Pervious Area					
Row Crop - High Till	0.00	32.2	0.00	0.0	0.00
Row Crop - Low Till	0.00	0.0	0.00	0.0	0.00
Pasture	107.77	32.2	73.07	0.0	107.77
Hay	0.83	0.0	0.83	0.0	0.83
Forest	54.57	0.0	54.57	0.0	54.57
Barren	1076.57	32.2	729.91	37.9	668.55
Low Density Residential	8.55	32.2	5.80	0.0	8.55
Medium Density Residential	0.16	32.2	0.11	0.0	0.16
High Density Residential	3.44	32.2	2.33	0.0	3.44
Transportation	8.77	32.2	5.95	0.0	8.77
AML	0.00	32.2	0.00	0.0	0.00
Mining Land Uses					
Extractive	52.44	32.2	35.55	0.0	52.44
Reclaimed	0.00	0.0	0.00	0.0	0.00
Released	0.00	0.0	0.00	0.0	0.00
Impervious Area					
Low Density Residential	0.37	32.2	0.25	0.0	0.37
Medium Density Residential	0.80	32.2	0.54	0.0	0.80
High Density Residential	4.64	32.2	3.14	0.0	4.64
Transportation	2.56	32.2	1.73	0.0	2.56
Direct Sources					
Channel Erosion	0.12	32.2	0.08	0.0	0.12
Reservoir Outfall			54.43		54.43
Permitted Loads					
Future Growth			10.89		10.89
Margin of Safety			108.86		108.86
Watershed Totals	**1321.58**	**17.7**	**1088.04**	**17.7**	**1087.73**

Table 4.2 Average annual sediment TMDL for the Lower North Fork Pound River

	WLA t/yr	LA t/yr	MOS t/yr	TMDL t/yr
Lower North Fork Pound River	**10.89**	**968.30**	**108.86**	**1088.04**
Future Growth	10.89			

Starting in 2007, the USEPA has mandated that TMDL studies include a maximum daily load (MDL) in addition to the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach found in the 2007 document titled Options for Expressing Daily Loads in TMDLs (USEPA, 2007). The procedure involved calculating the MDL from the long-term average annual TMDL load in addition to a coefficient of variation (CV) estimated from the annual load for ten years. The annual sediment load for the Lower North Fork Pound River had a CV of 0.467. A multiplier was used to estimate the MDL from the long-term average based on the USEPA guidance and this CV. The multiplier estimated for Lower North Fork Pound River was 3.14. In this case, the long-term average was the annual TMDL divided by 365 days (2.98 t/day), which when multiplied by the 3.14 results in an MDL of 9.35 t/day. The daily WLA was estimated as the annual WLA divided by 365. The daily MOS was estimated as 10% of the MDL. Finally, the daily LA was estimated as the MDL minus the daily MOS and the daily WLA. These results are shown in **Table 4.3**.

Table 4.3 Maximum daily sediment TMDL for Lower North Fork Pound River.

	WLA t/day	LA t/day	MOS t/day	TMDL t/day
Lower North Fork Pound River	**0.03**	**8.39**	**0.94**	**9.35**
Future Growth	0.03			

PHILLIPS CREEK

The target TMDL load for Phillips Creek is the average annual load in metric tons per year (t/yr) from the area-adjusted Upper Dismal Creek watershed under existing conditions. To reach the TMDL target goal (1136.42 t/yr), two different scenarios were run with GWLF (**Table 4.4**). Scenario 1 shows 36.5% reductions to residential, pasture, high-till cropland, barren areas, and abandoned and released mined land. Scenario 2 shows reductions limited to the two land uses contributing the greatest sediment loads, abandoned mine land and barren or transitional areas

(40.4%). Scenario 1 was chosen to use for the final TMDL because it has similar reductions on different land uses throughout the watershed. The final overall sediment load reduction required for the Phillips Creek watershed is 26.9%.

Table 4.4 Final TMDL allocation scenarios for the Phillips Creek watershed.

Sediment Source	Existing Phillips Creek Loads t/yr	Scenario 1 Reductions %	Scenario 1 Allocated Loads t/yr	Scenario 2 Reductions %	Scenario 2 Allocated Loads t/yr
Pervious Area					
Row Crop - High Till	21.17	36.5	13.44	0.0	21.17
Row Crop - Low Till	1.04	0.0	1.04	0.0	1.04
Pasture	33.03	36.5	20.98	0.0	33.03
Hay	0.27	0.0	0.27	0.0	0.27
Forest	36.23	0.0	36.23	0.0	36.23
Barren	458.71	36.5	291.28	40.4	273.39
Low Density Residential	0.00		0.00		0.00
Medium Density Residential	0.00		0.00		0.00
High Density Residential	0.00		0.00		0.00
Transportation	0.00		0.00		0.00
AML	96.90	36.5	61.53	0.0	96.90
Mining Land Uses[1]					
Extractive	*	*	*	*	*
Reclaimed	*	*	*	*	*
Released	877.17	36.5	557.00	40.6	521.04
Impervious Area					
Low Density Residential	0.00		0.00		0.00
Medium Density Residential	0.00		0.00		0.00
High Density Residential	0.00		0.00		0.00
Transportation	0.00		0.00		0.00
Direct Sources					
Channel Erosion	0.00	36.5	0.00	0.0	0.00
Permitted Sources					
Mining Permits	28.17		28.17		28.17
Future Load			11.36		11.36
Margin of Safety			113.64		113.64
Watershed Totals	**1552.68**	**26.9**	**1134.94**	**26.8**	**1136.24**

[1] An asterisk (*) denotes extractive and reclaimed land uses covered by DMME permits in the impaired watershed.

The sediment TMDL for Phillips Creek includes three components – WLA, LA, and the 10% MOS. The WLA was calculated as the sum of all permitted point source discharges as well as the future load allocation of 1% of the TMDL. The average annual sediment TMDLs for Phillips Creek are given in **Table 4.5**.

Table 4.5 Average annual sediment TMDL for Phillips Creek.

	WLA t/yr	LA t/yr	MOS t/yr	TMDL t/yr
Phillips Creek	**39.53**	**981.76**	**113.64**	**1134.94**
Surface Coal Mining Transient Permits				
1100033	1.87			
1100520	3.51			
1100787	5.29			
1101272	0.55			
1101565	2.19			
1101760	3.40			
1201664	0.02			
1501778	0.04			
1600876	11.31			
Future Growth	11.36			

The maximum daily loads for Phillips Creek were calculated in the same manner as Lower North Fork Pound River daily loads. The annual sediment load for Phillips Creek had a CV of 0.455. The multiplier estimated for Phillips Creek was 3.06. The long-term average was the annual TMDL divided by 365 days (3.11 t/day), which when multiplied by the 3.06 results in an MDL of 9.51 t/day. The daily WLA was estimated as the annual WLA divided by 365. The daily MOS was estimated as 10% of the MDL. Finally, the daily LA was estimated as the MDL minus the daily MOS and the daily WLA. These results are shown in **Table 4.6**.

Table 4.6 Maximum daily sediment TMDL for Phillips Creek.

	WLA t/day	LA t/day	MOS t/day	TMDL t/day
Phillips Creek	**0.11**	**8.45**	**0.95**	**9.51**
Surface Coal Mining Transient Permits				
1100033	0.01			
1100520	0.01			
1100787	0.01			
1101272	0.00			
1101565	0.01			
1101760	0.01			
1201664	0.00			
1501778	0.00			
1600876	0.03			
Future Growth	0.03			

SOUTH FORK POUND

The target TMDL load for the South Fork Pound River is the average annual load in metric tons per year (t/yr) from the area-adjusted Upper Dismal Creek watershed under existing conditions. To reach the TMDL target goal (5506.4 t/yr), two different scenarios were run with GWLF (**Table 4.7**). Scenario 1 shows 71.1% reductions to residential, pasture, high-till cropland, barren areas, and abandoned and released mined land. Scenario 2 shows reductions limited to the two land uses contributing the greatest sediment loads, abandoned mine land and barren or transitional areas (80.7%). Scenario 1 was chosen to use for the final TMDL because it has similar reductions on different land uses throughout the watershed. The final overall sediment load reduction required for the South Fork Pound River watershed is 55.2%.

Table 4.7 Final TMDL allocation scenarios for the South Fork Pound River watershed.

Sediment Source	Existing South Fork Pound River Loads t/yr	Scenario 1 Reductions %	Scenario 1 Allocated Loads t/yr	Scenario 2 Reductions %	Scenario 2 Allocated Loads t/yr
Pervious Area					
Row Crop - High Till	246.37	71.1	71.20	0.0	246.37
Row Crop - Low Till	12.51	0.0	12.51	0.0	12.51
Pasture	1119.85	71.1	323.64	0.0	1119.85
Hay	8.71	0.0	8.71	0.0	8.71
Forest	185.21	0.0	185.21	0.0	185.21
Barren	7999.92	71.1	2311.98	80.7	1543.98
Low Density Residential	12.55	71.1	3.63	0.0	12.55
Medium Density Residential	0.19	71.1	0.05	0.0	0.19
High Density Residential	3.22	71.1	0.93	0.0	3.22
Transportation	4.47	71.1	1.29	0.0	4.47
AML	2643.58	71.1	764.00	80.7	510.21
Mining Land Uses[1]					
Extractive	*	*	*	*	*
Reclaimed	*	*	*	*	*
Released	40.28	71.1	11.64	0.0	40.28
Impervious Area					
Low Density Residential	0.94	71.1	0.27	0.0	0.94
Medium Density Residential	0.13	71.1	0.04	0.0	0.13
High Density Residential	6.09	71.1	1.76	0.0	6.09
Transportation	2.58	71.1	0.74	0.0	2.58
Direct Sources					
Channel Erosion	1.22	71.1	0.35	0.0	1.22
Upstream Inputs					
Phillips Creek[2]	1552.68	26.9	1134.94	26.9	1134.94
Permitted Sources					
Mining Permits	64.46		64.46		64.46
Individual Residences	0.17		0.17		0.17
Future Growth			55.06		55.06
Margin of Safety			550.64		550.64
Watershed Totals	**12287.81**	**55.21**	**5503.21**	**55.21**	**5503.77**

[1] An asterisk (*) denotes extractive and reclaimed land uses covered by DMME permits in the impaired watershed.
[2] Reflects the allocated load from Phillips Creek watershed shown in **Table 4.4**

The sediment TMDL for South Fork Pound River includes three components – WLA, LA, and the 10% MOS. The WLA was calculated as the sum of all permitted point source discharges as well as the future load allocation of 1% of the TMDL. The average annual sediment TMDLs for South Fork Pound River are given in **Table 4.8**.

Table 4.8 Average annual sediment TMDL for South Fork Pound River.

	WLA t/yr	LA t/yr	MOS t/yr	TMDL t/yr
South Fork Pound River	**119.69**	**4832.88**	**550.64**	**5503.21**
VAG400005	0.04			
VAG400274	0.04			
VAG400556	0.04			
VAG400368	0.04			
Surface Coal Mining Transient Permits				
1100033	0.14			
1100044	0.05			
1100520	5.02			
1100717	10.46			
1100787	5.56			
1101102	1.20			
1101270	1.29			
1101272	17.32			
1101401	20.48			
1101565	0.43			
1201187	0.41			
1201338	0.81			
1600876	0.24			
1601939	1.05			
Future Growth	55.06			

The maximum daily loads for South Fork Pound River were calculated in the same manner as Lower North Fork Pound River and Phillips Creek daily loads. The annual sediment load for South Fork Pound River had a CV of 0.455. The multiplier estimated for South Fork Pound River was 3.06. The long-term average was the annual TMDL divided by 365 days (15.07 t/day), which when multiplied by the 3.06 results in an MDL of 46.1 t/day. The daily WLA was estimated as the annual WLA divided by 365. The daily MOS was estimated as 10% of the

MDL. Finally, the daily LA was estimated as the MDL minus the daily MOS and the daily WLA. These results are shown in **Table 4.9**.

Table 4.9 Maximum daily sediment TMDL for South Fork Pound River.

	WLA t/day	LA t/day	MOS t/day	TMDL t/day
South Fork Pound River	**0.33**	**41.17**	**4.61**	**46.10**
VAG400005	0.0001			
VAG400274	0.0001			
VAG400556	0.0001			
VAG400368	0.0001			
Surface Coal Mining Transient Permits				
1100033	0.0004			
1100044	0.0001			
1100520	0.0137			
1100717	0.0287			
1100787	0.0152			
1101102	0.0033			
1101270	0.0035			
1101272	0.0474			
1101401	0.0561			
1101565	0.0012			
1201187	0.0011			
1201338	0.0022			
1600876	0.0007			
1601939	0.0029			
Future Growth	0.1508			

4.2 TDS TMDL Allocations

The in-stream water quality endpoint, as established in the Phase I TMDL for Phillips Creek and South Fork Pound River is the 90th percentile of DEQ-monitored TDS concentrations from Lower Dismal Creek at DEQ monitoring station 6ADIS001.24 (369 mg/L). To reach the TMDL target goal, multiple scenarios were run with HSPF. Eight of the scenarios for Phillips Creek are shown in **Table 4.10**. The scenarios explored paralleled those in the original TMDL. Scenario 8 shows reductions that are adequate for reaching the TMDL endpoint. Scenario “0” shows the existing condition. The scenarios focus first on residential (straight pipe and failing septic systems), pre-law mine discharge, and AML sources. Scenarios 2 and 3 explore the impact of reductions to permitted surface mine discharges as compared to reductions to “non-background groundwater." The remaining scenarios examine reductions to both permitted surface mine discharges and "non-background groundwater." The "non-background groundwater" source includes persistent loads to the stream that are not dependent on active rainfall event (*e.g.*, unaccounted-for drainage from abandoned underground mine workings, and slow drainage from fill areas). Scenario 8 is recommended as a starting point during implementation for Phillips Creek.

Table 4.10 Phillips Creek TDS TMDL Re-Allocation.

Scenario	Reductions by Source (%)							Max Ave Daily TDS (mg/L)	Number of Days > 369 mg/L	TDS Load (kg/yr)
	Mine Pond Discharge	AML	Pre-Law Mine Discharge	Road Salt	Residential (Direct)[1]	Non-Background Groundwater[2]	Background[3]			
0	0	0	0	0	0	0	0	1,803	2,192	1,602,766
1	0	100	100	0	100	0	0	1,734	2,192	1,541,677
2	50	100	100	0	100	0	0	1,734	2,183	1,444,562
3	50	100	100	0	100	50	0	867	1,905	797,004
4	95	100	100	0	100	50	0	867	1,756	701,108
5	75	100	100	0	100	75	0	433	311	419,953
6	65	100	100	0	100	79	0	400	1	389,448
7	67	100	100	0	100	79	0	379	1	385,178
8	68	100	100	0	100	79	0	368	0	383,066

1 Includes straight pipes and failing septic systems.
2 Includes persistent loads to the stream, such as, unaccounted-for drainage from abandoned underground mine workings, slow drainage from fill areas, and any load contributed through groundwater that results from human activity.
3 Includes loads from undisturbed forest, and naturally occurring groundwater loads.

For South Fork Pound River **Table 4.11** shows six of the scenarios that were run. Scenario "0" shows the existing condition. Scenario 1 shows the Phillips Creek allocation applied throughout the South Fork Pound River watershed. The remaining scenarios examine reductions to both permitted surface mine discharges and "non-background groundwater" to achieve the water quality endpoint.

Table 4.11 South Fork Pound River TDS TMDL Re-Allocation.

Scenario	Reductions by Source (%)							Max Ave Daily TDS (mg/L)	Number of Days > 369 mg/L	TDS Load (kg/yr)
	Mine Pond Discharge	AML	Pre-Law Mine Discharge	Road Salt	Residential (Direct)[1]	Non-Background Groundwater[2]	Background[3]			
0[4]	0	0	0	0	0	0	0	1,433	2,192	10,087,859
1[4]	68	100	100	0	100	79	0	334	0	2,368,568
2	60	100	100	0	100	72	0	371	3	2,867,082
3	40	100	100	0	100	73	0	371	1	2,942,435
4	41	100	100	0	100	73	0	370	1	2,935,501
5	42	100	100	0	100	73	0	369	1	2,928,547
6	43	100	100	0	100	73	0	368	0	2,921,613

1 Includes straight pipes and failing septic systems.
2 Includes persistent loads to the stream, such as, unaccounted-for drainage from abandoned underground mine workings, slow drainage from fill areas, and any load contributed through groundwater that results from human activity.
3 Includes loads from undisturbed forest, and naturally occurring groundwater loads.
4 These scenarios indicate reductions throughout the watershed (including Phillips Creek). The remaining scenarios apply only to areas outside of Phillips Creek.

The TDS TMDLs for the Pound River include three components – WLA, LA, and the MOS (Implicit). The WLA was calculated as the sum of all permitted point source discharges. The average annual TDS loads for Phillips Creek and South Fork Pound River are given in **Table 4.12** and **Table 4.13**, respectively.

Table 4.12 Average annual TDS TMDL for the Phillips Creek watershed.

WLA			LA[1]	MOS	TMDL
149,444			233,622	Implicit	383,066
Mining Permit Numbers	**NPDES MPIDs**	**Permit WLAs**			
1100033	none	9,903			
1100520	none	18,609			
1100787	none	28,046			
1101272	0001737, 3470068, 3470199, 3470200, 3470259	2,893			
1101565	1239	11,642			
1101760	none	18,020			
1201664	none	110			
1501778	none	203			
1600876	none	60,018			

1 LA includes loads from Road Salt and Background Interflow contributions.

Table 4.13 Average annual TDS TMDL for the South Fork Pound River watershed.

WLA			LA[1]	MOS	TMDL
313,966			2,607,647	Implicit	2,921,613
Mining Permit Numbers	NPDES MPIDs	Permit WLAs			
1100033	none	699			
1100044	none	266			
1100520	none	24,443			
1100717	2670086, 3470155, 3470156, 3470157, 3470158, 3470159, 3470160	50,975			
1100787	none	27,059			
1101102	3470072	5,828			
1101270	none	6,273			
1101272	0001737, 3470068, 3470199, 3470200, 3470259	84,384			
1101401	0005182, 3470286, 3470287, 3470288, 3470289, 3470290, 3470291, 3470293, 3470294	99,764			
1101565	1239	2,087			
1201187	3470069	1,976			
1201338	none	3,931			
1600876	none	1,168			
1601939	0004373, 0004374, 0005819, 0005820, 0006287	5,113			

[1] LA includes loads from Road Salt and Background Interflow contributions.

As noted earlier in this document, the USEPA has mandated that TMDL studies include a daily maximum load in addition to the average annual load. The approach to developing a daily maximum load for TDS is similar to the approach used for sediment. The coefficient of variation was estimated (*i.e.*, the CV was set to 0.6) due to a lack of data. This resulted in a multiplier of 4.0. The results are shown in **Table 4.14** and **Table 4.15**.

Table 4.14 Average annual TDS TMDL for the Phillips Creek watershed.

WLA			LA[1]	MOS	TMDL
409			3,789	Implicit	4,198
Mining Permit Numbers	NPDES MPIDs	Permit WLAs			
1100033	none	27			
1100520	none	51			
1100787	none	77			
1101272	0001737, 3470068, 3470199, 3470200, 3470259	8			
1101565	1239	32			
1101760	none	49			
1201664	none	0			
1501778	none	1			
1600876	none	164			

[1] LA includes loads from Road Salt and Background Interflow contributions.

Table 4.15 Average annual TDS TMDL for the South Fork Pound River watershed.

WLA			LA[1]	MOS	TMDL
860			31,158	Implicit	32,018
Mining Permit Numbers	NPDES MPIDs	Permit WLAs			
1100033	none	2			
1100044	none	1			
1100520	none	67			
1100717	2670086, 3470155, 3470156, 3470157, 3470158, 3470159, 3470160	140			
1100787	none	74			
1101102	3470072	16			
1101270	none	17			
1101272	0001737, 3470068, 3470199, 3470200, 3470259	231			
1101401	0005182, 3470286, 3470287, 3470288, 3470289, 3470290, 3470291, 3470293, 3470294	273			
1101565	1239	6			
1201187	3470069	5			
1201338	none	11			
1600876	none	3			
1601939	0004373, 0004374, 0005819, 0005820, 0006287	14			

[1] LA includes loads from Road Salt and Background Interflow contributions.

This revised TMDL document (addendum) was developed by the Virginia Department of Environmental Quality (VADEQ) and the Virginia Department of Mines, Minerals, and Energy's Division of Mined Land Reclamation (DMLR). The revision is being submitted to the U.S. EPA following on the U.S. EPA Region III approval and the Virginia State Water Control Board (SWCB) adoption of the "Phase I" Powell River TMDL. DMLR took the lead role with these revisions.

Appendix A

Representation of TSS Loads in Coalfield TMDLs

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Phased TMDL Project
Representation of TSS Loads in Coalfield TMDLs

1. BACKGROUND

During development of aquatic life (benthic) TMDLs for Bull Creek, Levisa Fork, Pound River, and Powell River, questions arose regarding the representation of Total Suspended Solids (TSS) loads from permitted mining areas. Due to these questions, as well as other uncertainties and differences of interpretation regarding report narrative, report format, data, and predictive tools, the reports were presented as "phased" TMDLs in accordance with EPA guidance. The TMDL was developed with best available data and information to determine pollution load reductions. Additional monitoring was conducted to aid in resolving the uncertainties in pollutant sources. This report describes the effort to better characterize the TSS (sediment) loads in the models.

The goal of the TSS monitoring project, was to better quantify sediment contributions to the watershed from active mining operations during larger storm events. More specifically, the questions that need to be answered are:

- What is the best approach for representing existing contributions from permitted mining discharges?
- What is the best approach for representing allocated loads (*i.e.*, waste load allocations – WLAs) from permitted mining discharges?

Two approaches have been used for modeling these discharges. The "*Traditional*" approach assumes that the permitted discharges are in compliance with their permits, and that the semi-monthly sampling, required by Virginia's Department of Mines, Minerals, and Energy (DMME) is adequate to describe long-term loading conditions for the discharges in question. The "*Proposed*" approach, assumes that the TSS load from large storm events is not being fully characterized by semi-monthly sampling, with the result that TSS loads from permitted discharges are being under-represented in the TSS TMDL. The TMDLs for the Powell River and Levisa Fork were developed using the *Traditional* approach, while the TSS TMDLs for the Pound River and Bull Creek were developed using the *Proposed* approach.

The difference between these approaches is primarily related to the impact of large storms on sediment delivery from permitted discharges. In order to assess this impact, three sites were identified where auto-samplers, programmed to collect multiple samples during storm events, could be installed. Samples were collected and analyzed for TSS. Stream stage monitors were also installed at these sites, with the intent of estimating flow volumes during storm events. The results were used to assess the overall impact of storm events on TSS loads.

2. SITE SELECTION

Three sites were identified in the Powell River watershed where auto-samplers could be installed on surface mine discharges. The location of these sites is displayed in **Figure 2.1**. The site locations and general conditions of the contributing drainage areas are described in **Table 2.1**. These sites were selected primarily based on being granted permission to access the sites for the purposes of installing and servicing monitoring equipment. As such, there was a reasonable question as to whether they were representative of mine operations in the area. This was evaluated through assessment of land cover conditions in the drainages, as well as analysis of historical water quality data.

Table 2.1 provides a verbal interpretation of land cover, and **Figure 2.2** shows the spatial distribution of the land cover. As it happens, the sites appear to provide reasonable examples of a “worst case” scenario (Outfall A, with significant land disturbance), a “best case” scenario (Outfall B, with large proportion of the drainage reclaimed or undisturbed), and an “average” scenario (Outfall 004, with a significant amount of recently mined, but reclaimed area).

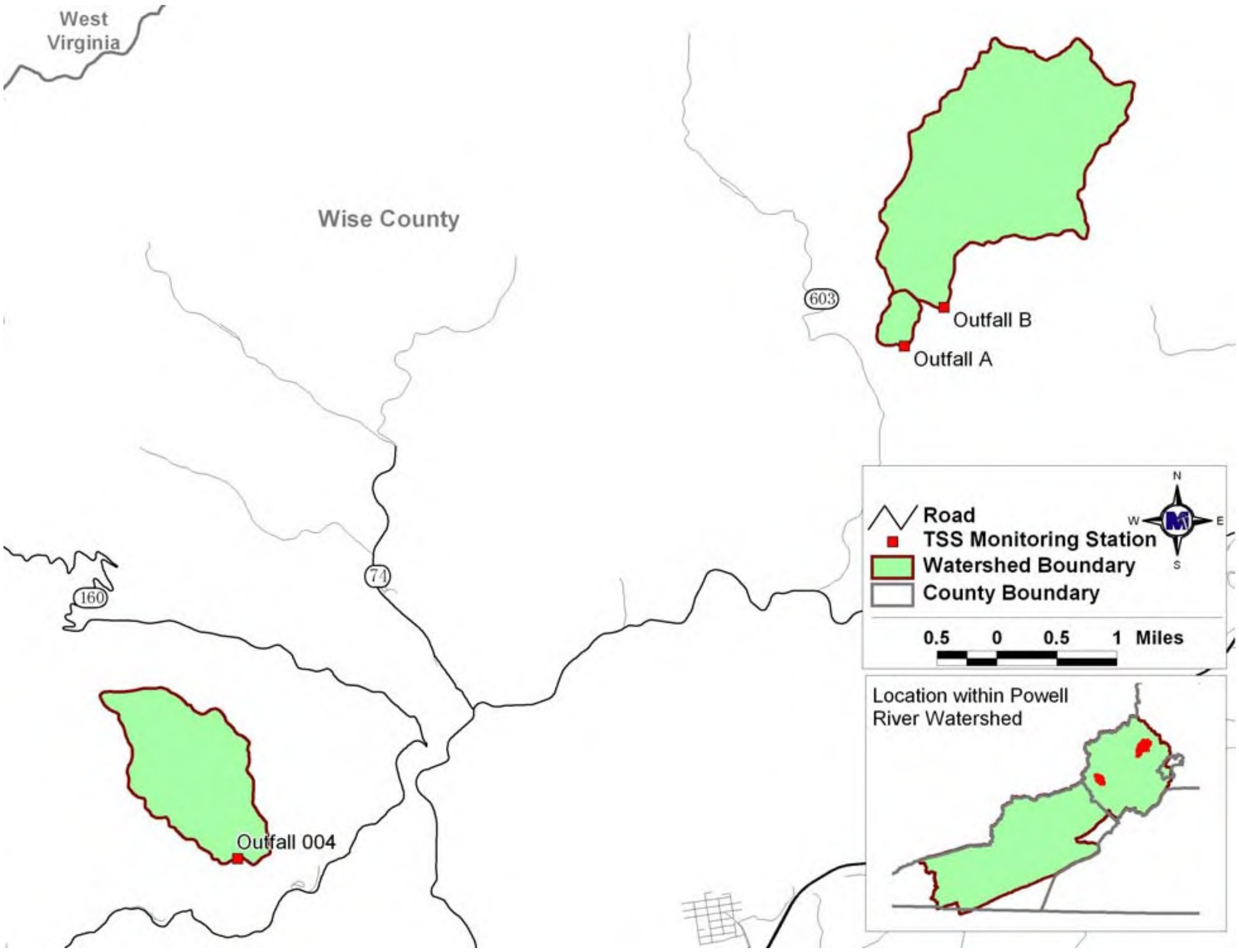

Figure 2.1 Location of Total Suspended Solids (TSS) monitoring sites.

Table 2.1 Description of monitoring sites in the Powell River watershed, where auto-samplers were installed for assessing TSS delivery during storm events.

MPID	Outfall	LAT	LON	Description of Drainage.[1]
0003400	004	36.8878	-82.8179	Approximately 760 acres, on Bearpen Branch, with approximately 30% undisturbed, 65% recently reclaimed, and 5% active mining.
0005433	A	36.9526	-82.7168	Approximately 85 acres, on a tributary to Canepatch Creek, with approximately 5% undisturbed and 95% active mining.
0005578	B	36.9575	-82.7108	Approximately 1,780 acres, on Canepatch Creek (headwaters), with approximately 50% undisturbed, 30% reclaimed, and 20% active mining.

[1] Land cover distribution estimates are based on visual assessment of 2011 aerial photos. “Undisturbed” areas may be reclaimed, but appear to have mature forest cover.

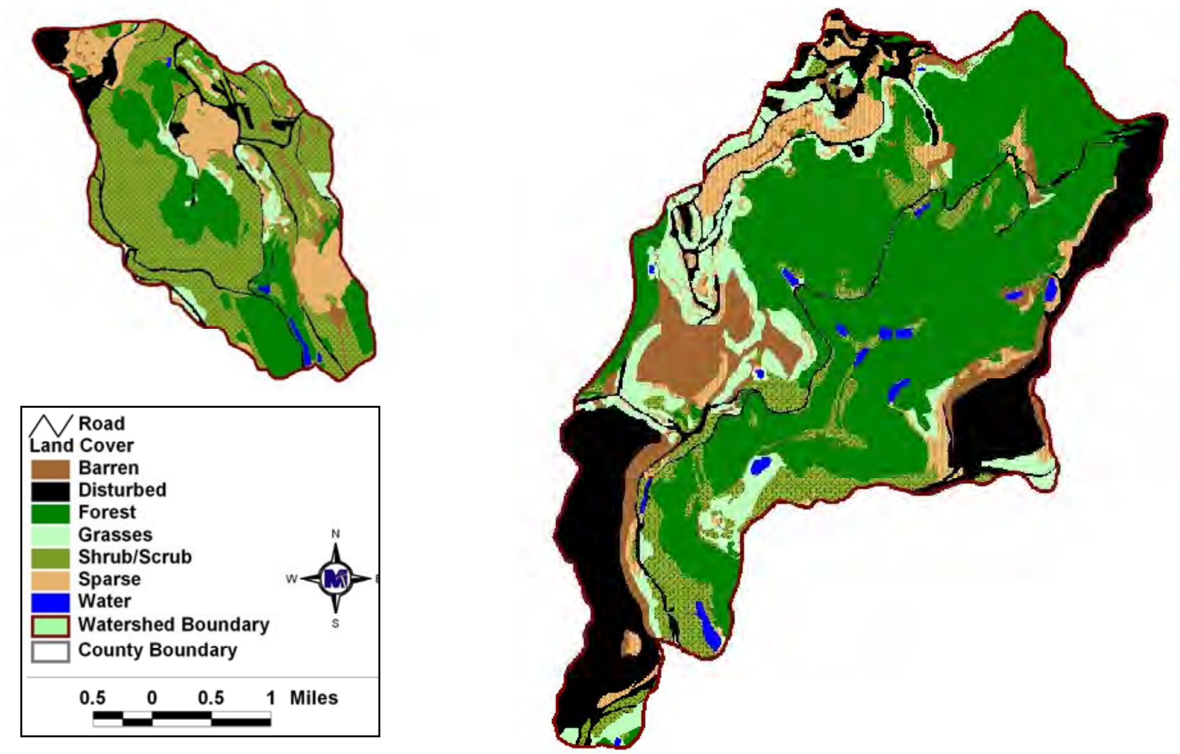

Figure 2.2 Land cover in Total Suspended Solids (TSS) monitoring site drasinages.

Historical monitored data were analyzed to further assess the representativeness of these sites. Samples collected by the permitted mining operators at the three sites were compared with data collected at 424 other permitted sediment control sites in the Powell River watershed. **Figure 2.3** shows a comparison of conditions at permitted surface mine discharges throughout the Powell River watershed. This plot uses all available data from 1987 through 2013. Percentile ranks of the TSS data from the three selected monitoring sites compared favorably with percentile ranks from the remaining permitted sites, especially the 10th, 25th, 50th and 75th percentiles, however, all of the sites in question had lower 90th percentile concentrations. Since the sites in question have only been monitored in more recent years (2005 – 2013), and since sediment delivery can fluctuate widely, dependent on rainfall conditions, it was considered a more evenhanded comparison to only include data collected on the same dates in the comparison. The results of this analysis is presented in **Figure 2.4**. Overall, the sites seem reasonably representative of conditions in the area.

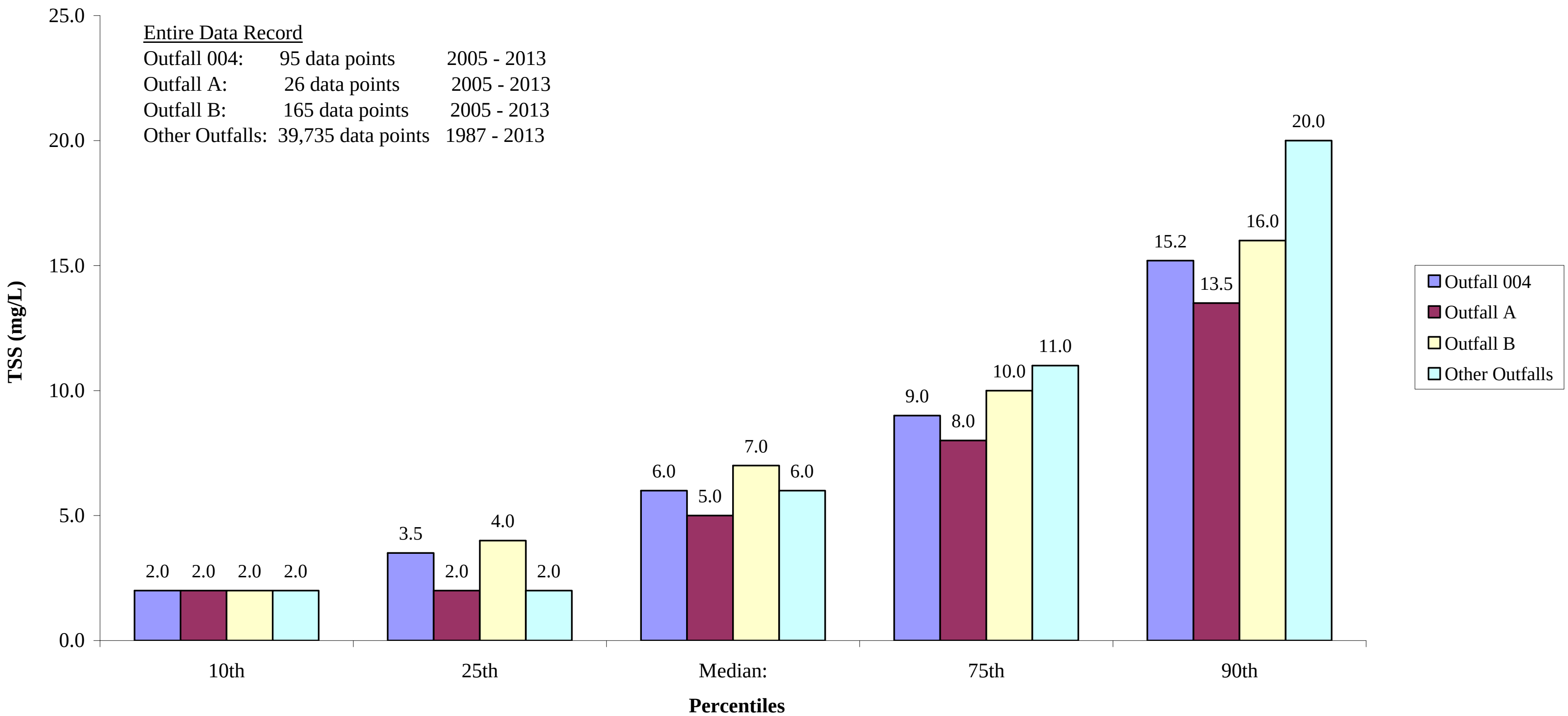

Figure 2.3 **TSS data from selected DMME permitted sites in the Powell River Basin compared to data from all of the remaining permitted sites in the Powell River basin, using all available data from 1987 to the 2013.**

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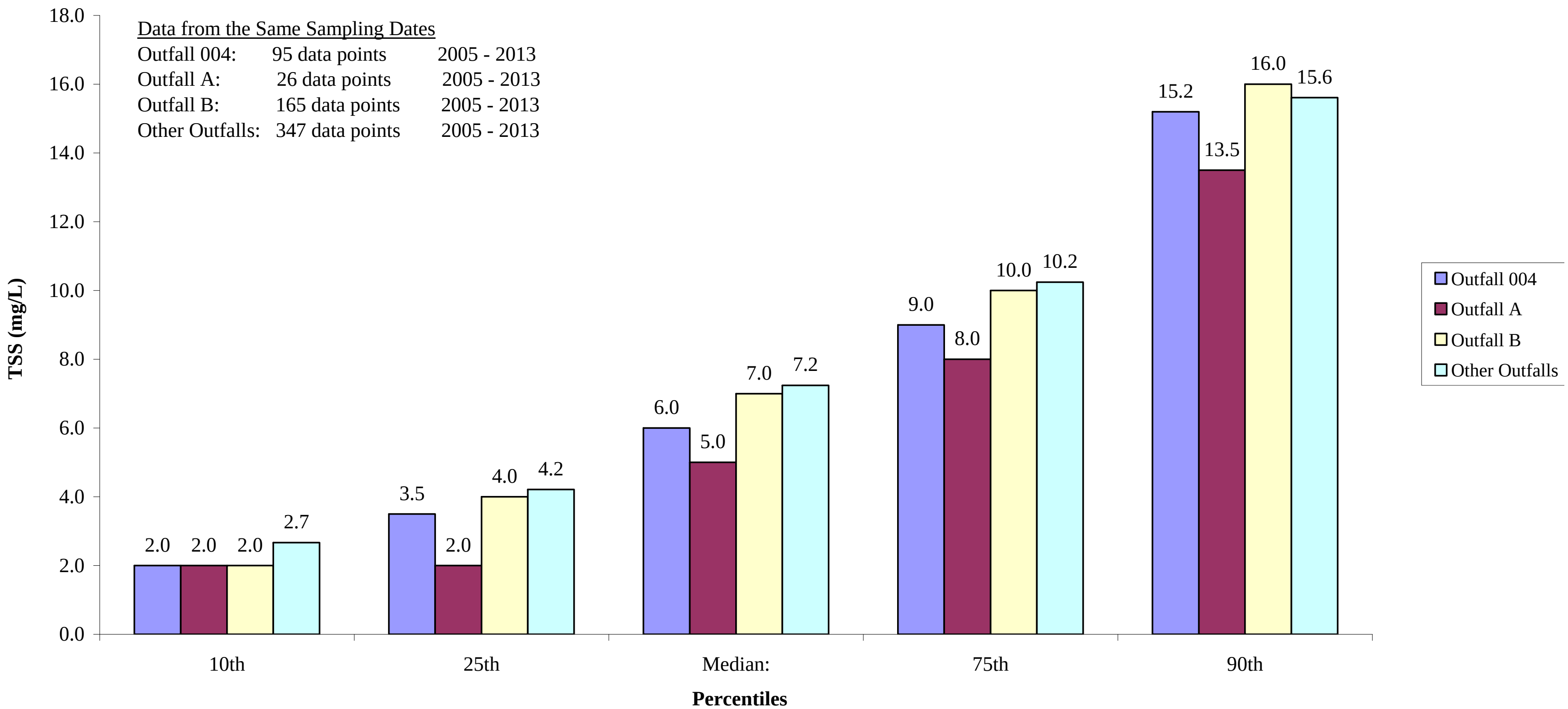

Figure 2.4 **TSS data from selected DMME permitted sites in the Powell River basin compared to data from all of the remaining permitted sites in the Powell River basin, on the same monitoring dates.**

3. MONITORING DESCRIPTION

The goal of the monitoring effort was to assess the existing monitoring approach, and the model estimates, using a more comprehensive dataset. The focus was on the storm discharge from sediment ponds of active mines. This was accomplished through the use of automated samplers, rain gages, and stream gages. Each sediment sampling station consisted of a data collection platform (DCP) with pressure transducer to record stream levels, an auto-sampler, and a rain gauge (**Figure 3.1**). The automated samplers were configured to collect 24 individual samples during storm events. The samplers used were equipped with a liquid level sensor, which was designed to initiate the sampling routine when the stream level increased by a prescribed amount, as determined through trial and error on site. Upon initiation of a sampling event, sampling occurred at 30-minute intervals for the first 3.5 hours of the event, then continued at 3-hour intervals until all 24 sample bottles were utilized. One sampler was deployed at each of the three sites discussed earlier in this report.

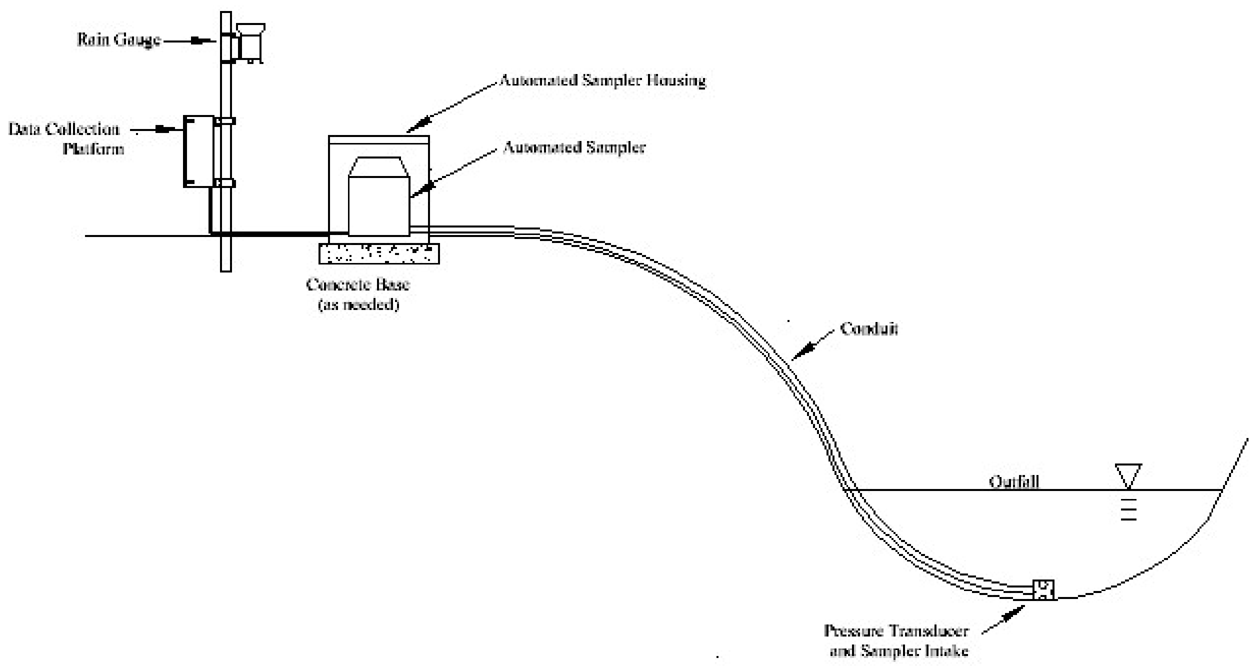

Figure 3.1 Sediment sampling station schematic, showing data collection platform connected to auto sampler, pressure transducer, and rain gauge.

Due to scheduling delays and equipment problems, the stream level measuring equipment (DCP and pressure transducer) were not installed until after the first seven of fourteen sampling events had occurred. One site (Outfall A) was equipped with a compound weir (**Figure 3.2**), to concentrate flow and provide an engineered structure for flow monitoring. Additional equipment malfunctions resulted in data being successfully collected during only four events.

Figure 3.2 Outfall A after weir installation. Data collection platform visible on left. Plastic sheeting is peeled back to expose structure for the photograph.

After each storm event, samples were collected from the auto-samplers and the auto-samplers were reset with new bottles. The collected samples were delivered to the laboratory for processing. The samplers were removed during the month of April while the flow monitoring equipment was being installed. During each site visit, a grab sample was collected and a flow measurement was taken.

4. RESULTS

As discussed earlier in this report, the drainages contributing to these sample sites varied in size and land cover. The effects of these differences can be seen in the flow response. **Table 4.1** shows the results of instantaneous sampling conducted during site visits. These measurements represent base flow conditions at each site. As might be expected, flow volume increases with drainage basin size, but the baseflow TSS concentrations are similar.

Table 4.1 Instantaneous flow measurements and TSS from grab samples.

Date	Outfall 004		Outfall A		Outfall B	
	Flow (CFS)	TSS (mg/L)	Flow (CFS)	TSS (mg/L)	Flow (CFS)	TSS (mg/L)
3/4/2013	2.401	------	0.004	------	5.415	------
3/8/2013	------	<5.0	0.13	2.0	7.272	17.0
3/14/2013	2.638	2.0	0.064	2.0	5.288	3.0
3/21/2013	1.292	5.0	0.067	5.0	7.708	7.0
3/28/2013	1.078	<2.0	0.107	<2.0	------	6.0
5/2/2013	1.71	8.0	------	------	5.236	2.5
5/9/2013	1.43	2.0	0.055	6.0	5.973	2.0
5/16/2013	0.869	2.0	0.036	3.0	4.492	6.0
5/23/2013	1.323	6.0	0.017	4.0	4.673	5.0
6/5/2013	0.92	5.0	0.005	<2.0	2.213	2.0
6/11/2013	1.365	8.0	0.095	7.0	8.29	10.0
6/17/2013	0.893	12.0	0.022	7.0	3.352	3.0
6/24/2013	0.919	17.0	0.024	6.0	4.393	11.0
7/1/2013	1.806	7.0	0.108	6.0	9.008	8.0
Average[1]	*1.4*	*6.0*	*0.06*	*4.2*	*5.6*	*6.3*

[1] For the purpose of calculating averages, non-detects were estimated at half of the detection limit.

Preliminary assessment of the TSS data collected from the auto-samplers showed that very few events had TSS values exceeding the 70 mg/L standard (**Table 4.2**). Flow-weighted concentration was only calculated for a limited number of events due to data limitations. Further, flow-weighted concentration calculations were only performed on events associated with outfall A, where the engineered structure (weir) was installed, as the rating curves developed for outfalls B and 004 were not considered accurate enough for use without further data collected for validation. Determining a relationship between rainfall and flow in order to make approximate flow-weighted calculations was unsuccessful. Correlations between TSS and rainfall were also unclear, though various methods were explored.

Six of the seven storm events that resulted in maximum TSS values above the 70 mg/L standard were associated with outfall A. The area that drains to outfall A contains a much higher percentage of recently disturbed land than either of the other two outfalls, so it is not surprising that it should have higher TSS concentrations as well. However, a weir was installed at this site on May 2, 2013, and the response in TSS concentrations to similarly sized storms appeared to have changed after the installation of the weir. This discrepancy led to further analysis.

Table 4.2 Total suspended solids (TSS) and rainfall data from sampling events. Flow-weighted concentration is provided where calculations were possible.

Event Date	Max TSS (mg/L)	Average TSS (mg/L)	Peak 5-min Rainfall (in)	Total Rainfall (in)	Flow-Weighted Concentration (mg/L)
Outfall A (weir site)					
3/5/2013	**150**	41.9	0.04	1.05	
3/11/2013	13	6.0	0.02	0.44	
3/18/2013	**83**	21.7	0.05	0.96	
3/24/2013	55	10.3	0.07	1.06	
5/18/2013*	**75**	22.8	0.20	1.15	31
5/24/2013*	38	9.3	0.04	0.23	13
6/5/2013*	**890**	138.2	0.36	1.11	
6/17/2013*	**317**	49.7	0.09	1.75	
6/27/2013*	**1,250**	243.0	0.16	1.39	685
Outfall B					
3/5/2013	56	23.5	0.04	1.23	
3/11/2013	9	6.8	0.02	0.46	
3/19/2013	19	9.2	0.06	0.94	
3/24/2013	12	6.5	0.07	1.11	
5/5/2013	11	5.3	0.02	1.20	
5/20/2013	18	7.8	0.23	0.66	
6/5/2013	22	15.5	0.29	1.20	
6/17/2013	85	46.6	0.12	1.80	
6/27/2013	**161**	75.6	0.16	1.36	
Outfall 004					
3/5/2013	33	8.3	0.04	1.10	
3/11/2013	8	3.7	0.02	0.54	
3/18/2013	12	7.4	0.06	0.96	
3/24/2013	7	3.4	0.06	1.07	
5/7/2013	7	3.8	0.04	0.27	
5/10/2013	49	6.2	0.01	0.18	
6/10/2013	26	12.5	0.01	0.05	
6/17/2013	47	12.6	0.15	1.46	
6/27/2013	63	21.0	0.10	0.48	

* Indicates measurements taken after installation of the weir.

As can be seen in **Figure 4.1**, before the installation of the weir there was consistently seen a ‘build-up’ of sediment concentration in the flow before reaching a peak concentration and then falling back off. This is the expected response for a system where sediment builds up in a retention or detention basin during rainfall events, with the concentration in the outfall water increasing and then falling back off. What is seen after the weir installation is an immediate peak of TSS concentration in conjunction with rainfall events (**Figure 4.2**), which is indicative of localized soil disturbance.

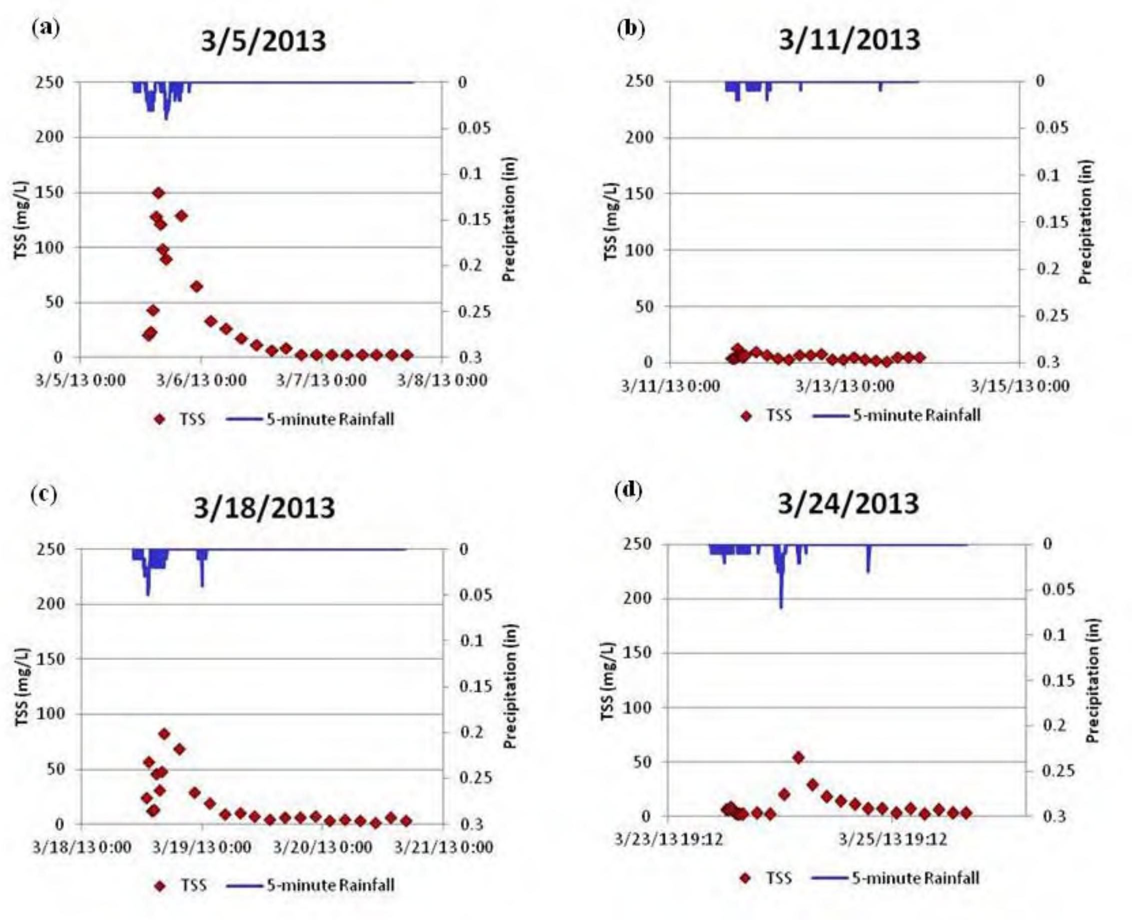

Figure 4.1. Total suspended solids (TSS) and 5-minute rainfall for the four monitored storm events prior to the installation of the weir.

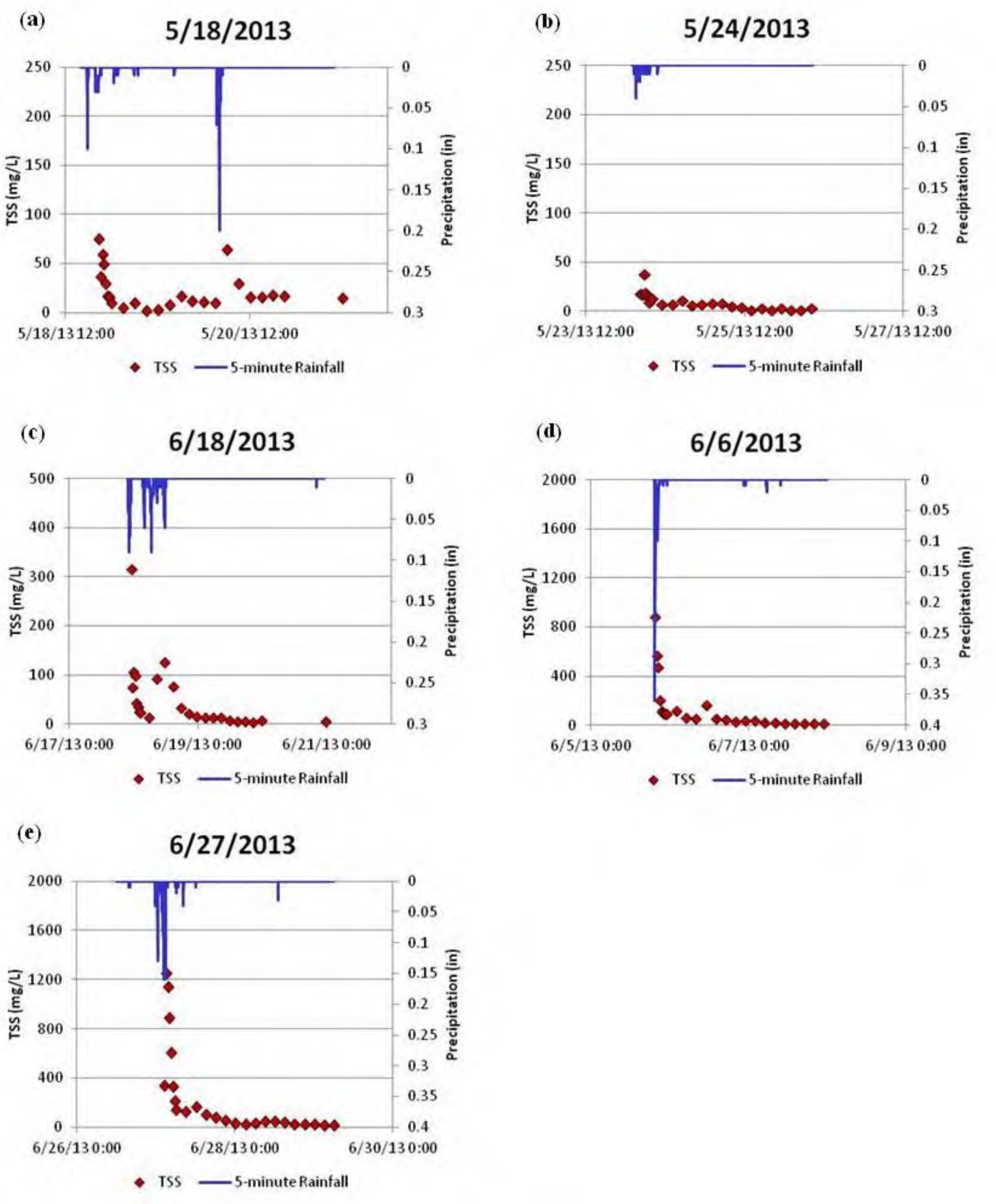

Figure 4.2. Total suspended solids (TSS) and 5-minute rainfall for the five monitored storm events after installation of the weir.

During the weir installation, an earthen berm was created to hold back the water flowing from the outlet. This obstruction was removed after installation of the weir was completed, however, the monitoring site at which all of the sediment samples were taken was located between the berm location and the weir. Changes in the response in TSS to rainfall events in the watershed indicate that the land disturbance associated with the construction and removal of the temporary berm have impacted the TSS measurements being taken at outfall A. As the TSS concentrations measured after the installation of the weir include sediment from local disturbance as well as sediment being carried out of the storm pond, it is recommended that the data from these sampling events be viewed as questionable.

One goal of this effort was to assess the usefulness of historical DMME monitoring of permitted discharges in representing existing TSS conditions. **Table 4.3** shows a comparison of DMME data to data collected during this study. As would be expected, the DMME averages are higher than the baseflow grab samples collected during this study, but lower than the average maximum TSS values collected during storm events. For Outfalls 004 and B, the DMME data is close to the average storm TSS recorded. However, for Outfall A, the DMME value is considerably less than the average storm TSS. In order to account for possible effects from the weir installation, the pre-weir data was assessed separately. The average storm TSS for Outfall A using these data is more comparable to the DMME data, however, the values at the other two outfalls (not impacted by the weir installation) also drop significantly, indicating that the storms monitored after the weir installation had a greater impact on TSS delivery.

Table 4.3 Comparison of DMME long-term monitoring to storm-event monitoring.

Data Source	Outfall 004 TSS (mg/L)	Outfall A TSS (mg/L)	Outfall B TSS (mg/L)
DMME Monitoring [1]	8.4	8.5	19.8
Baseflow Average [2]	6.0	4.2	6.3
Average Storm Max [3]	28	319	44
Average Storm [4]	9	60	22
Average Storm Max: Pre-Weir [5]	*15*	*75*	*24*
Average Storm: Pre-Weir	*6*	*20*	*12*

[1] "DMME Monitoring" data are flow-weighted averages based on all available permit compliance monitoring data.
[2] "Baseflow Average" represents the average of the TSS values recorded for during baseflow conditions.
[3] "Average Storm Max" represents the average of the maximum TSS values recorded for each storm.
[4] "Average Storm" represents the average of all TSS values recorded for during storms.
[5] "Pre-Weir" indicates that only data collected prior to the weir installation were used.

5. RECOMMENDATIONS

The data available from this monitoring effort is limited, however, it does provide insight toward answering the two questions stated earlier in this report.

- What is the best approach for representing existing contributions from permitted mining discharges?

- What is the best approach for representing allocated loads from permitted mining discharges?

As stated earlier, two approaches have been used for modeling these discharges (*Traditional* and *Proposed*). These recommendations will examine each, in light of the additional data that the monitoring proveds.

5.1 Existing Permit Loads

Both the *Traditional* and *Proposed* approaches calculate a load that is intended to represent long-term, average conditions across the broad spectrum of climate and land use circumstances that are encountered among permitted dischargers. The *Traditional* approach accomplished this by using long-term monitoring data to calculate flow-weighted average TSS concentrations, and apply them to flow volumes modeled from active mine areas. These long-term average concentrations are, typically, less than the permitted 70 mg/L. **Table 4.3** showed how this approach compared to the storm event data that was monitored during this effort. Keeping in mind that the goal is to provide a long-term average representation of varied conditions, this approach may be reasonable, but, arguably may be biased a bit low, particularly as compared to the "worst-case" scenario of Outfall A.

The *Proposed* approach calculated a load based on modeling conditions in the permitted areas (extractive, reclaimed, and released). This approach yields an annual sediment load from each land use, an annual runoff volume from each land use, and annual groundwater volume that is delivered to the stream. Using these values from the Bull Creek TMDL, a long-term average TSS concentration was calculated at greater than 2,000 mg/L. While it is conceivable that a peak TSS concentration could reach this level, based on the monitoring effort conducted for this study, it is, arguably, too large a concentration to represent long-term, average conditions.

The *Traditional* approach appears to be potentially biased low, while the *Proposed* approach appears to be biased high. A reasonable compromise, based on this monitored data, would be to model the existing load from permitted mine sources at the permitted level of 70 mg/L. This value is higher than the average storm event concentrations calculated for each site (**Table 4.3**), and is arguably a conservative estimate for the long-term average condition. This concentration should be applied to the average annual flow volume from disturbed areas to estimate the existing TSS load.

5.2 Allocated Permit Loads

Both the *Traditional* and *Proposed* approaches use the permitted TSS concentration (70 mg/L) to calculate the allocated permit loads. The *Traditional* approach applies this concentration to the average annual flow volume from disturbed areas to estimate the allocated TSS load. The *Proposed* approach applies this concentration to the average annual flow volume from all permitted areas. While the *Proposed* approach represents the "worst-case" scenario in terms of water quality, where all permitted mine areas within a watershed are disturbed at the same time, it does not represent a "typical" scenario. In fact, this condition has not been seen during any known TMDL development. Since surface mine operators are only permitted for discharge from storm ponds, as compared to all runoff from permitted areas whether actively being mined or not, and since mine operators only install ponds in conjunction with mine operations, TSS loads associated with runoff from non-disturbed lands should remain in the load allocation (LA), rather than the waste load allocation (WLA). While this may be somewhat limiting to the mine operators, it is protective of water quality.

5.3 Conclusions

In the current state of knowledge, regarding TSS delivery from surface mine operations, the following recommendation is offered.

- Both existing and permitted conditions should be modeled at the permitted level of 70 mg/L. This concentration should be applied to the average annual flow volume from disturbed areas to estimate TSS loads.

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Appendix B

Phased TMDL: Bull Creek Watershed Total Dissolved Solids Evaluation, September 17, 2013

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Phased TMDLs:
Total Dissolved Solids Evaluation for
Bull Creek and South Fork Pound Watersheds

Submitted to

Virginia Department of Mines, Minerals and Energy
Division of Mined Land Reclamation
Post Office Drawer 900
Big Stone Gap, VA 24219

September 17, 2013

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Prepared by:

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3154 State Street
Blacksburg, VA 24060

MAPTECH

NATURAL RESOURCE SOLUTIONS THROUGH *Science* AND *Engineering*

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Appendix Tables

PHASED TMDLS:

Total Dissolved Solids Evaluation for

Bull Creek and South Fork Pound Watersheds

1. Summary

MapTech, Inc. was contracted to furnish the necessary labor and resources to accomplish Task 8: Utilizing existing data and the additional data collected during the "phased" monitoring, provide the necessary evaluation, modeling, and technical services to complete revisions to each of the four "phased" TMDLs. Data collected as well as existing data were to be analyzed to determine the necessary course of action for the TMDL. MapTech will recommend a course of action based on an assessment of all available data.

The work documented here evaluates pre-existing Total Dissolved Solids (TDS) data, and data collected in 2012-2013 from mine springs in the Bull Creek watershed. The objective was to uncover any relationships between mining activities and in-stream TDS concentrations for use in other watersheds.

- There is a seasonal trend in spring flow is: low in autumn, moderate in early winter, and highest in late winter.
- The TDS concentration in mine springs decreases with flow increase.
- The volume of a spring primarily controls its TDS load.
- Large-volume springs provide the majority of the TDS load.
- The dominant TDS load springs in the Bull Creek watershed are Up and Down Belcher, Burnt Hollow and HMBC.
- Spring elevation has a minor impact on flow volume and TDS load.
- Recent precipitation tends to increase TDS load at low flows. At high spring flows the relationship disappears.
- The volume of a spring tends to be larger from functional hydrologic islands with large footprints and volumes.
- Prominent abandoned mine scars above a mine spring dilute the TDS in springs but add substantially to the volume of the spring. Thus AML features lead to high TDS load.
- In the Bull Creek watershed, there is not a clear relationship between mine parameters and TDS load and flow volume as there is for hydrologic island footprint.

-

2. Background

2.1 Groundwater Flow

Topography, geologic structure, and stratigraphy control groundwater flow patterns. The discussion of the interrelationships is based on various sources in Callaghan et. al. (2000) and USEPA (1980).

Groundwater flow is divided into shallow, intermediate, and deep systems. The shallow flow system transports groundwater only short distances and rapidly responds to precipitation and other environmental changes. The lower, intermediate flow systems travel up to thousands of feet with response times of months to years. The deep flow systems transport groundwater up to tens of miles with response measured in decades to centuries (Freeze & Cherry 1979; Kleinmann, 2000).

Shallow groundwater flow systems typically exist near the land surface and in the vicinity of surface-drainage features. The depth of shallow groundwater circulation below the land surface is typically ten to sixty feet. The travel time is, in general, a few weeks to a few years after entry. The groundwater drainage divides of shallow flow systems usually coincide with surface water divides, and can be approximated from topographic maps. Variations in flow quantity and quality are more dependent on daily and seasonal climatological fluctuations. Meanwhile, intermediate and deep flow systems deviate progressively from shallow systems in every respect with the degree of difference depending upon depth.

In the Bull Creek watershed, shallow flow system can be thought of, in general, as occurring within isolated hydrologic islands within the steep-sided hills. The uppermost component of this flow system consists of infiltrated rainwater flowing through unconsolidated regolith covering the hill surfaces and slopes. It can be perched above low-permeability strata. The lower surface flow component found within the hill core is fed by the upper component through faults and porous strata. Recharge of hydrologic islands is completely from within the hydrologic island. Depending on the presence of low-permeability strata, discharge may be from springs in valley walls above local streams, or to local streams directly.

The intermediate flow system flows beneath two or more hydrologic islands and discharges in valleys above it. It is recharged by the shallow flow systems through faults and by its recharge area at the drainage basin divide.

The deep flow system lies below the hydrologic islands and the intermediate flow system. Recharge is from major drainage basin divides and leakage from many of the shallower systems.

2.2 Total dissolved solids (TDS)

Total dissolved solids (TDS) refer to the total dissolved solids content of a water sample. It is distinct from suspended solids consisting of silt and other fine ore material, which remains in suspension for a prolonged period and is retained upon passing through a fine filter. Electrical conductivity (EC) is a numerical expression of the ability of aqueous solution to carry an electric current. High level of mineralization is a typical characteristic of many coal mining discharges. In most cases, a direct relationship between conductivity and TDS can be established. This makes determination of TDS easier as conductivity can be measured readily in the field. The following relationship exists for Australian surface waters.

$$\text{TDS (mg/L)} = 0.62\ \text{EC}\ (\mu\text{S/cm})$$

The electrical conductivity for mine water can be substantially high due to the presence of dissolved salts. Where tap water has a conductivity of 60–100 (µS/cm) and river water ranges from 200–800 (µS/cm), mine water typically ranges from 1,000–10,000 (µS/cm). This translates into TDS ranges of 37-62 mg/L (tap water), 124-496 mg/L (river water), and 620-6,200 mg/L (mine water). Thus, the transition from fresh water to mine water is here chosen to be **620 mg/L**, the lower end of the mine water range. In a general sense fresh water tends to have TDS less than 1,500 mg/L[1].

2.3 TDS Sources

TDS originates from the dissolution of chemicals in the regolith which the groundwater contacts. Shallow groundwater flow is through the zone of highly weathered regolith. Weathering has removed most soluble minerals so this groundwater tends to be low in mineral matter and, thereby low in TDS (< 20 mg/L; Perry, 2000).

Shallow groundwater flow in the hill core may contain significant TDS if it circulates through un-weathered calcareous strata. If confined above a low-permeability layer, hill-core groundwater mounds and flows laterally, albeit slowly, to mix with flow from the weathered regolith groundwater into the adjacent valley. Intermediate groundwater flow also tends to become mineralized and behave similarly although it is found at greater depth.

1 Ela, Wendell P., *Introduction to Environmental Engineering and Science,* Prentice Hall, 3rd ed. 2007.

The deep groundwater flow system contains highly mineralized water naturally at depths of less than 500 feet. The uppermost zone is characterized by calcium bicarbonate water which chemically grades to NaCl-rich brine in the deepest level.

For pre-mined groundwater, there is a direct relationship between the amount of calcareous material in the overburden and the alkalinity, conductivity and pH (Callaghan et. al., 2000). On the other hand, mine drainage water quality is largely determined by sulfides and carbonates even though they usually constitute only a few percent of the rock mass (Perry, 2000). Mine drainage water quality is often moderated by mixing with shallow groundwater. The degree of mixing is important because groundwater from the weathered zone has low TDS and little alkalinity while groundwater from deeper strata and mines has much higher alkalinity and TDS.

2.4 Precipitation

In the study area, the infiltration rate is high enough to consistently flush groundwater through the shallow rock strata from recharge to discharge points. In general, 32% of the average precipitation infiltrates the groundwater system. Twenty percent is lost through evaporation and transpiration. About 26% runs off to surface waterways (Callaghan et. al., 2000). The vast majority of groundwater circulates in the fractured near-surface bedrock, along stress-relief fracture networks, open joints, and within the weathered regolith zone.

2.5 Mine Outflow

The study area is in the eastern edge of the southwest Virginia coal fields. Because of the high topographic relief, undisturbed groundwater systems are of small areal extent. Topographic highs are recharge areas. Water infiltrates the regolith and moves laterally and downward through bedrock fractures. With depth and decreasing permeability, most water moves laterally along the flat-lying bedding planes or through coal seams until it encounters fractures or more permeable rock to move downward. The pathways are stair-steps through the depths. But, topographic differences entrain groundwater causing it to conform to the topography, rising under and within hills and dropping below valley bottoms.

Mines located above stream levels serve as free drains and highly permeable aquifers. They often produce large man-made springs at mine openings (Callaghan et. al., 2000)

In the coal fields of southwest Virginia, coal seams have higher transmissivity than other rock types. Most rock layers are permeable to a depth of about 100 feet. Below 200 ft, on the other hand, only coal seams have measurable permeability. Therefore, at depth, most lateral groundwater flow is through coal seams (Kleinmann, 2000).

Potential mine water sources include precipitation/infiltration through the overburden into the mine, and groundwater infiltration of the mine. In mined areas rainwater infiltrates the land surface and may mix with resident groundwater. Interconnected underground workings act as man-made aquifers with high conductivities. In the flat-lying sedimentary rocks of the eastern bituminous coal measures which includes the study area, underground mining is routinely accompanied by overburden movement, fracturing, and separation along bedding planes. This increased permeability leads to more rapid groundwater flow.

In mined lands, water quality (including TDS) is directly related to the flow path, the dissolution of minerals encountered by the groundwater, and the contact time of the water in the rock. High TDS indicates the presence of calcareous strata, probably near the sampling point, within the groundwater flow path for that water.

In underground mines, recharge results in partial to complete flooding after closure. Recharge rates are controlled primarily by overburden thickness. Rates vary from 0.8 gpm/acre for shallow (< 250 ft) cover, to 0.05 gpm/acre or less under thick cover (Perry, 2000).

2.6 Mine Water

The flows that were monitored in the Bull Creek watershed are referred to as “mine springs”. Some emerge from culverts that are connected directly to mines. Others are seeps issuing from hillsides that are also expected to derive their water from mines.

In areas that have experienced underground mining the source for mine water is essentially from seepage of the excavated area of the mine. During mining water is collected in underground sumps with a nominal retention time. The quantity of the mine water greatly depends on the level of the groundwater table and the ground conditions. The quality of the mine water varies widely from mine to mine depending upon the local conditions. The main pollutants of mine water are dissolved minerals (TDS) from the aquiferous rock strata. A typical range for the mine water total dissolved solids is 500 - 2000 mg/L. These dissolved minerals give high hardness to the water. The major pollutants associated with coal mining are suspended solids, dissolved salts (especially chlorides), acidity and iron compounds. These are also the main concern in springs that issue from abandoned mines (Kleinmann 2000).

Mining practices may generally be divided into surface and underground mining. The latter, used in the study area, takes on a variety of different forms (**Figure 2.1**).

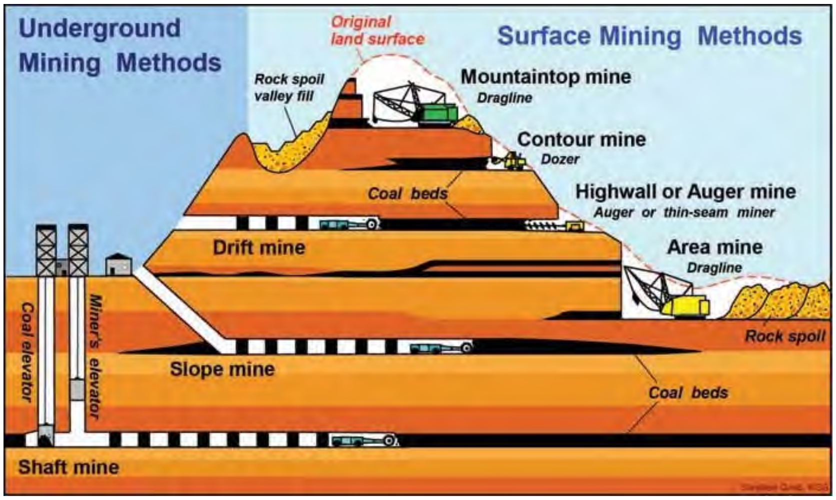

Figure 2.1 Surface versus underground mining (U. of KY 2013).

3. Bull Creek Watershed and Monitoring

The study area is the Bull Creek watershed for which a TMDL has been partially completed. The watershed is within the southeastern edge of the Appalachian Coal Basin. The topography is characterized by many steep-sided hills carved by steep-gradient dendritic streams (**Figure 3.1**).

Coinciding with the watershed's name, the main stream in the area is Bull Creek. It appears to be formed by the union of Jess Fork and Deel Fork. Mine spring HMBC was monitored on Bull Creek and two were monitored on Deel Fork: Deel Up and Deel Down. Two were also monitored on the Bull Cr. tributary Belcher Branch: Up Belcher and Down Belcher. Additional springs were monitored on other tributaries to Bull Creek: Charlie Up and Charlie Down on Big Branch, Cove Hollow on Cove Hollow stream, and Burnt Hollow on Burnt Popular Fork. Nine springs in all were monitored on the steep valley walls near streams in the Bull Creek watershed.

TDS, temperature, pH, dissolved oxygen, conductivity and flow were monitored at the springs. Sampling occurred bi-monthly over the six month period from September 2012 to February 2013. Spring flow varied from 0.0 to 6.8 cfs (cubic feet per second) and averaged 0.6 cfs. Most of these springs tend to have a slightly basic pH ranging from 6.5 to 8.4. Charlie Up and Up Belcher fluctuated from slightly acidic to slightly basic, while Burnt Hollow was consistently slightly acidic, 6.5 – 7.0, suggesting a moderate difference in bedrock chemistries.

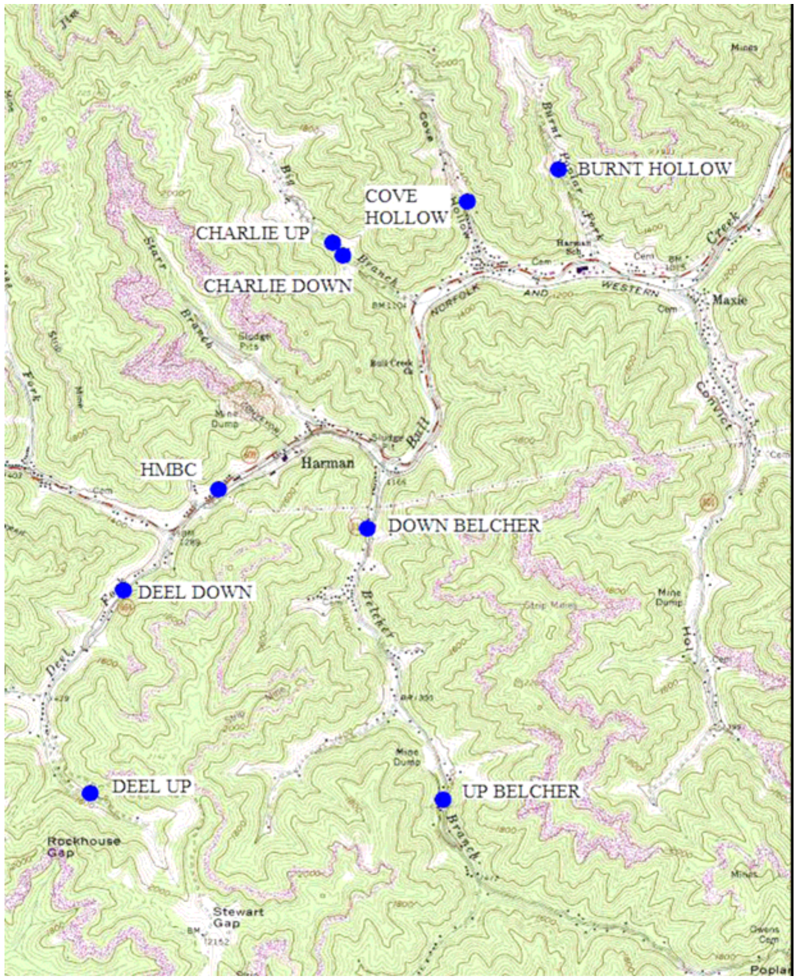

Figure 3.1 Sample locations in the Bull Cr. watershed (REI Consultants 2013).

3.1 Monitored TDS

TDS due to surface sources or transported by streams in the Bull Creek watershed is not considered in this section. TDS samples were collected from mine springs precluding input from overland TDS.

3.2 Seasonal trend

The concentration of TDS (mg/L) trended downward over the six-month sampling period. This period covered the typical low flow of autumn and early winter months, that is followed by increased flow accompanying increased rainfall and thawing in February. But, as to be discussed later, this period's precipitation was abnormal. Nevertheless, flow increased and TDS trended downward. The flow and TDS concentration for the HMBC spring is shown in **Figure 3.2.** For the HMBC spring the TDS concentration dropped 28% while the flow increased 270%.

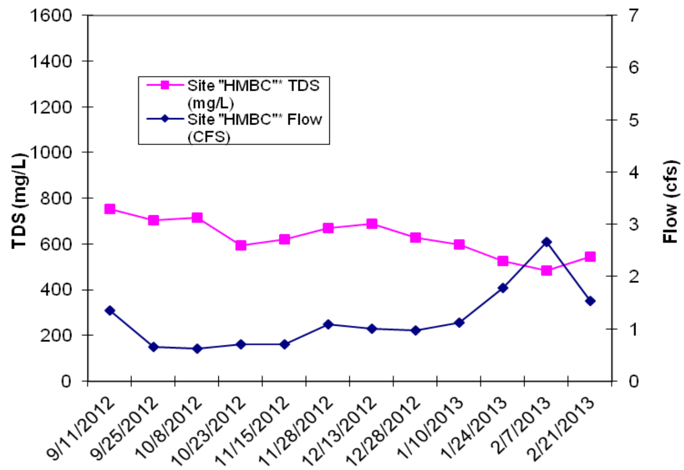

Figure 3.2 Recent TDS and flow trends at the HMBC spring.[2]

The TDS concentration trend for all stations is provided in **Figure 3.3**. With the exception of Deel Up (dark blue line), all springs show a decline in TDS concentration over the sample period. At the same time, the volume of the springs increased (**Figure 3.4**). Deel Up has very low flow and TDS. Consequently, its deviation from the general pattern is of negligible importance.

2 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[HMBC]".

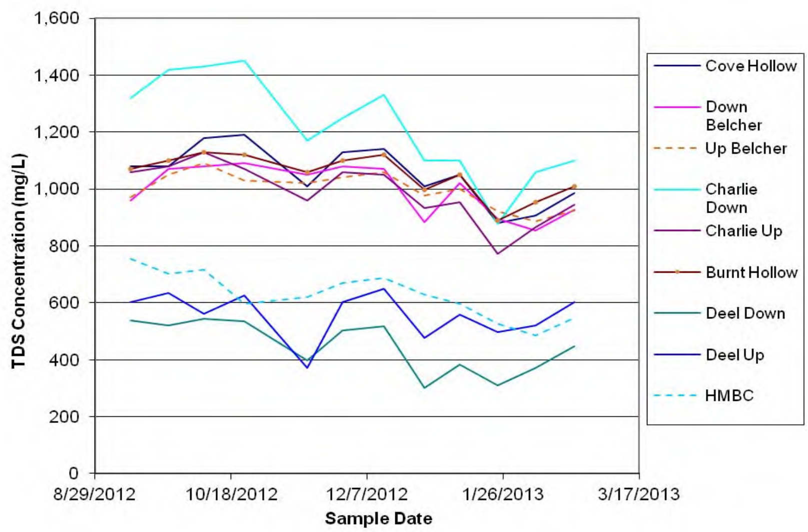

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Figure 3.3 TDS concentration in mine springs over the sample period in the Bull Cr. watershed. [3]

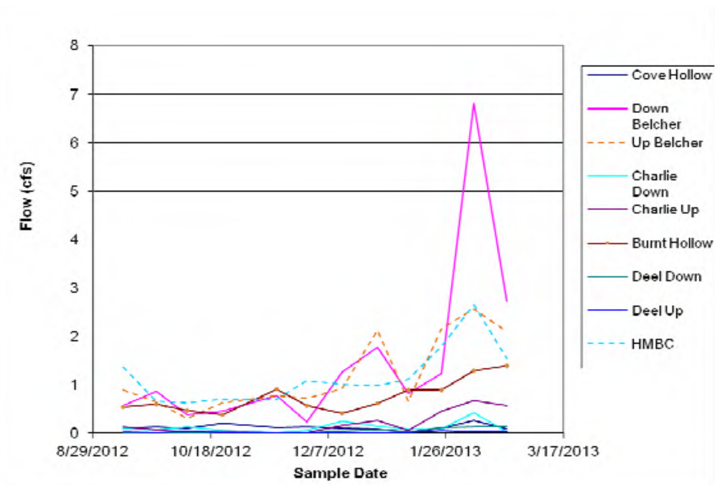


Figure 3.4 Mine spring volume over the sample period in the Bull Cr. watershed. [4]

3.3 Mining

Coal has been extensively removed from strata in the watershed by means of underground mining. Two mines, Splashdam Mine and Norton Mine, are responsible for most of the excavation shown in **Figure 3.5**. Four other minor mines contribute to the total mine footprint. The Bull Creek TMDL watershed

3 Data in Table A. 1 and Table A. 2figure from “E:\Projects\Proj_DMME_Phased-TMDLs\TDS Evaluation\[TDS v Flow with Totals and Averages_MJS_6.xlsx]Combined”.

4 Data in Table A. 1 and figure from “E:\Projects\Proj_DMME_Phased-TMDLs\TDS Evaluation\[TDS v Flow with Totals and Averages_MJS_6.xlsx]Combined”.

perimeter is marked by a dark red line in the figure. Mine units that are part of Splashdam Mine are shown in gray and Norton Mine units are outlined in black. The un-mined area of the watershed indicated in green generally occurs along streams and represents about 15% of the watershed. The Splashdam and Norton Mines both extend well beyond the Bull Creek watershed boundary although the Splashdam mine is much larger.

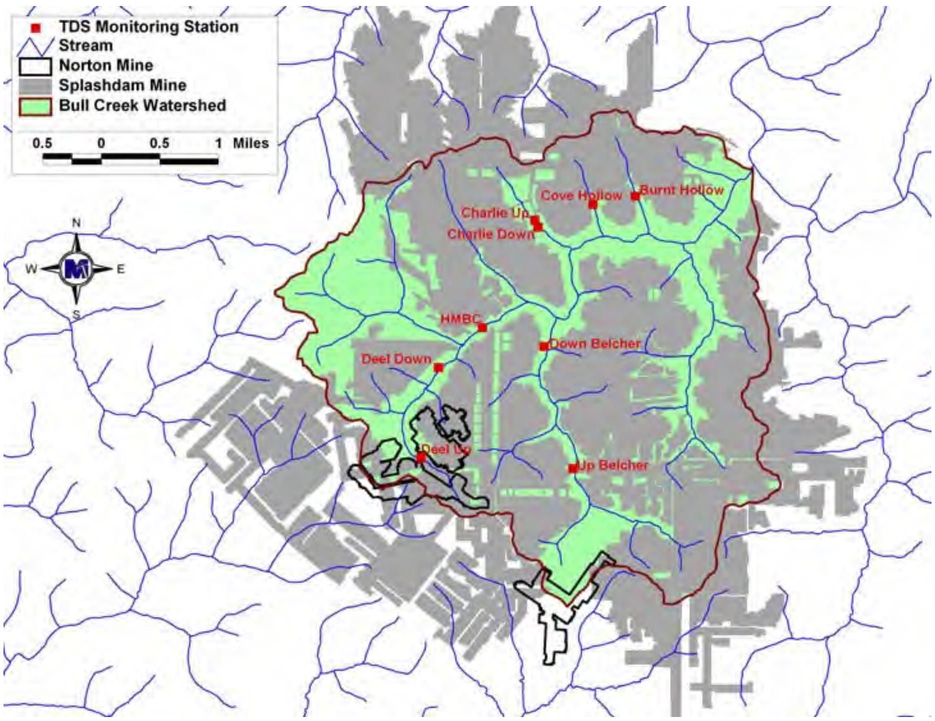


Figure 3.5 Location of monitored springs relative to underground mined footprint in the Bull Cr. watershed.

Underground mining has occurred at multiple depths in the watershed. As is indicated by dark shading in **Figure 3.6**, multiple levels generally occur within the ridges, and along the TMDL watershed boundary where the elevation is highest. In this mined area, the sedimentary rock layers and coal seams are expected to exhibit the typical flat-lying aspect of strata in the bituminous coal fields of the Appalachian Coal Basin.

Elevations for most of the mine footprint are uncertain. On the eastern edge of the watershed the depths are believed to span about 868 feet of elevation. The three units of the Norton Mine on the southwestern boundary of the watershed have mine floor elevations of approximately 1,600 feet while the land surface ranges from 1,700 to 2,100 feet. So these mines are about 300 feet deep and are at, or just above, the Deel Up spring elevation.

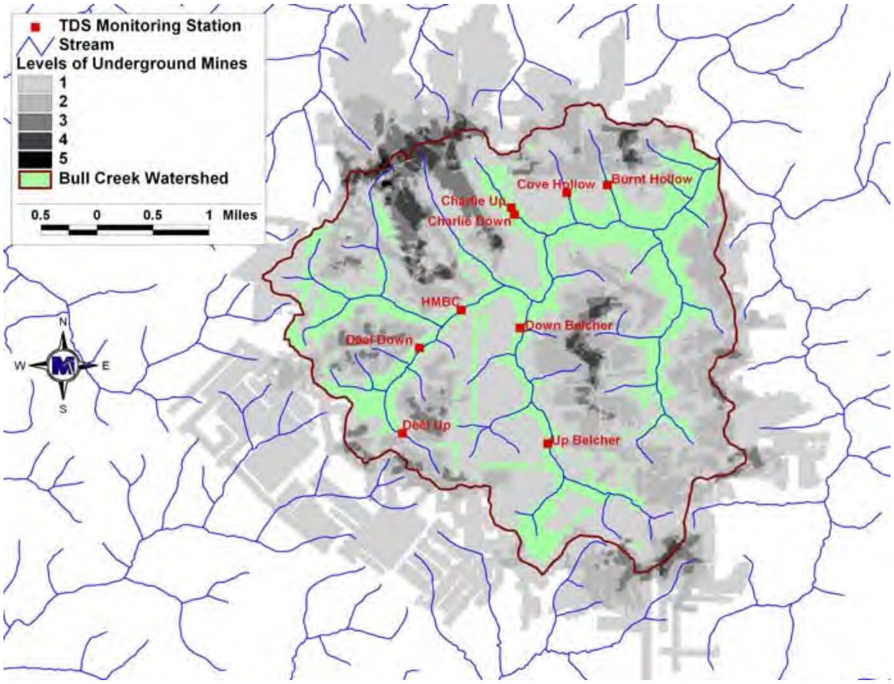


Figure 3.6 Underground mine layers in the Bull Cr. watershed.

Although the sampling focus was on underground mines, a large area in the southeastern part of the watershed was omitted from sampling (see area "E" of **Figure 3.20** on page **28**). This area equals about 30% of the TMDL watershed. It is bounded by Belcher Branch on the west and Bull Creek on the north. It is not unusual to omit portions of a project area from sampling because it is difficult to census the entire population of springs.

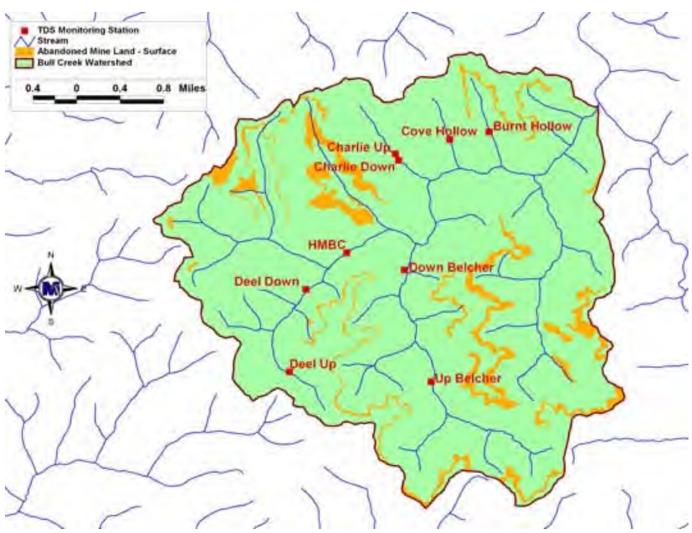


Figure 3.7 Abandoned surface mines in the Bull Cr. watershed.

While surface mining was not the focus of this study, it has been commonly employed in the watershed (**Figure 3.7**). Abandoned surface mine tracts present a ready path for precipitation to enter the ground through material-rich materials that provide TDS. Notably, there is a large, abandoned surface mine above the HMBC spring. This appears to provide increased infiltration and, consequently, lower than expected TDS groundwater to the spring (see later discussion).

3.4 TDS Concentration and Spring Flow

For the Bull Creek watershed, the relationship between flow volume and TDS concentration in the mine springs is graphed in **Figure 3.8**. Note the flow axis has a log scale. Freshwater streams typically range from 124 to 500 mg/L and mine water typically ranges from 620 to 6,200 mg/L. Here we use 620 mg/L as the mine water threshold.

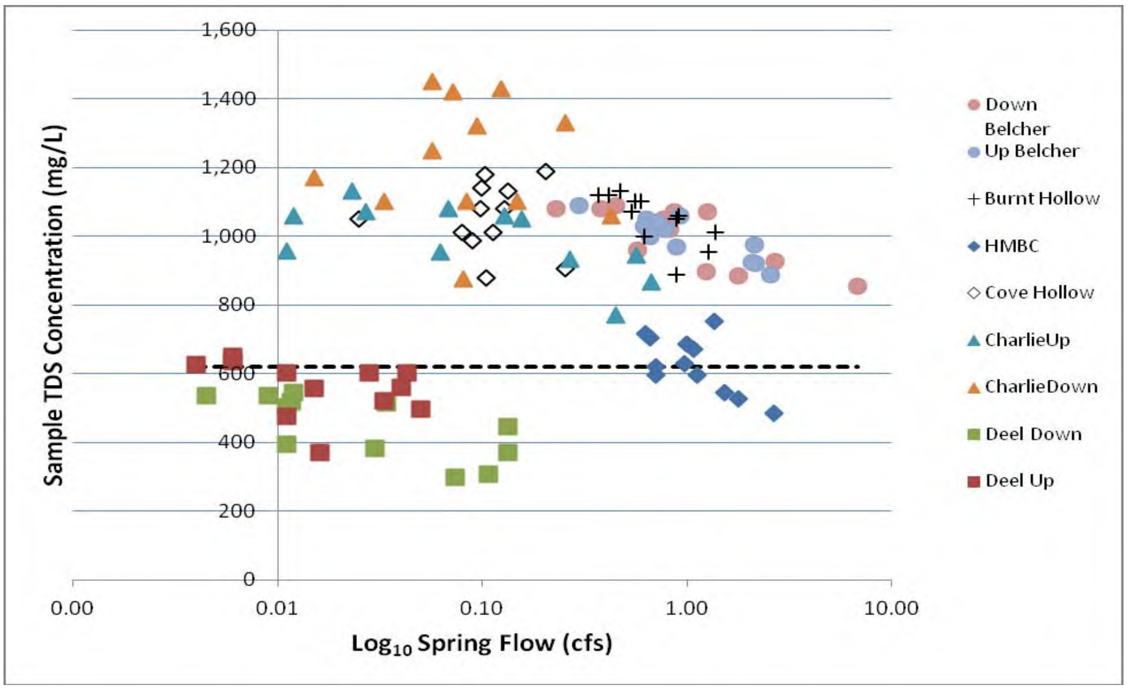


Figure 3.8 Relationship of TDS concentration to flow in mine springs of the Bull Cr. watershed. The dashed line at TDS 620 mg/L is the transition to mine water.[5]

In the Bull Creek mine springs the TDS concentration varies from 300 to 1,400 mg/L. That is, the lower concentrations are more akin to freshwater than to mine discharge. Most low TDS concentrations were found in the Deel Up and Deel Down springs even though these springs originate from mines. The low concentrations are believed due to Deel Up's location near the edge of the watershed, and that both springs are topographically the highest springs. Their low flow suggests there is very little hydrologic

5 Data source: TDS v Flow with Totals and Averages_MJS_6.xlsx.

head behind them. Spring HMBC has TDS concentrations in the middle range 500 to 800 mg/L straddling the transition from freshwater to mine water. The remaining springs have TDS concentrations consistently above 800 mg/L and so are certainly of mine origin.

Of the seven high-TDS springs, three have a high TDS concentration but low flow: Charlie Up, Charlie Down, and Cove Hollow. The remaining three springs have high TDS and high flow: Up Belcher, Down Belcher, and Burnt Hollow. But, the four springs with the highest flow are the dominant springs in the watershed from a TDS load perspective; HMBC, Up Belcher, Down Belcher, and Burnt Hollow (**Table 3.1**).

Bedrock minerals in mines dissolve when in contact with water. If the water in a mine deepens, less of the water is in contact with rock so there is less dissolution for the volume of water. If spring flow volume reflects mine groundwater volume, there should be a negative relationship between the volume of a spring and its TDS concentration. On the other hand, the volume in a spring may increase due to infiltration of low-TDS rain water that dilutes the mine water. Whatever the reason, the TDS concentration and flow patterns for individual springs graphed in **Figure 3.8** suggest there is a negative logarithmic relationship.

Table 3.1 Mine spring flow, and spring-TDS over the study period in the Bull Cr. watershed.[6]

Site	Ave. Flow (cfs)	Median Flow (cfs)	Mean TDS mg/L	Median TDS mg/L	Mean TDS Mg/yr	Median TDS Load Mg/yr	Load Ratio[a]	Elevation (feet)
Down Belcher	1.49	0.85	999	1,035	1,239	790	118	1,232
Up Belcher	1.21	0.83	997	1,010	1,039	741	111	1,377
Burnt Hollow	0.74	0.61	1,050	1,065	684	569	85	1,305
HMBC	1.18	1.04	627	625	636	607	91	1,261
Cove Hollow	0.12	0.10	1,054	1,065	112	101	15	1,260
Charlie Up	0.20	0.10	990	1,004	165	93	14	1,309
Charlie Down	0.12	0.08	1,217	1,210	129	87	13	1,293
Deel Down	0.05	0.02	447	475	17	8	1	1,383
Deel Up	0.02	0.02	559	581	11	7	1	1,567
maximum:	1.49	1.04	1,217	1,210	1,239	790	118	1,567
minimum:	0.02	0.02	447	475	11	7	1	1,232
median:		0.10		1,010		101		1,332

a ..= Median TDS Load divided by 7, the minimum Median TDS Load.

3.5 TDS Load

TDS load is the mass of dissolved solids produced over a period of time. Here the TDS load from a mine spring is calculated by multiplying the TDS concentration (mg/L) by the flow (cfs).

6 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[Averages], and TDS v Flow with Totals and Averages_MJS_6.xlsx[Precip].

Mg/yr = mg/L * cfs * 0.89359105

The product is multiplied by 0.89359105 to convert the units to Mega grams per year (Mg/yr). The origin of the conversion factor is as follows.

0.89359105 = (ft^3 / sec) * (1L / 0.0353147 ft^3) * (1 kg/10^6 mg) * (1 Mg/10^3 kg) * (3.15569*10^7 sec/yr)

In **Figure 3.9**, where TDS load is graphed against spring flow, both graph axes are linear. Considering the data for all springs except HMBC, there is a significant, positive response of TDS-load to flow; the correlation coefficient R^2 is highly significant (0.99). There is a similar, significant relationship for the HMBC spring by itself but with a slower rate of increase. The consistent, positive relationship for TDS load and flow evident in this graph is the reverse of the relationship for TDS concentration and flow. That is, TDS load increases with flow volume. Among dominant springs Up Belcher, Down Belcher and Burnt Hollow, for a unit increase in flow, there is the same rate of increase in TDS load. However, dominant spring HMBC exhibits only half the increase (R^2 = 0.90). This situation for HMBC is opposite its quick decrease in TDS concentration with flow (see **Figure 3.8**).

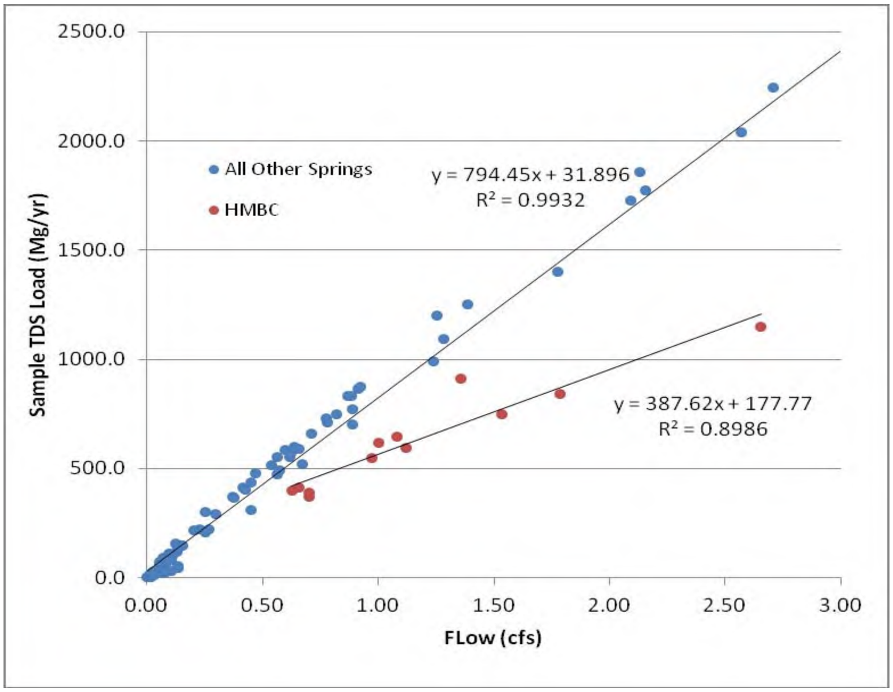


Figure 3.9 TDS load and flow for HMBC compared to all other mine springs (one extreme data point omitted = Down Belcher). [7]

7 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined]".

The uncertainty in the regression coefficients based on Monte Carlo permutation resampling is expressed by the approximate 95% confidence intervals (C.I.) in the following table. Because the regression slope intervals do not overlap, they are significantly different at the P(< 0.05) level.

Table 3.2 Uncertainty of coefficients for the regression of TDS load on spring flow.

Data	Resamples	Mean Intercept, a	Approximate 95% C.I. for a	Mean Regression	Approximate 95% C.I. for b
HMBC	1,000	155.0	+/- 132.0	413.5	+/- 130.8
Non-HMBC	300	26.3	+/- 19.8	808.6	+/- 45.7

Source: Bull Cr Regression MonteCarlo v05.xls.

The increase in TDS load with flow appears counterintuitive because, as demonstrated earlier, TDS concentration decreases with flow. The contradiction is resolved by the relatively minor fluctuation in TDS concentration compared to the major change in flow. That is, the volume of a spring controls its TDS load. The data for Down Belcher is used to demonstrate this point (**Figure 3.10**).

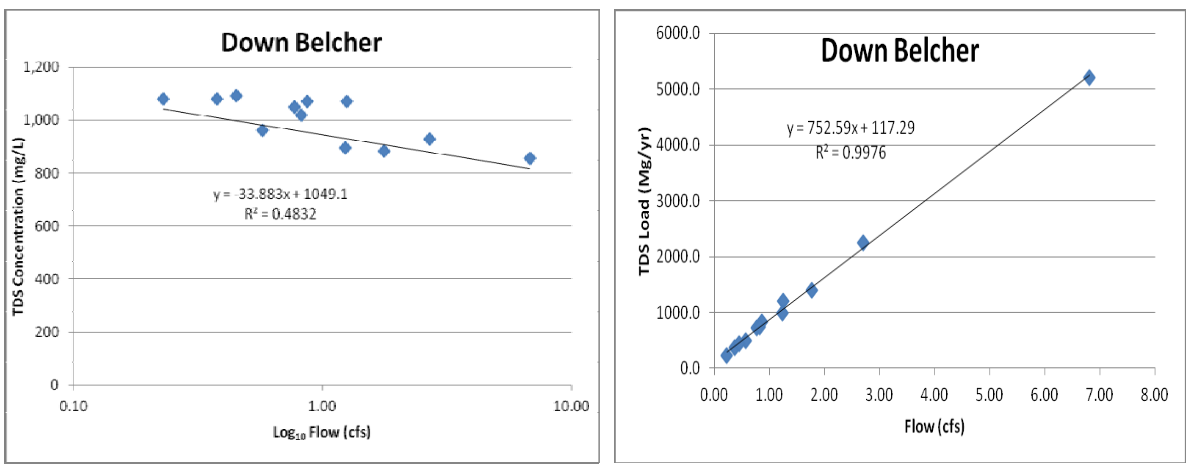
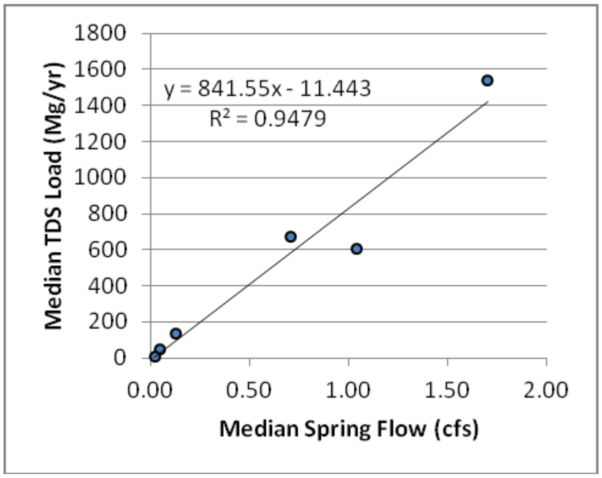


Figure 3.10 Change in TDS concentration and load with flow. [8]

TDS load is a product of TDS concentration and flow. Over the study period at Down Belcher, concentration decreased from about 1,040 to 820 mg/L; a decline of about 22%. Meanwhile, flow volume increased from about 0.25 to 6.9 cfs; an increase of 2,700%. Thus, while TDS concentration and flow volume are determinants of TDS load, by far the controlling variable is flow volume. TDS concentration can almost be considered constant. This provides a basis for projecting TDS loads in other mined watersheds with similar TDS concentration and flow volume ranges such as the South Fork Pound

8 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].

River watershed. The same relationship is observed whether comparing the median TDS load for the springs in a hydrologic island or for a sample date (**Figure 3.11**).



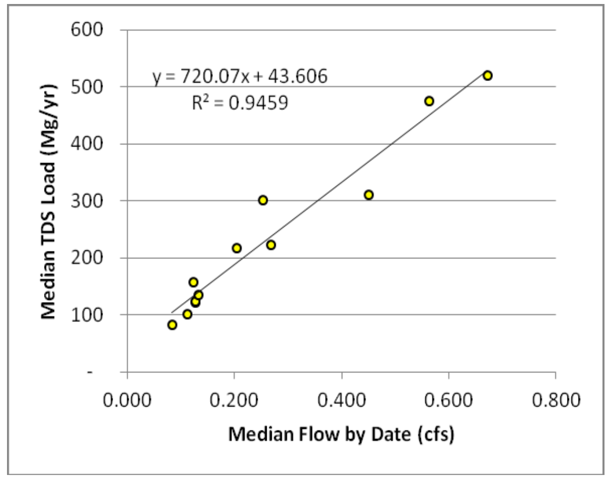


Figure 3.11 TDS load versus spring flow volume for 6 hydrologic islands (left) [9] and 12 sample dates (right) [10].

Among the four major springs, HMBC has an unusually slow rate of change in TDS load with flow (**Figure 3.9**). For the same increase in flow, HMBC shows a smaller increase in TDS load than the other dominant springs. But, the TDS concentration is also lower at HMBC. Coincidentally, the median HMBC flow is the highest monitored and less variable. Thus the source of groundwater for HMBC is less mineralized but larger in volume. This appears related to a large abandoned mine on the surface of the HMBC hill system (**Figure 3.7**). This surface mine scar is the largest of those on hydrologic islands with monitored springs in the watershed. Also, it covers a significant part of the surface of the hill system from which HMBC emerges. The hill system of HMBC is also extensively mined underground suggesting the groundwater should have a high TDS concentration. But if the groundwater is recharged in part through the surface mine with low-TDS rainwater (< 20 mg/L) that quickly moves through the hill caverns, the result would be the observed, moderate TDS concentration at HMBC. The AML (abandoned mine land) scar is very porous and should capture a larger fraction of rainfall. Therefore, it is proposed that the surface AML provides a large catchment for low-TDS rain which is rapidly conducted through mines in the HMBC hydrologic island to the spring. This would explain the unique relationship of TDS concentration and load to flow in the HMBC spring.

Belcher Branch is fed by Up and Down Belcher springs. Convict Hollow Creek flows parallel to Belcher Branch and is in the next stream valley to the east **(**see **Figure 3.1**). The hill systems bordering both sides

9 Source: Hydrologic Island Vars v02.xlsx.
10 Source: TDS_Monitoring_Analysis_v02_MJS.xls.

of Convict Hollow Creek have large AML areas. No spring monitoring was conducted along Convict Hollow Creek. However, based on the TDS and AML relationship for HMBC spring, it is proposed that if there are mine springs in the Convict Hollow Creek valley, they should be of high volume and low TDS concentration. The Up Belcher and Down Belcher springs emerge from hydrologic islands #1 and #2, respectively, in the southwestern part of the watershed. These islands are adjacent and mined mostly at one level and continuously from #1 to #2. Thus they are thought to be the same hill system. Their springs produce the largest TDS load in the watershed. The Belcher springs are also downhill from a large expanse of the Norton Mine.

3.5.1 Seasonal Patterns

Flow and TDS were measured in the mine springs from September 2012 through February 2013. Springs with high flow and moderate to high TDS concentration dominate TDS production in the Bull Creek watershed. Key contributors include Up Belcher, Down Belcher and Burnt Hollow due to combined high flow and high TDS concentration. Although the TDS concentration in HMBC is less than in these three springs, its higher flow volume makes it a large source as well. The TDS load dominance of these four sources is especially apparent in the later part of the sampling period when flow is elevated (**Figure 3.12**). Over the September to February sample period, the TDS load from the mine springs was low in autumn, moderate in early winter, and highest in late winter.

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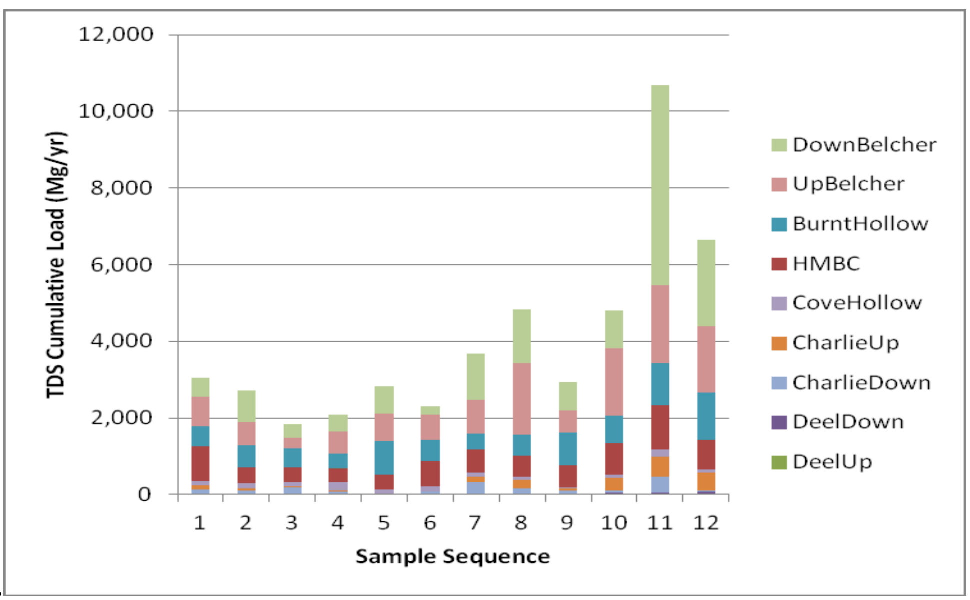


defined.

Figure 3.12 TDS Load from mine springs over a six-month sample period from September 2012 through February 2013. [11]

3.5.2 Elevation

Elevation was expected to be inversely related to the flow of a spring because the hydrologic head typically increases with decreasing elevation. For example, Deel Up and Deel Down have the highest topographic position of the eight springs and lowest flow volumes. But when all springs are considered, there is only a minor indication of a relationship between the elevation at which a spring occurs and its median flow over the sample period (R^2 = 0.18, **Figure 3.13**). The four largest volume springs in the figures are the dominants Down Belcher, Up Belcher, Burnt Hollow and HMBC.

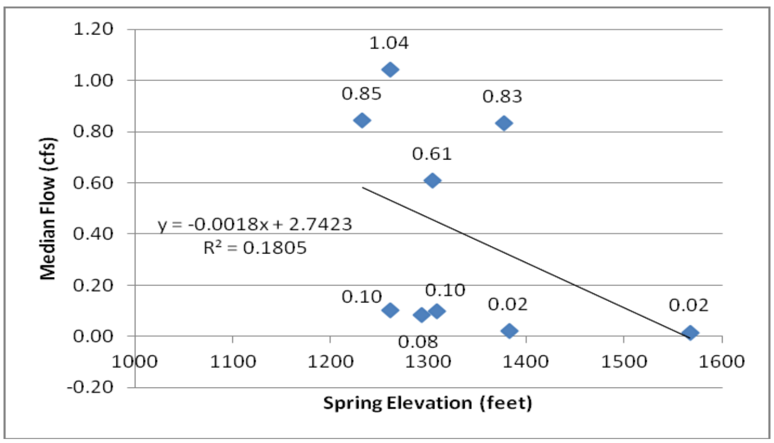
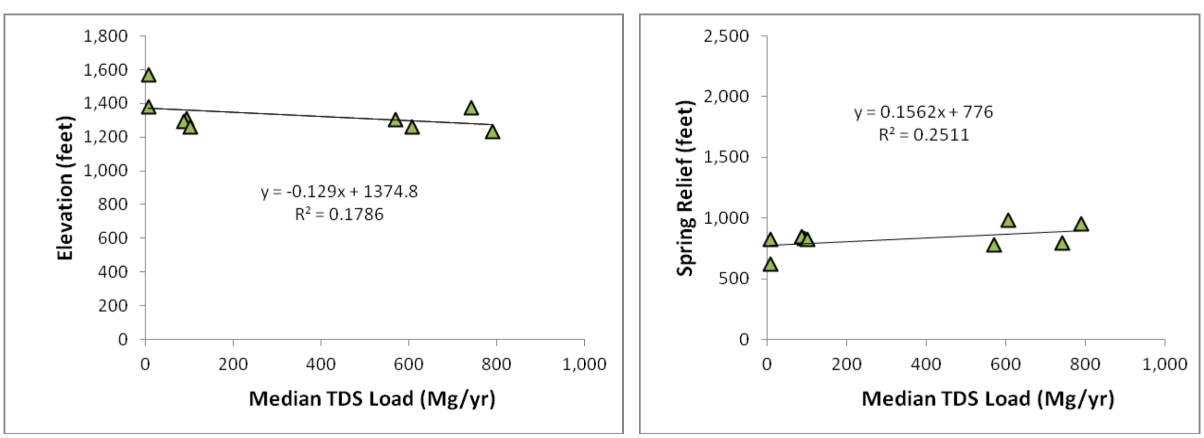


Figure 3.13 Median flow and elevation of mine springs. [12]

Likewise, springs at lower elevations might be expected to have a larger proportion of deep, mineralized water. There is a suggestion that spring elevation and the relief above the spring may play a role (**Figure 3.14**).



11 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].
12 From TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].

Figure 3.14 TDS Load with spring elevation (left) and relief (right) above spring. [13]

3.5.3 Precipitation

Because precipitation infiltrates the regolith to recharge groundwater, the amount of precipitation is expected to control the TDS load by contributing to flow. To examine this relationship, rainfall data from a station 7 miles from the watershed was obtained and summed for the month, and for the four-day period preceding each sampling event (US Weather Station ID GHCND:USC00443640).

Among the samples there is a modest increase in median TDS load with rainfall volume in the first four and a half months wherein TDS rises with recent rainfall ("Early", **Figure 3.15**). However, in the last three sample dates ("Late"), the relationship disappeared. In this last period of sampling, the flow at most springs increased substantially despite the lack of recent rainfall.

Historically, monthly precipitation averages about the same from one month to the next (**Table 3.3**). However, during the six-month study period, monthly precipitation deviated widely from this pattern. Precipitation was markedly low in November and February, and high in September and January. Thus the amount of rainfall preceding sampling events was expected to be a factor in determining spring volume. To test this hypothesis, the rainfall in the four-day period prior to sampling was totaled for the two sampling events each month as were flow volume and load. Based on the recent monthly values listed in **Figure 3.15**, there is no obvious relationship between rainfall and spring volume in the study data.

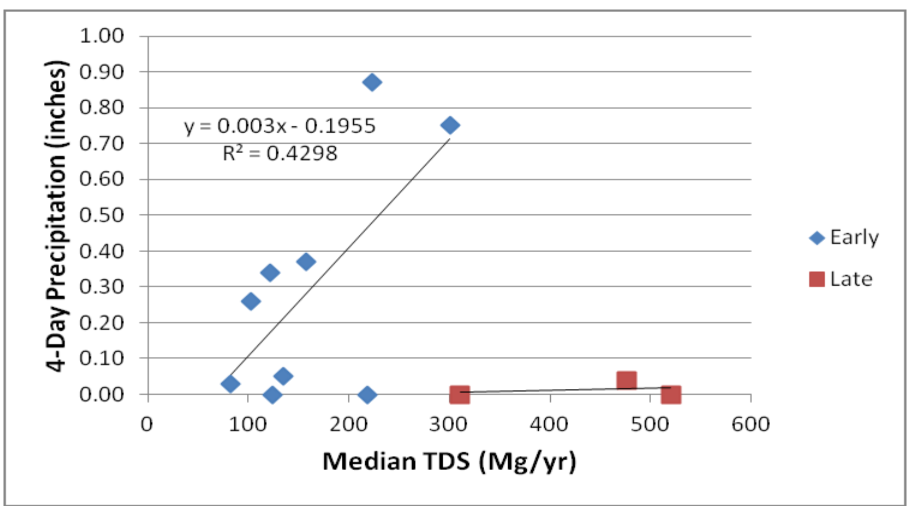


Figure 3.15 Sample date median TDS load and four-day precipitation separated into "Early" and "Late" sampling periods for monitored springs. [14]

13 From TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].
14 TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined] and [Precip].

It is possible that precipitation is very local so that precipitation 7 miles distant is very different. It is also possible that spring flow is more dependent on deeper groundwater and little affected by local precipitation. On the other hand, our data set consists of only six data points collected over six months, which may be too few and in too short a period to elucidate any relationship. Whatever the case, there was a TDS load response to 4-day precipitation in the early part of the sampling period, but no evidence of direct precipitation impact on spring flow (**Figure 3.15**).

Table 3.3 Precipitation, spring flow, and TDS load over the study period.[15]

Sample Period	Precipitation				Spring Flow (cfs)	Median Month Spring Flow (cfs)	Median Monthly TDS Annual Load (Mg/yr)
	Historical Average (inch)	Observed (inch)	4-Day Prior to Sampling (inch)	Total 4-Day Prior to Sampling (inch)			
Early Sep. 2012			0.34		3.71		
Late Sep. 2012	3.14	6.47	0.00	0.34	3.05	3.38	2,879
Early Oct. 2012			0.37		2.08		
Late Oct. 2012	2.82	4.11	0.00	0.37	2.45	2.26	1,963
Early Nov. 2012			0.26		3.34		
Late Nov. 2012	2.91	0.71	0.05	0.31	2.81	3.08	2,569
Early Dec. 2012			0.75		4.14		
Late Dec. 2012	3.27	2.74	0.87	1.62	6.08	5.11	4,248
Early Jan. 2012			0.03		3.70		
Late Jan. 2013	3.19	5.92	0.00	0.03	6.86	5.28	3,879
Early Feb. 2012			0.00		14.84		
Late Feb. 2013	3.09	1.26	0.04	0.04	8.59	11.71	8,655
Total:	18.42	21.21	2.71	N/A	61.64	30.82	N/A

Note: Precipitation based on US Weather Station GHCND:USC00443640 about 7 miles east of study site.

3.6 TDS Load and Mine Springs

Of primary concern is the source of TDS in the mine springs. Although all nine springs are of interest, those of main concern are the dominant TDS sources. In **Figure 3.16**, blue arrows indicate the suspected direction of flow for each spring and, therefore, the immediate origin of TDS. The arrow width indicates its contribution to overall TDS load. The distribution of TDS load and flow between samples is highly variable based on the coefficient of variation of the data. Consequently, in comparisons of TDS load and spring volume, the median is used as the representative value instead of the mean.

15 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx]Averages.

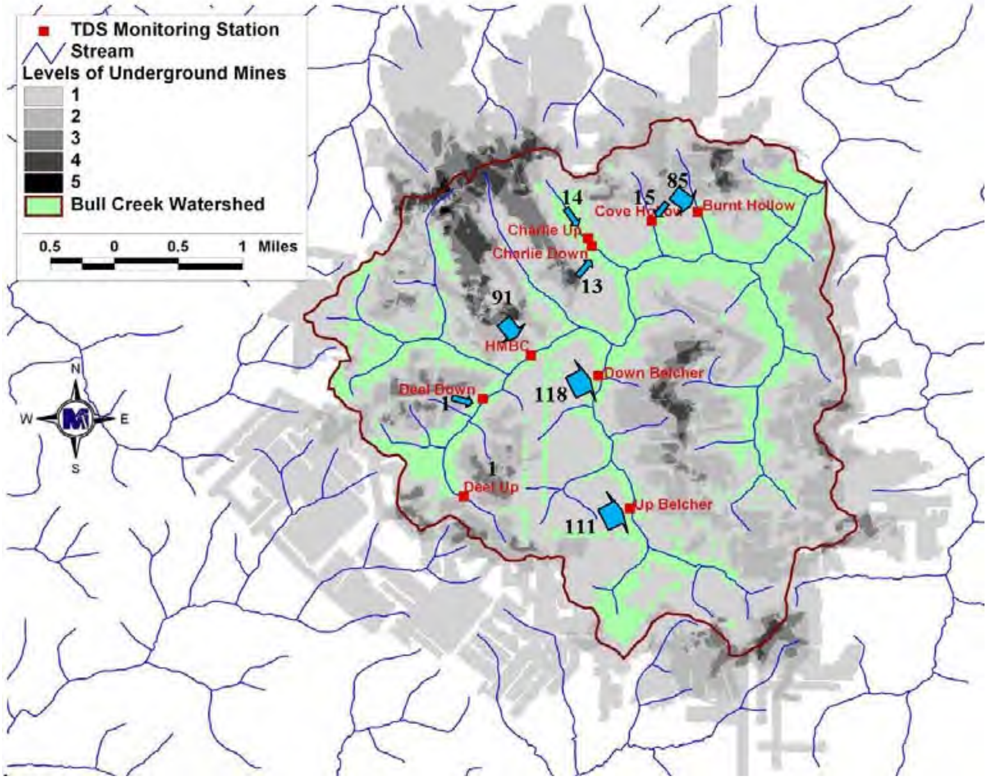


Figure 3.16 Relative Median TDS load and origin of spring flow.[16]

The Deel Up mine spring produces the smallest sample median TDS load (7 Mg/yr) over the sample period; about the same as Deel Down. Thus the Deel Up minimum was used as a base for comparing the loads indicated in **Figure 3.16**. Up Belcher and Down Belcher produce about equal TDS loads, over 100 times that at Deel Up (**Table 3.1**). Together they contribute 57% the TDS load in the watershed. Burnt Hollow and HMBC, also large sources, produce 85 and 91 times the load from Deel Up. Taken together, Up Belcher, Down Belcher, Burnt Hollow and HMBC (the dominant springs) account for 89% of the total TDS load. The remaining springs, Charlie Up, Charlie Down, and Cove Hollow, each produce about 14 times that from Deel Up. In summary, the mine springs that primarily determine the TDS load in the Bull Creek watershed are Up and Down Belcher, Burnt Hollow and HMBC.

3.7 Hydrologic Island

In the Bull Creek watershed, steep-sided hills are hydrologically isolated from one another by stream valleys into hydrologic islands. Groundwater accumulates in the hydrologic islands due to infiltration of rain that falls on the hill surfaces, and is released in springs. Because infiltration becomes groundwater,

16 From: DMME_TDS_Source_Arrows4.doc, *.pdf, *.png.

larger hill surfaces should accumulate more groundwater. Then the size of a hydrologic island footprint should be a factor in determining the volume of its springs.

The size of a hydrologic island in an un-mined watershed may be estimated through the topography (see **Figure 3.1 page 7)**. In the study area, although hill units may extend outside the Bull Creek watershed, the watershed divide is both an area of recharge for groundwater close to the surface, and a hydrologic divide. Surface groundwater within a watershed boundary tends to flow underground away from the divide towards the center of the watershed. Correspondingly, groundwater outside the boundary tends to flow in the opposite direction. Thus, hydrologic islands within the Bull Creek watershed operationally terminate at the watershed boundary. Where a spring emerges at the base of a hill, the hill system up-gradient is the spring's water source. i.e., its hydrologic island. **Figure 3.16** shows the inferred origin of the monitored springs in the Bull Creek watershed. **Figure 3.17** (page **23**) is a map of the hydrologic islands and their springs.

Mining complicates the consideration of groundwater availability and spring flow in a hydrologic island. As mentioned previously, abandoned coal mines can be reservoirs for groundwater. Coal mining in the Bull Creek watershed has been extensive, and at multiple levels where the topographic relief was sufficient to support it. These mine caverns are both conduits for rapid groundwater flow, and reservoirs for groundwater.

3.7.1 Functional Hydrologic Island

As mentioned earlier, in the study area groundwater tends to collect within hills above impermeable strata, and to behave separately from groundwater in adjoining hills. Consequently, it is useful to delineate hydrologically isolated hill systems in the watershed. This amounts to putting boundaries around the hills. Stream valleys are a logical indicator of the limits of hydrologic islands because that is where hill-derived groundwater discharges (Freeze & Cherry, 1979). However, if a stream is under-mined, it no longer forms a boundary. Consequently, the term "functional hydrologic island" is employed for hill systems that are separated by stream valleys but which share groundwater because the adjoining valleys are undermined. Functional hydrologic islands tend to be larger than "natural" hydrologic islands because mining has created underground conduits connecting two or more natural hydrologic islands into a functional whole. The proposed seven functional hydrologic islands with springs in the Bull Creek watershed are identified in **Figure 3.17**.

The hydrologic islands tend to be differently elongated. Elongated islands may generate higher TDS concentrations because the groundwater takes a longer mineral path. However, the length:width ratio was not examined in this study.

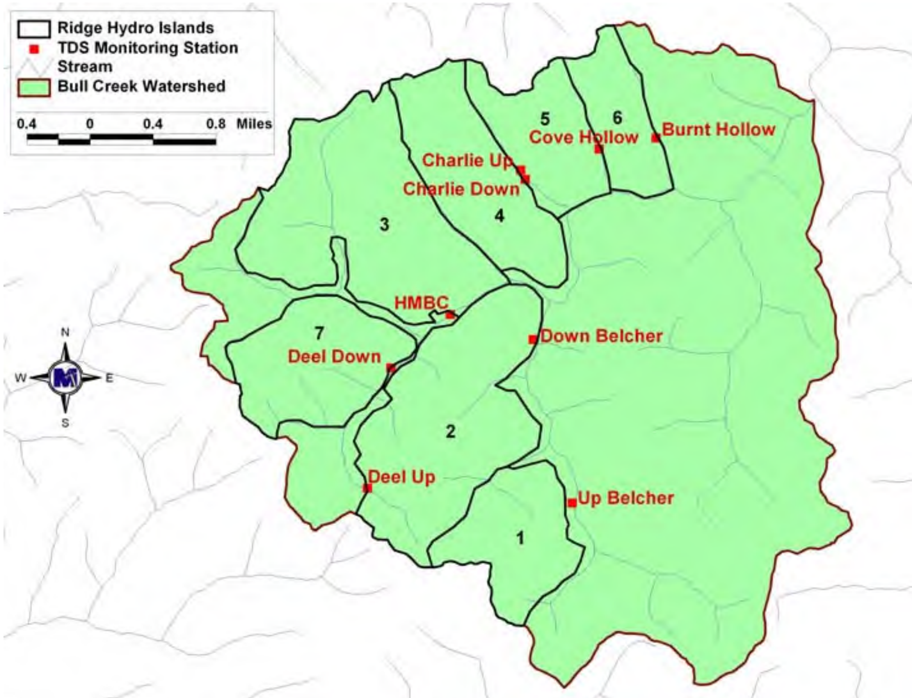


Figure 3.17 Functional hydrologic islands and mine springs in the Bull Cr. watershed.[17]

From a groundwater volume perspective, one important attribute of a functional hydrologic island is its surface area (**Table 3.4**). The surface area is the catchment for precipitation that recharges groundwater in the island. The surface area of the hydrologic island is taken to be its topographic footprint, the acres of land surface overshadowed by the hill when viewed from above. Admittedly, the surface area covers a three-dimensional bulge and so is larger than the footprint. Still, the footprint is likely to closely approximate the surface area since the islands are flat-topped and steep-sided. The relief of the island is the difference between the general elevation of the top, and the general elevation of the lowest part of the footprint.

17 Source: Hydro_Islands_v1.jpg

Table 3.4 Hydrologic island topography in the Bull Cr. watershed. [18]

Island No.	Island Foot-print (acre)	Top Elevation (ft)	Bottom Elevation (ft)	Relief (ft)	Standard Island Volume (10^9 ft^3)	Spring Elevation (ft)	"Spring Island" Relief (ft)	"Spring Island" Volume (10^9 ft^3)	Monitored Springs (dominant bolded)
1	359	2,172	1,427	745	12	1,377	795	12	**Up Belcher**
2	795	2,185	1,178	1,007	35	1232, 1567	953	33	**Down Belcher** + Deel Up
1+2	1154	2,185	1,178	1,007	51	1377, 1232, 1567	953	48	**Up Belcher + Down Belcher** + Deel Up
3	874	2,240	1,218	1,022	39	1261	979	37	**HMBC**
4	481	2,140	1,200	940	20	1309, 1293	847	18	0.5*Charlie Up + Charlie Down
5	324	2,095	1,065	1,030	15	1309	786	11	0.5*Charlie Up
6	244	2,085	1,035	1,050	11	1260, 1305	825	9	Cove Hollow + **Burnt Hollow**
7	444	2,207	1,312	895	17	1383	824	16	Deel Down
sum:	3,521				152			139	

Note: 1 acre = 43,560 square feet

The volume of the functional hydrologic island, "Standard Island Volume", in **Table 3** is calculated by multiplying the island footprint by its relief. Sometimes the lowest elevation of the island approximates that of the spring (**Table 3**). Because groundwater flows down the hydrologic gradient, the island volume above a spring or, "Spring Island Volume", is the more likely source of its groundwater. Then this volume is more likely to be related to spring flow volume and TDS concentration than the "Standard Island Volume". "Spring Island Volume" is based on the relief from the island top to the spring elevation. Where more than one spring emerges from the island, the lowest spring elevation is used in the volume estimate. Clearly, there are only minor differences between the standard island volume and the spring island volume. Consequently, for making other comparisons the standard island volume is used.

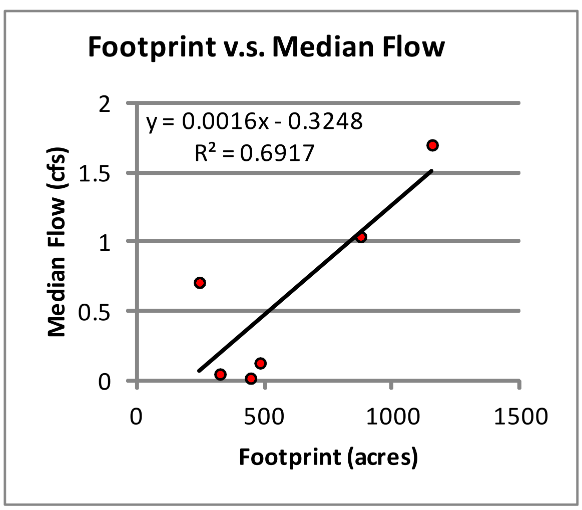
When all features of the Bull Creek hydrologic islands are compared to spring flow and to TDS concentration and load, island footprint stands out as the most consistently important (**Figure 3.18**). Footprint is correlated with spring flow volume and load; R^2 = .69 and .59, respectively.

18 Source: Hydrologic Island Vars v02.xlsx.

Table 3.5 Hydrologic island barriers, hydrology and TDS in the Bull Cr. watershed. [19]

Island No.	Largest Width of Valley Barrier (ft)	Smallest Width of Valley Barrier (ft)	Sum Medi-an Flow (cfs)	Flow-Weighted Median TDS Conc. (mg/L)	Flow-Weight. Median TDS Load (Mg/yr)[a]	Sum of Raw Median TDS Load (Mg/yr)	TDS Load Ratio[b]	Sum Mean TDS Load (Mg/yr)	Monitored Springs (dominant bolded)
1	339	339	0.83	1010	749	741	111	1,039	**Up Belcher**
2	678	678	0.87	1025	797	797	118 + 1	1,250	**Down Belcher** + Deel Up
1+2	678	678	1.70	1017	1546	1538	111+ 118+1	2,289	**Up Belcher + Down Belcher** + Deel Up
3	647	443	1.04	625	581	607	91	636	**HMBC**
4	990	628	0.13	1131	131	134	0.5*14 + 13	211	0.5*Charlie Up + Charlie Down
5	1102	452	0.05	502	22	47	0.5*14	83	0.5*Charlie Up
6	1498	370	0.71	1065	676	670	15 + 85	797	Cove Hollow + **Burnt Hollow**
7	647	629	0.02	475	8	8	1	17	Deel Down
Totals			**5.35**		**2,964**	**3,003**			

a product of Sum Median Flow and Flow-Weighted Median TDS Conc.
b ratio is based on "Sum of Raw Median TDS Load" divided by 7, that in Deel Up; **Table 3.1**.



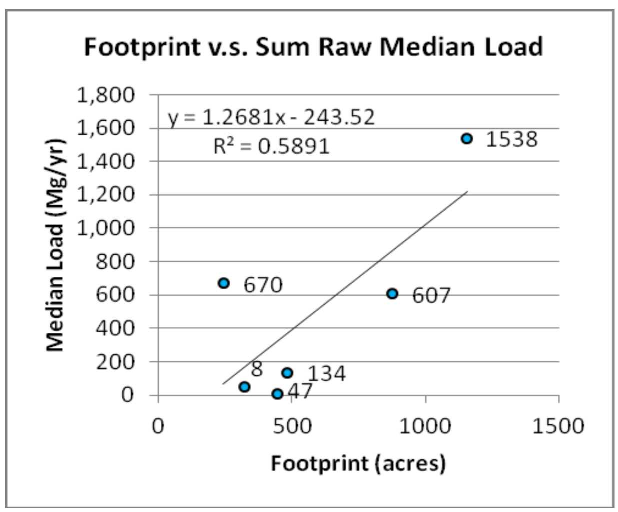


Figure 3.18 Hydrologic island footprint relationship to spring flow (left) and TDS load (right). [20]

19 Source: Hydrologic Island Vars v02.xlsx, and TDS v Flow with Totals and a

3.7.2 Barriers to Groundwater Flow

Stream beds are very permeable and, when undisturbed, are zones where groundwater emerges from rocks below the stream bed and from surrounding hills. Thus these depressions in the ground surface delimit hydrologic islands and represent barriers to horizontal groundwater movement. Further, the broader the un-mined area under a stream valley, the greater barrier it presents. These barriers are shaded green in **Figure 3.19** where the average boundary width is indicated at critical points. The largest and smallest boundary widths proximate to the spring in a hydrologic island are listed in **Table 3.5**. Although perennial streams in the watershed have been undisturbed by mining, most intermittent streams have been under-mined. Under-mined streams are shown in **Figure 3.19** as blue lines.

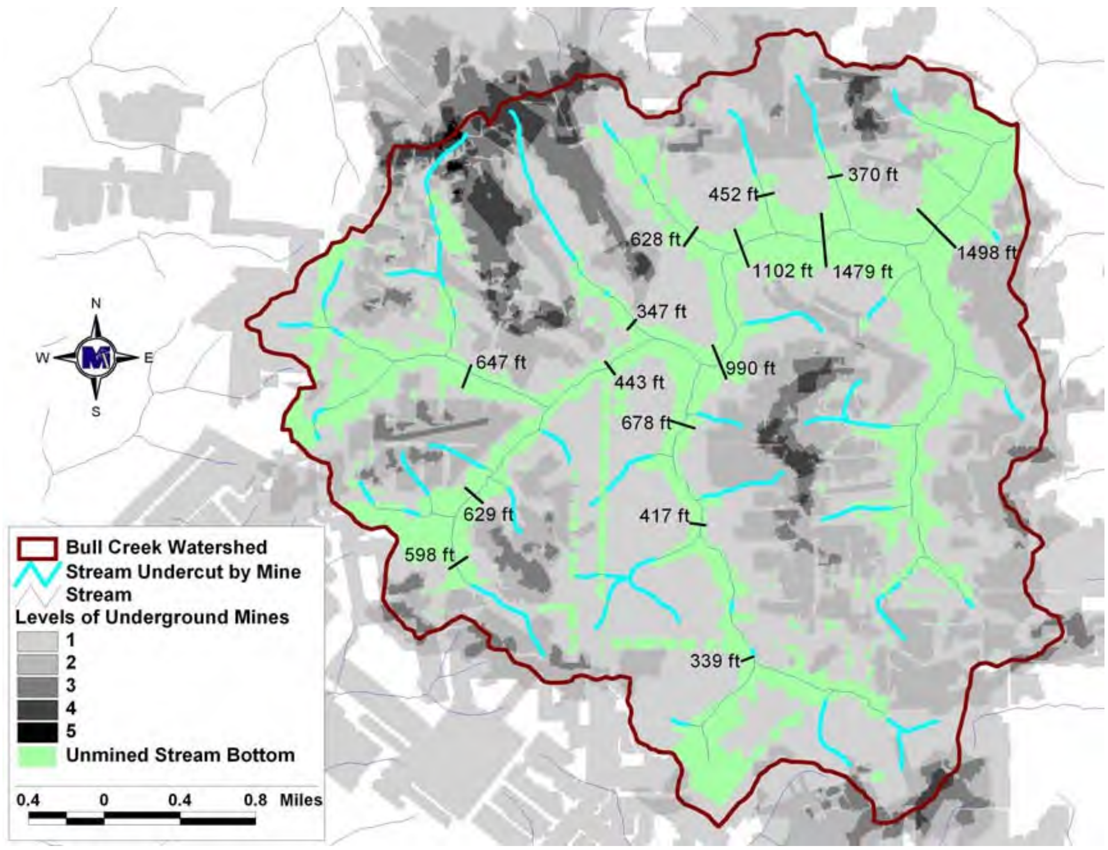


Figure 3.19 Hydrologic buffers (green) and under-mined headwater streams (cyan).

Under-mined streams may reverse their operation by acting as recharge zones where precipitation and overland flow move downward to groundwater. For this reason they are not thought to define the periphery of functionally hydrologic islands from a groundwater perspective. The stream barriers and

20 Source: Graphs Island Dimensions vs Load.xls.

under-mined streams in **Figure 3.19** were considered when delimiting the hydrologic islands in **Figure 3.17**.

3.7.3 Hydrologic Islands and Springs

Islands #1 and #2 are considered one unit, “#1 +#2”, because of the undermining of the intermittent stream valley between them. It has by far the largest footprint and hill volume in the Bull Creek watershed (**Table 3.4**). Consequently, as expected, it yields the largest volume of spring (1.70 cfs) and the largest median TDS load (1,546 Mg/yr). Next in footprint size and hill volume is hydrologic island #3 which has the second highest flow and produces the third highest TDS load. Hydrologic island #3 is associated with the HMBC spring in which TDS and flow are significantly affected by the AML on the hill surface. There is a stream valley between hydrologic islands #3 and #4 that has been undermined for more than half its length. If, as this suggests, the two islands are a single functional unit, that would help explain the volume of flow in HMBC. Following island #3 in size of footprint and hill volume is island #4 from which issue Charlie Up and Charlie Down springs. Although its TDS concentration is the second highest of the islands, its spring flow volume is low. Thus it produces only moderate TDS load.

Among the smaller islands, the leader in TDS load is #6 with the greatest relief of all hydrologic islands. Its footprint and volume are smaller than in units #5 and #7. But its spring volume far exceeds that of islands #4, #5, or #7. Thus it produces one of the top TDS loads through dominant spring Burnt Hollow, and moderate spring Cove Hollow. It is also possible that hydrologic islands #6 and #5 are a functional unit because the stream valley between them has been partially undermined. Small hydrologic islands #5 and #7 contribute only minor TDS loads through springs Charlie Up and Deel Down, respectively. Island #7 has the smallest footprint, and its spring Deel Down is located well above most other springs which may explain the small TDS load. In conclusion, the hydrologic footprint appears to be a reasonable determinant of the volume of spring flow and thereby TDS load.

Table 3.6 Regression of spring flow and TDS load against island footprint.[21]

Parameter	Estimate	Std. Error	p (t-value)
Median Flow, intercept a	-0.3248	0.3553	0.412
“ “, slope b	0.0016	0.0005	0.040
Sum Raw Median Load, intercept a	-243.5	354.5	0.530
“ “, slope b	1.268	0.530	0.075

The statistical relationship of island footprint to spring flow volume and to TDS load is tabled above. Neither intercept is significant. The probabilities for the slopes are marginal principally because of the

21 Source: Graphs Island Dimensions vs Load.xls.

high leverage of island #6; its load and flow are higher than predicted by the regressions. This suggests that the footprint of island #6 is underestimated. Given the statistical improvement of the results when island #6 is removed, the models in **Table 3.6** will be used in a later section to predict spring flow and load in the South Fork Pound watershed. In conclusion, hydrologic footprint appears to be a reasonable determinant of the volume of spring flow and thereby TDS load.

3.8 Mining Extent

The Department of Mines, Minerals and Energy provided ArcView shape files for mine floor space in and near the Bull Creek watershed. ArcView was used to measure the aerial extent of the mining.

It has been noted earlier that the Bull Creek watershed has been mined extensively. To provide some organization to the mining data, the study area was divided into mine units that appeared unconnected. Essentially, the five units are outlined in **Figure 3.20** in red are separate mainly because they are unconnected by mine galleries.

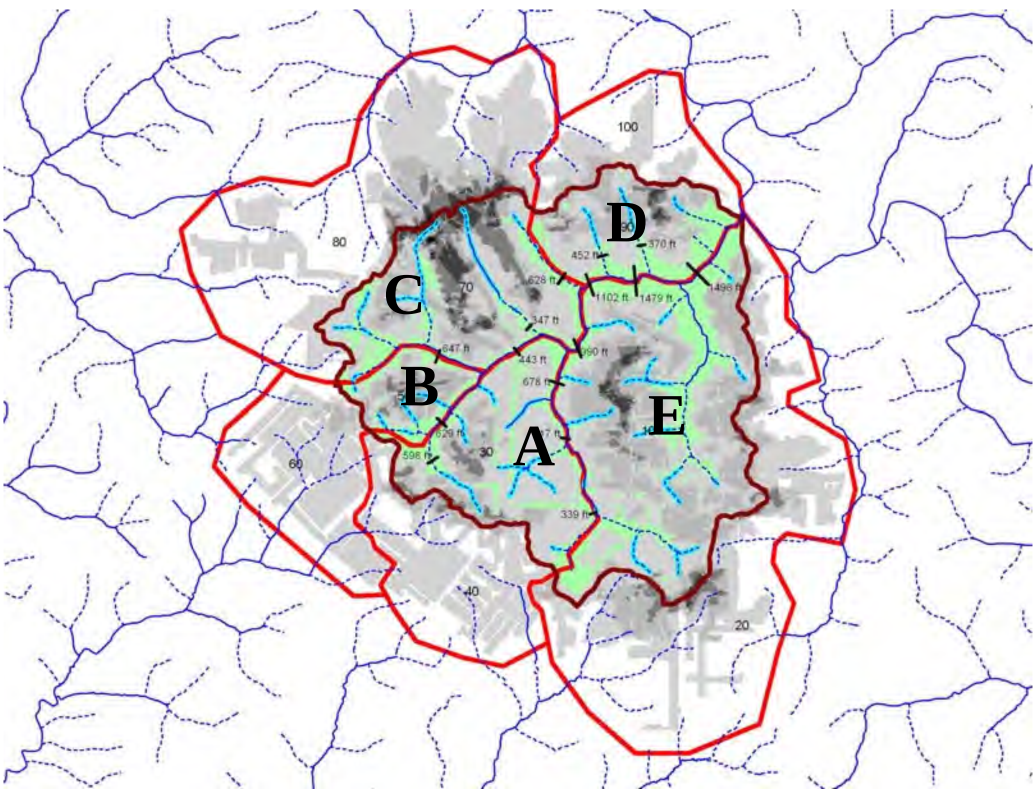


Figure 3.20 Mine units in the Bull Creek watershed area.

While units A, B and E exhibit no obvious connection to other mined areas, areas C and D do have a few connections to bordering mine units. Mined subareas within the individual units have been mined at two or more levels, have multiple connections, and thereby are likely to share groundwater. Then, for purposes of analysis, the five units may be considered separate sources of mine water. Each unit also extends beyond the Bull Creek watershed boundary. Because groundwater, especially surface groundwater, tends to flow from the highlands towards streams that feed the watershed outlet (Freeze & Cherry 1979), it is reasonable to distinguish the mined area inside the watershed from that outside. The mining characteristics of these mined areas are listed in **Table 3.7**.

Two measures of mining were expected to be useful in terms of predicting groundwater quality and quantity, mine footprint and total mine floor. Looking down on the land surface, the area that has been mined is referred to as the "mined footprint". This area together with the un-mined footprint equals the area of the mine unit.

Because mines tend to collect and transport groundwater, areas with multiple mine levels should be better collectors and conduits of groundwater. Consequently, the total mine floor in a unit was measured. This is the "Total Mine Floor" value in **Table 3.7**. Also, the mine floor within the watershed is presented separate from that outside because the watershed boundary is a groundwater hydrologic divide.

It is believed that the sampled springs originate from mines. In attempting to relate mine parameters to the TDS in a spring, there is no tie between mine and spring elevation except that the spring is reported to originate in a mine. Thus the elevation of a spring and its groundwater source could vary from the level of the lowest mine, to the highest. Despite this uncoupling, the general relationship between spring TDS and mine footprint or floor space should be detectable.

3.8.1 Impact on Flow

Mining techniques that open passages in hills make them more porous to groundwater. Thus mine caverns may serve as reservoirs for groundwater. Mining impacts hills in three dimensions. But, because mine galleries tend to be a consistent height, mine floor space is a good yardstick of mining extent. Then mine floor space summed across all levels in a hill system, should reflect the potential size of the groundwater reservoir.

Mine interconnections provide conduits for groundwater movement between mine cells. Then, extensively mined hills are expected to produce larger volume springs. As discussed earlier, spring volume is the primary factor controlling TDS load in mine springs. Then the impacts of mine parameters on TDS concentration are likely to produce only minor changes in TDS load. The impacts of mining on TDS are discussed next.

Table 3.7 Watershed footprint, mine extent, and spring characteristics in the Bull Creek watershed. [22]

Mine Area	Location With Respect to Bull Cr. Watershed	Mined Footprint (ac)	Un-Mined Footprint (ac)	Total Footprint (ac)	Mined Levels	Total Mine Floor (ac)	% of Footprint Mined [a]	Ratio Mine Floor to Footprint [b]	Sum Median Spring Flow (cfs)	Sum Median TDS Load (Mg/yr)	Monitored Spring
A	inside	1115	345	1460	3	1464	76%	1.0	1.70	1,538	Deel Up + **Up Belcher + Down Belcher**
	outside	855	534	1389	3	948	62%	0.7			none
	total	1970	879	2849		2412	69%	0.8			
B	inside	315	152	467	3	546	67%	1.2	0.02	8	Deel Down
	outside	777	544	1322	2	813	59%	0.6			none
	total	1092	696	1788		1359	61%	0.8			
C	inside	1359	365	1724	5	2534	79%	1.5	1.17	741	0.5*Charlie Up+Charlie D+**HMBC**
	outside	1513	1844	3357	5	1982	45%	0.6			none
	total	2872	2209	5081		4516	57%	0.9			
D	inside	705	289	994	4	1097	71%	1.1	0.76	717	0.5*Charlie Up+Cove Ho+**Burnt Ho**
	outside	373	527	900	3	426	41%	0.5			none
	total	1078	815	1894		1523	57%	0.8			
E	inside	2331	755	3086	4	3671	76%	1.2	NA	NA	none
	outside	1443	1790	3233	4	2001	45%	0.6			none
	total	3774	2544	6318		5672	60%	0.9			
Totals	inside	5,825	1,906	7731		9,312	75%	1.2			
	outside	4,961	5,239	10201		6,170	49%	0.6			
	total	10,786	7,143	17930		15,482	60%	0.9			

a .. = 100% * mined Footprint / Total Footprint; implies the percent of area mined.
b .. = Total Mine Floor / Total Footprint; implies the extent of mining in the hill; e.g., 1.5 indicates mining has removed an area equal to 1 ½ times the footprint.

3.8.2 Impact on TDS Concentration

Because mine galleries tend to be a fixed height, the groundwater exposure to minerals in mines should be a linear function of mine floor space. The larger the mined floor space the greater the exposure. Then the amount of mine floor in a hill should relate to the TDS concentration. **Table 3.7** lists the mine floor space for each of the five mined units in the Bull Creek watershed. A larger reservoir may lead to longer

22 From Mine Footprint Vars v02.xls.

groundwater detention time which should result in higher TDS concentration. However, in hills made porous by mining, the water detention time is reduced leading to lower TDS concentration in the groundwater. Therefore, mining may increase or decrease TDS concentration.

3.8.3 Mine Footprint

While the amount of mine floor in a hill system relates to the groundwater volume of a hill system, the footprint still has some attraction. The percent mined footprint (as a % of total footprint) suggests the extent of mining across the hill system. Mining could be extensive, even at several levels, but be restricted to only a portion of the system.

The principal mining factors controlling groundwater and TDS are expected to be those within the Bull Creek watershed because groundwater moves from the watershed boundary downhill. However, mining just outside the watershed boundary, especially if extensive, may modify groundwater volume or TDS in the watershed. Consequently, an estimate was made of the mine footprint and mine floor of the extent of mines in and around Bull Creek watershed (**Table 3.7**).

3.8.4 Mine Units

Mine unit A seems unique in that more than 50% of it has been mined primarily at one level compared to units C and E which have been mined at multiple levels. Mine unit A is the same as hydrologic island #1+#2. Mine Unit A has the highest spring volume among the four mined areas with springs. Therefore, it yields the highest TDS load. Dominant springs Up Belcher and Down Belcher are the contributors. Unit A's mined footprint and total footprint are the second largest of the four mined areas with springs. It also has the second largest mine floor.

Mine unit B has the smallest total footprint inside the watershed, and, as might be expected, the smallest mined footprint. It has by far the smallest mined floor space and the smallest percent of mined footprint to total footprint (67%). Consequently, its spring Deel Down has the lowest TDS load of all mine units with springs. Unit B covers the same area within the Bull Creek watershed that hydrologic island #7 covers.

Unit C, of the spring-monitored units, has the most extensive total footprint, mine footprint, and number of mine floors. Consequently, unit C has one of the highest spring volumes and TDS loads, although these measures are only about half the values in unit A. Its springs include dominant spring HMBC and moderate volume springs Charlie Up and Charlie Down. Unit C covers the same area within the watershed as hydrologic islands #3 and #4 combined.

Mine unit D has a mined and total footprint more than half the size of A, and produces about half the TDS load. The ratio of mined footprint to total footprint in D is also smaller; 71% versus 76% while its ratio of mine floor to footprint is slightly larger. Unit D covers, within the watershed, the same area as hydrologic islands #5 and #6.

Mine unit E is the largest in the study area. But it lacks monitored springs and so provides no indication of the relationship between mine features and spring water quality or quantity.

Based on the above discussion, for predicting TDS load or spring volume, mine parameters appear useful measures for distinguishing mine units. The identified mine units appear to have reasonable boundaries but there does not appear to be a relationship to TDS load or flow volume for the measured mine parameters. Perhaps because of the small number of units for comparison there is not a clear relationship between the examined parameters and TDS load and flow volume as there was for hydrologic island footprint. As an example of the lack of relationship, mine unit loads are graphed against mine floor area in **Figure 3.21**. The R-squared coefficient of 0.13 suggests there is no clear relationship. The spread of data points suggests much more data are needed to determine whether any relationship exists.

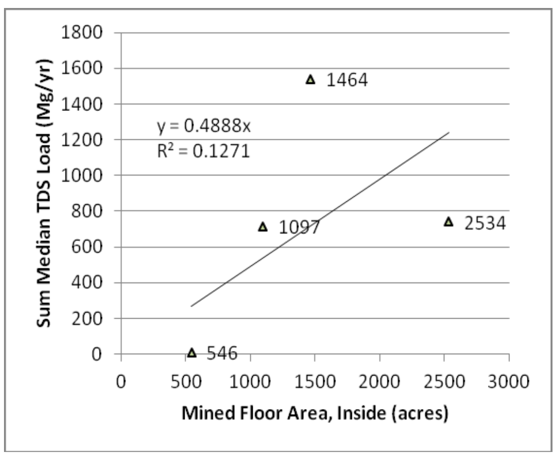


Figure 3.21 Relationship between mine floor and TDS load in the Bull Cr. watershed. [23]

23 Source: Mine_param_totals.xls[Totals].

4. South Fork Pound River Watershed and Monitoring

Water quality data have been collected since about 1995 in the South Fork Pound watershed. Samples have been collected in-stream (**Figure 4.1**) as well at National Pollutant Discharge Elimination System (NPDES) outfalls associated with mining (**Figure 4.13**). These data are discussed in the following sections. Following that, hydrologic islands and mining activities are detailed.

4.1 In-stream Water Quality, S. F. Pound

The TDS load at the final S. F. Pound watershed outlet originates primarily in the upper watershed. It can be traced up the mainstem of the river in which the load remains approximately constant from the outlet across the lower watershed and halfway up the upper watershed. Thus, although the outlet has a TDS load of 29.4 $*10^6$ kg/yr (station #12), half way up the upper watershed it is 28.3$*10^6$ kg/yr (station #27); about the same (**Table 4.1**). Over that distance the stream volume decreases by one third and the TDS concentration correspondingly increases upstream. That the source of TDS is not in the lower watershed is supported by noting that the TDS concentration at station #14, which drains the southeast quarter of the lower watershed is 424 mg/L.

4.1.1 Mainstem

Generally, the mainstem in the lower watershed has about 28% higher flow than the upper watershed because of its larger catchment (comparing stations #12 and #37). But the TDS concentration is about 25% lower. Thus, the TDS load at the outlet of the lower watershed is only slightly larger than in the upper watershed. The differences in potential loads from the two parts of the S. F. Pound River watershed contrast more when normalized to 11,000 gpm, the flow at the outlet. The normalized loads emphasize the TDS strength of mainstem streams in the upper watershed.

4.1.2 Intermittent streams

Intermittent streams in the lower watershed on average have TDS concentration medians ranging from freshwater range to dilute mine water; 236 - 958 mg/L. This is expected because there is very little mining in the area so that few mineral-rich discharges are available to add TDS. On the other hand, intermittent streams in the upper watershed are fed by many mineral-rich discharges regularly generating high TDS concentrations. Based on 2012-2013 data, the TDS concentration median range is 1,189 – 3,265 mg/L. The difference in tributary TDS strength is especially evident when the TDS load is normalized to a flow of 11,000 gpm as provided in **Table 4.1**.

It is worth noting that a tributary in the lower watershed contains less than 4% the TDS load of the mainstem, while a tributary in the upper watershed contains up to 14% of the mainstem load.

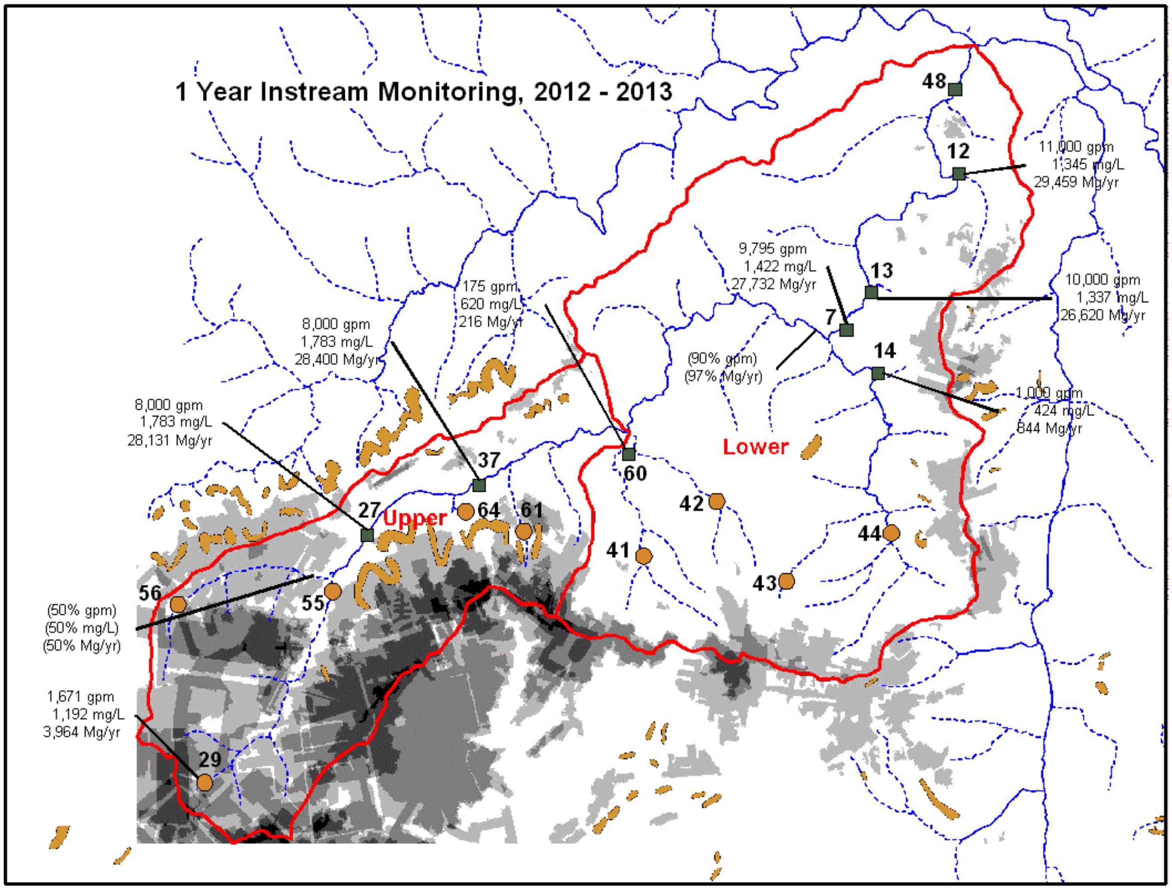


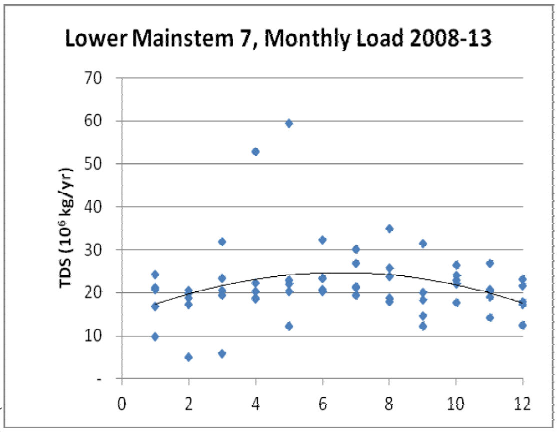
Figure 4.1 In-stream median TDS, TDS load (Mg/yr), and stream flow for one year in the S.F. Pound River watershed. Squares mark perennial streams and circles mark intermittent stream stations.[24]

4.2 Seasonality

A comparison of mainstem flow seasonality was attempted for 2009-2013 (**Figure 4.2)**. Of note is the disparity between the median flow at station 12 of 25,500 gpm for the period and 11,000 gpm for the current year. The period of record flow is double that predicted from feeder stations 13, 7, and 37 for the same period and so is erroneous. This means the TDS loads would be over-estimated as well. Consequently, flow was examined for station 7 a few miles upstream. In both the lower and upper watersheds, mainstem flow is somewhat lower during the growing season (**Figure 4.2**). At the same

24 Source: SFP_Monitoring_v4.png; SFP_Monitoring_v4.vsd.

time, TDS load tends to be higher during the growing season in both watersheds (



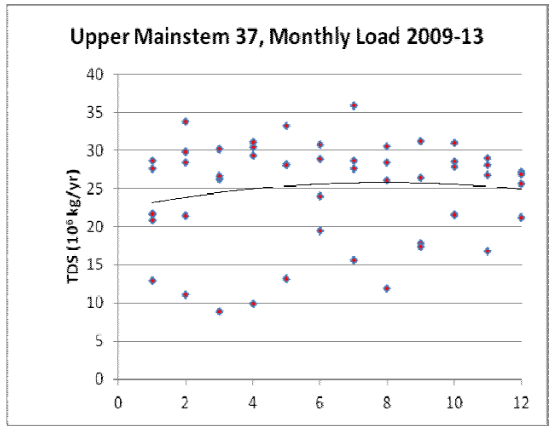


Figure 4.3).

Table 4.1 In-stream water quality over the recent 12 months as mapped in Figure 4.1 for the S. F. Pound River watershed.[25]

Watershed	Map No.	DMME MpNo	Median Flow (gpm)	Median TDS conc. (mg/L)	Median TDS Load (10^6 kg/yr)	TDS Load Normalized to 11,000 gpm (10^6 kg/yr)	Sample Period
Perennial							
Lower, mainstem*	**12**	0007245	**11,000**	**1,345**	29.394	29.4	2012-13
" "	**13**	0007246	**10,000**	1,337	26.563	29.2	2012-13
" "	**7**	0006928	**9,795**	1,422	27.673	31.1	2012-13
" " , tributary	**14**	0007696	1,000	424	0.842	9.3	2012-13
Upper, mainstem	**37**	3420109	8,000	**1,783**	28.339	39.0	2012-13
" "	**27**	3420066	8,000	**1,766**	28.069	38.6	2012-13
Intermittent							
Lower, tributary	**60**	3420267	175	620	0.216	13.5	2012-13
" "	**44**	3420178	**450**	498	0.445	10.9	2012-13
" "	**43**	3420177	38	958	0.072	20.9	2012-13
" "	**42**	3420176	5	236	0.002	5.2	2012-13
" "	**41**	3420175	75	834	0.124	18.2	2012-13
Upper, tributary	**61**	3420268	43	**2,843**	0.243	62.1	2012-13
" "	**64**	3420271	30	**3,265**	0.195	71.4	2012-13
" "	**55**	3420257	**500**	736	0.731	16.1	1995**
" "	**56**	3420258	88	551	0.096	12.0	1995**
" "	**29**	3420085	**1,671**	**1,192**	3.957	26.1	2012-13
" "	**39**	3420111	1,685	1,189	3.980	26.0	2012-13

* ..outlet of the S. F. Pound watershed.

25 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[tab: Instream Extracted].

** .. no more recent data. TDS concentrations from this period are substantially lower than in 2012-13.

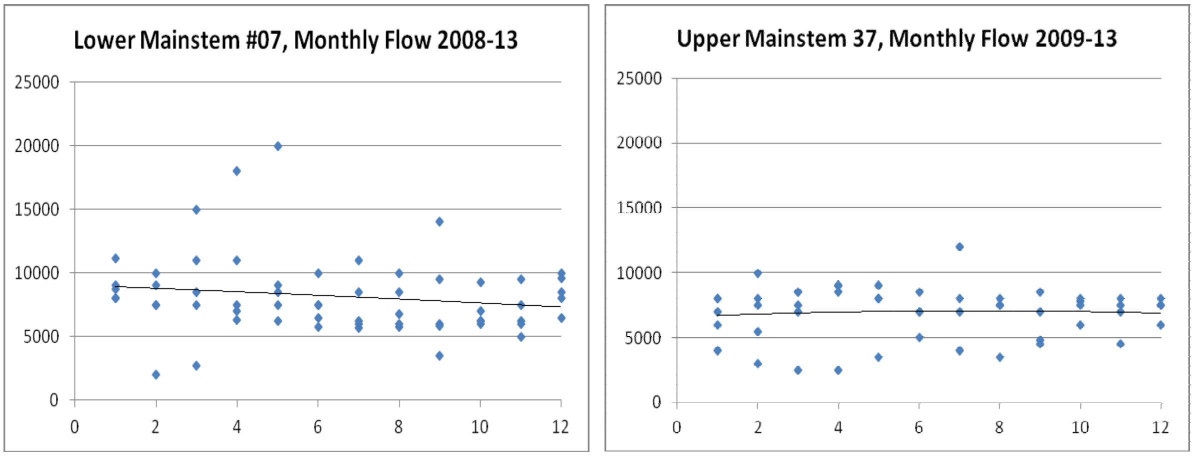


Figure 4.2 Monthly flow (gpm) in the lower (station 07) and upper (station 37) S. F. Pound. [26]

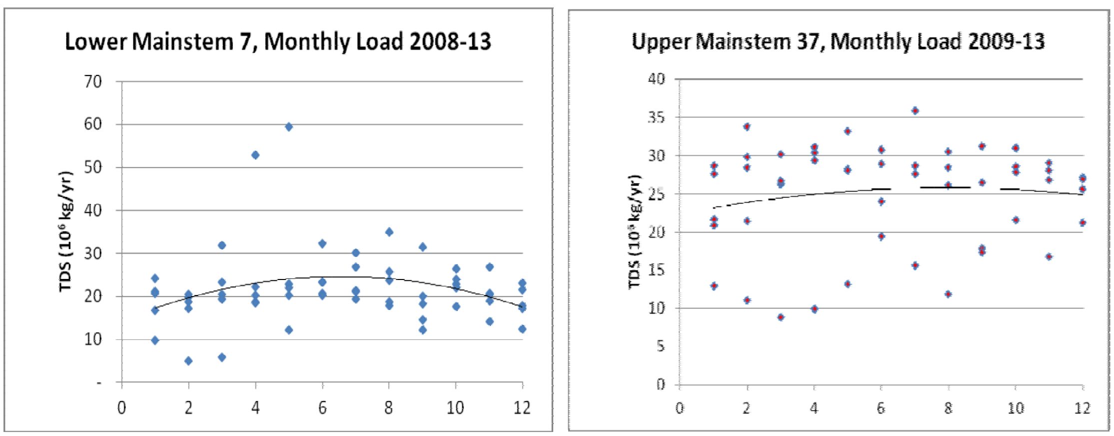


Figure 4.3 Monthly TDS Load (10^6 kg/yr) in the lower and upper S. F. Pound.

Based on the most recent year's data, mainstem flow in the upper watershed tends to fluctuate around a median flow of 8,000 gpm (stations 37 and 27; **Figure 4.4**). Meanwhile, tributary flow tends to be low in the growing season and high from November through March (stations 64 and 61; **Figure 4.4**).

26 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

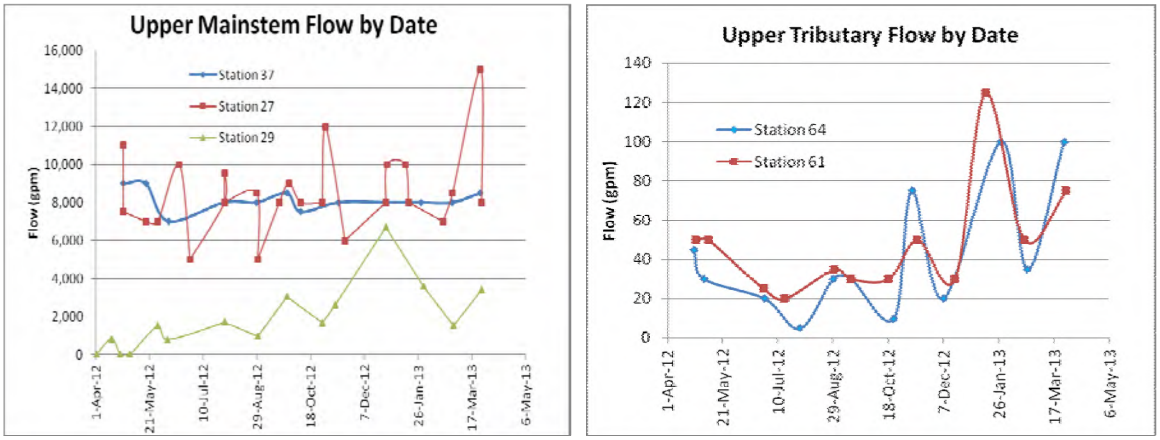
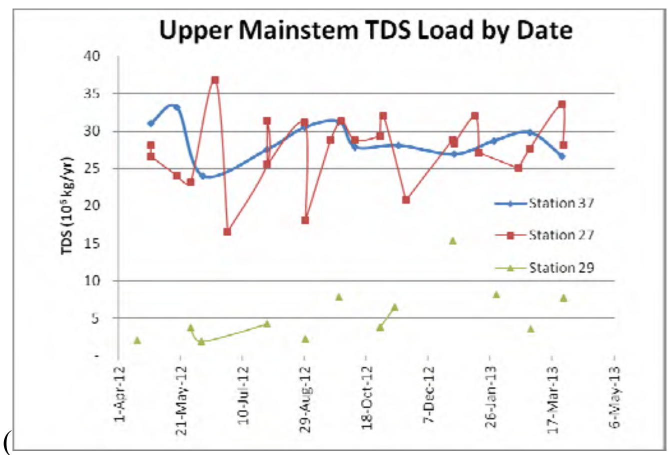


Figure 4.4 Mainstem and tributary flow (gpm) in the upper S. F. Pound. [27]

Based on recent data, mainstem TDS concentration and load also fluctuate around the median in the mainstem (**Figure 4.5**). However, tributary stream TDS concentration is highest in the growing season, and as much as double that in the mainstem. While TDS load tends to fluctuate about the median in the mainstem, tributary TDS load is highest when the flow is high from November through March (



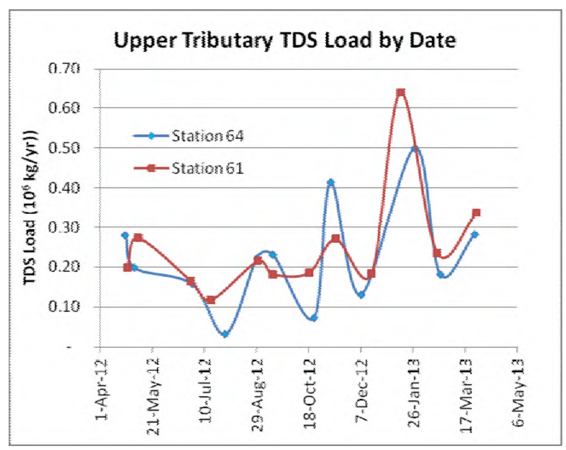


Figure 4.6). The seasonal tributary TDS load pattern is similar to that for Bull Cr. watershed springs.

In the upper watershed, the great difference in mainstem and tributary loads and the difference in seasonality indicates that tributary TDS-loading of the mainstem is diluted by substantial runoff and other low-TDS sources in the upper S. F. Pound watershed.

27 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_Extracted].

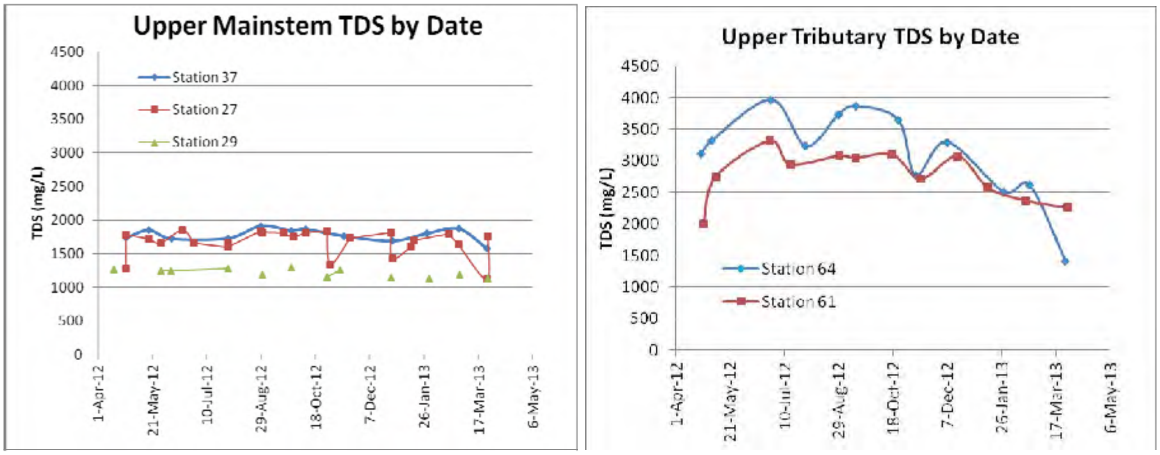


Figure 4.5 Mainstem and tributary TDS concentration (mg/L) in the upper S. F. Pound. [28]

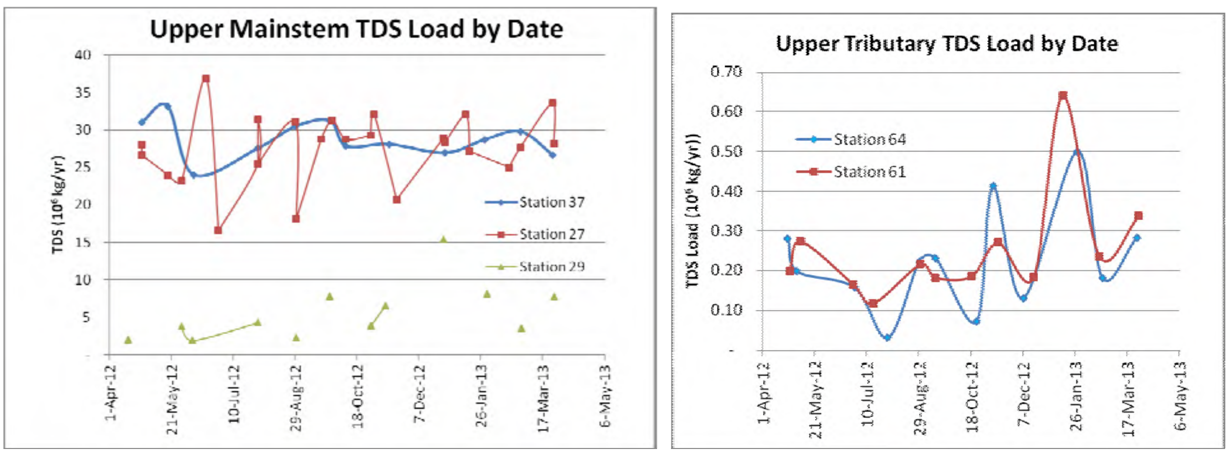


Figure 4.6 Mainstem and tributary TDS load (10^6 kg/yr) in the upper S. F. Pound. [29]

4.3 In-stream Historical Patterns, S. F. Pound

In-stream water quality data for the S. F. Pound mainstem and tributaries have been collected since 1995. A few stations have been monitored continuously over that period. The recent conditions of TDS concentration, TDS load and flow are indicated in **Figure 4.1**.

Near the outlet of the S. F. Pound watershed is in-stream station 48. Because it was only monitored from 1995 through 2005, the data for station 7 has been added to complete the TDS record through 2013 although there is a 2006 gap. Note that the data for station 7 has not been adjusted to account for the smaller catchment at station 7.

28 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_Extracted].
29 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

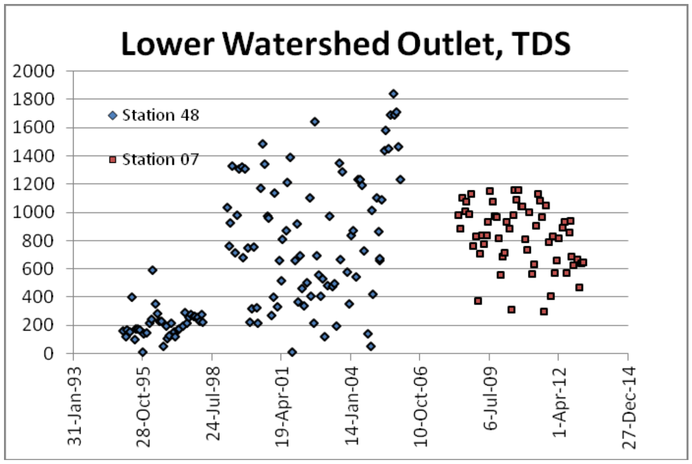


Figure 4.7 In-stream TDS concentration (mg/L) at the S. F. Pound River watershed outlet.[30]

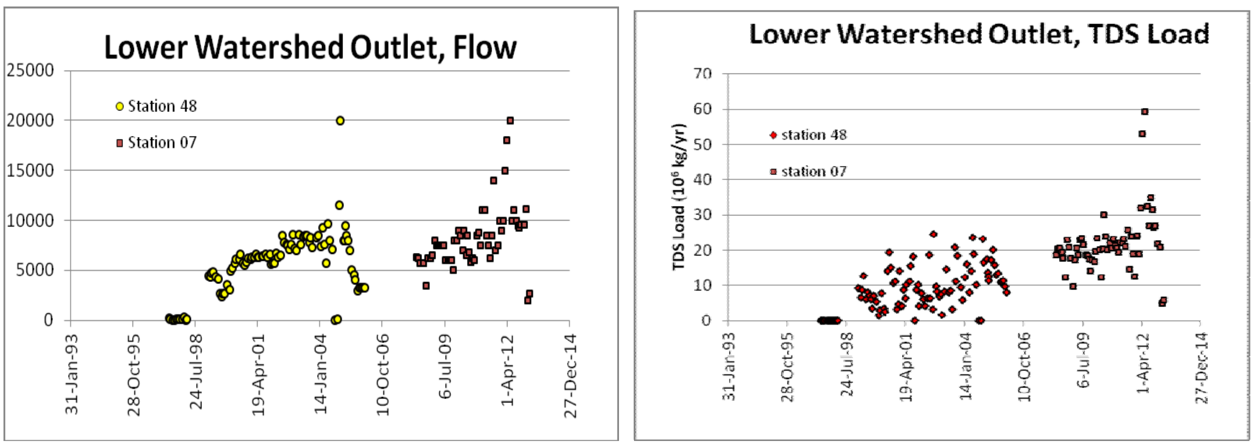


Figure 4.8 In-stream flow (gpm) and TDS load (10^6 kg/yr) at the S. F. Pound River watershed outlet.[31]

At station #48/#07, the TDS concentration abruptly rose 600 mg/L in early 1998 and became more variable (**Figure 4.7**). The early TDS concentration was often typical of freshwater, while after 1997 the TDS was mainly in the range expected of mine discharge waters (>620 mg/L). Meanwhile, the flow gradually doubled over the 1998 to 2005 period. The TDS load abruptly increased in 1998 and continued an upward trend through 2013 (**Figure 4.8**).

In the upper watershed, which today is extensively mined, the water quality record is presented for station #37, which is very similar for station #27 located 1.4 miles upstream. The data suggests that the TDS concentration has been steadily increasing from 1995 to 2013 (**Figure 4.9**). TDS variability also appears to have reduced as the concentration became consistently high. A second-order polynomial is used to track the TDS concentration trend.

30 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].
31 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

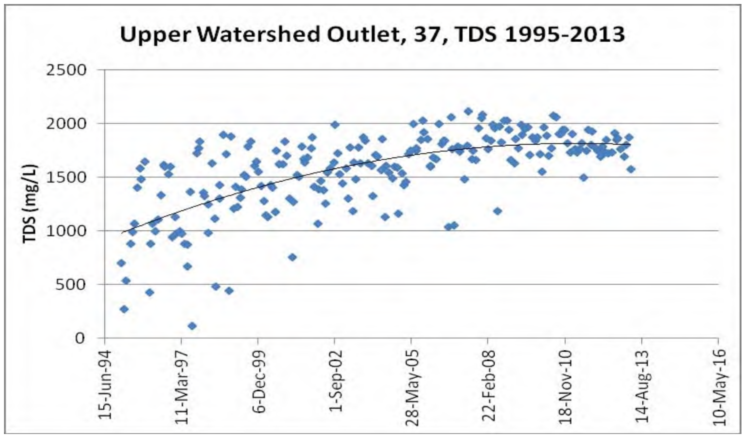


Figure 4.9 In-stream TDS (mg/L) near the outlet of the upper S. F. Pound R. watershed. [32]

The flow volume at station #37 follows a rollercoaster pattern (**Figure 4.10**, left). It began low in 1995, rose to average 4,000 in 1999, dropped to about 3,000 gpm for about 6 years, and rose to about 7,500 gpm in 2009 to 2013. Because TDS load is strongly controlled by flow, it demonstrated a similar pattern starting at a low of about 2 x 10^6 kg/yr in 1995 and reached about 35 x 10^6 kg/yr recently. It is possible that the flow pattern is an artifact of a change in the method of flow measurement method. Nonetheless, the recent flows and TDS values are thought to be dependable, and the increasing trend in TDS concentration is consistent. The overall increase in TDS concentration and load is corresponds with increased mine activity, as evidenced by aerial photography.

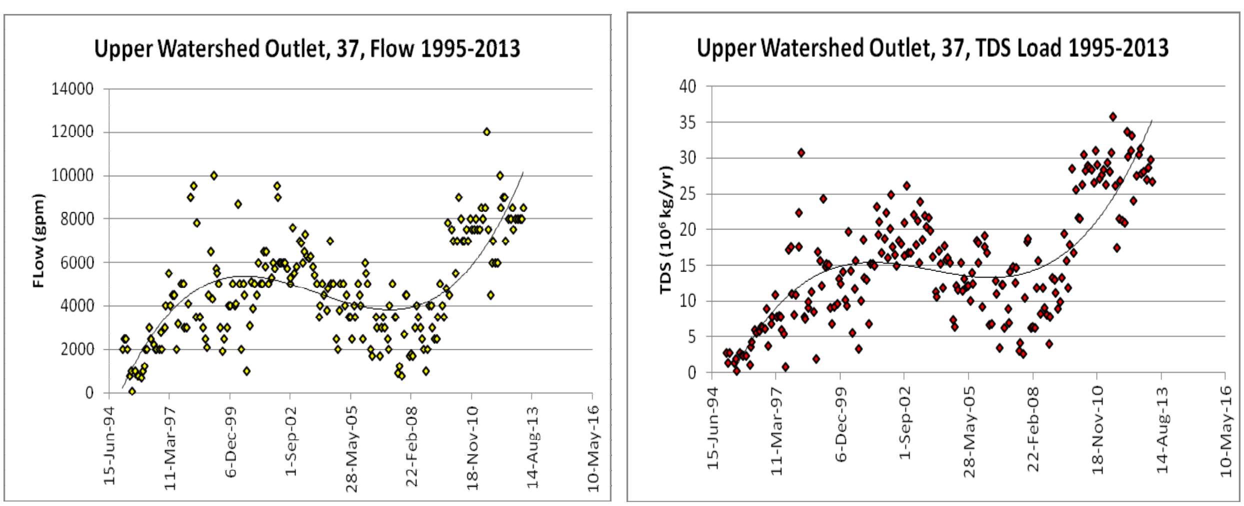


Figure 4.10 In-stream flow (gpm) and TDS load (10^6 Mg/yr) near the outlet of the upper S. F. Pound River watershed.

To confirm that much of the TDS in the mainstem originates in the upper S. F. Pound watershed, the water quality is examined for tributaries in the watershed. Tributary station 42 in the upper part of the

32 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

lower watershed is used as the example. The TDS concentration was initially somewhat variable in the 1990s but became relatively stable through the present at about 236 mg/L; a freshwater concentration. Tributary flow has been a relatively low 5 gpm and, consequently, the TDS load has been a fraction of the mainstem. Finally, normalized to the watershed outlet flow, the TDS load strength is well below that of the outlet. The same low strength applies to the other lower watershed tributaries for which there are data (**Table 4.1**). The reverse is true of upper watershed tributaries, which have TDS load strengths equal to, or exceeding the load of the watershed outlet.

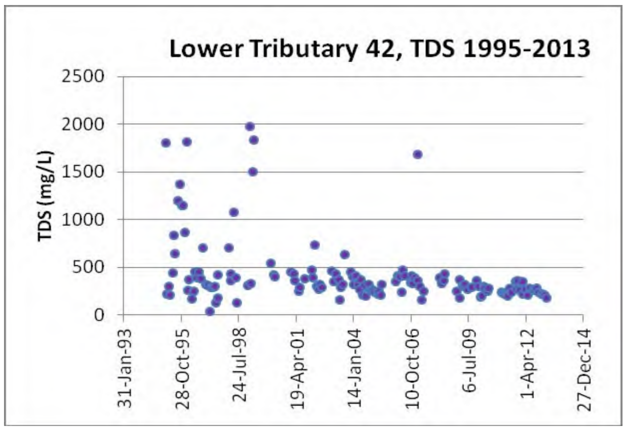


Figure 4.11 Tributary TDS (mg/L) in the lower S. F. Pound River watershed (1995-2013). [33]

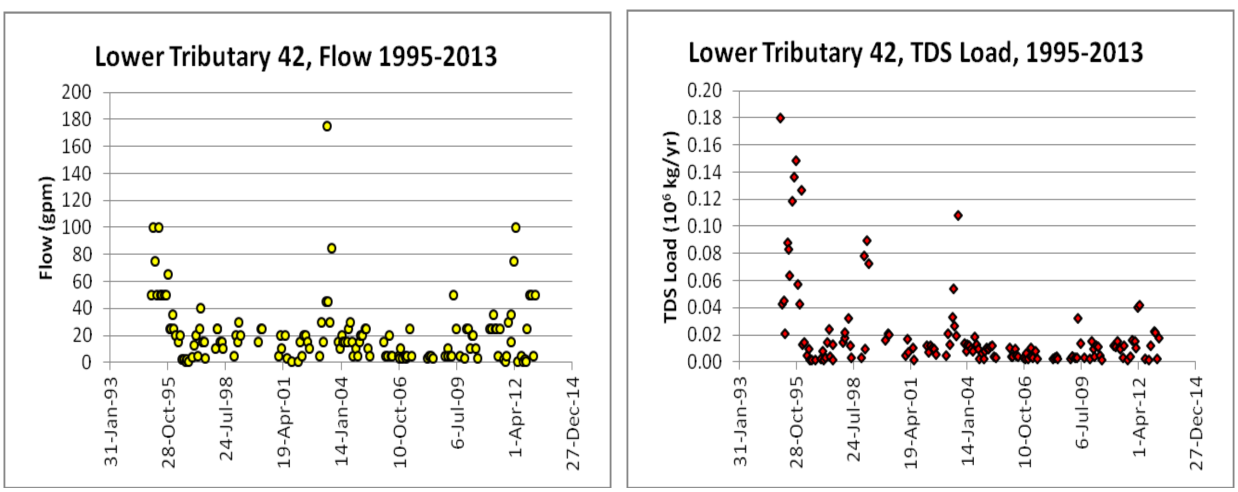


Figure 4.12 Tributary flow (gpm) and TDS load (10^6 Mg/yr) in the lower S. F. Pound River watershed.

33 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

4.4 Mining NPDES Permitted Discharges, S. F. Pound

There are water quality records for many NPDES permitted discharges in the watershed (Appendix A, **Figure)**. However, only twelve have been monitored for flow and TDS. The characteristics of these discharges for the most recent 12 months are presented in **Table 4.2** and **Figure 4.13**. The data for stations 82 and 34 is viewed with caution because the record period is earlier.

Table 4.2 NPDES discharge over the recent 12 months in the S. F. Pound River watershed.[34]

Map No.	DMME MpNo	Median Flow (gpm)	Median TDS (mg/L)	Median TDS Load (10^6 kg /yr)	TDS Load Normalized to 11,000 gpm (10^6 kg/yr)	Sample Period	Notes
Lower Watershed:							
12	0006925	30	405	0.024	8.9	2012-2013	
64	3470158	50	778	0.077	17.0	2012-2013	
20	2670086	100	1,202	0.239	26.3	2012-2013	
89	3470291	100	**2,098**	0.417	45.9	2012-2013	
Upper Watershed:							
92	3470294	**554**	**2,006**	**2.208**	43.8	2012-2013	compare IS#37
85	3470287	**554**	**2,016**	**2.219**	44.1	2012-2013	adjacent to #92
84	3470286	25	1,744	0.087	38.1	2012-2013	compare IS#27
86	3470288	52	**2,328**	0.241	50.9	2012-2013	
91	3470293	52	**2,322**	0.240	50.7	2012-2013	adjacent to #86
82	3470259	**700**	928	**1.291**	20.3	**2009-**	
35	3470069	63	1,771	0.222	38.7	2012-2013	adjacent to #82
34	3470068	100	1,272	0.253	27.8	**2009-**	near #82

* .. no more recent data.

NPDES discharges in the lower watershed, based on recent monitoring, exhibit a range of TDS concentration from freshwater to mine water quality. Meanwhile, discharges in the upper watershed exhibit TDS in the mine water range; all exceed a median of 1,700 mg/L. The individual TDS loads are small compared to the load at the S. F. Pound outlet, 29.4 x 10^6 kg/yr, because the flows are relatively small. However, when normalized to the flow at the outlet, especially the discharges in the upper watershed exhibit larger TDS strength than the mainstem outlet. This indicates that these small discharges, if representative of a larger contributing area, can significantly raise the TDS load in area streams.

34 DMME SFPound IS and NP data 7_26_13_CDF.xls[NPDES Extracted].

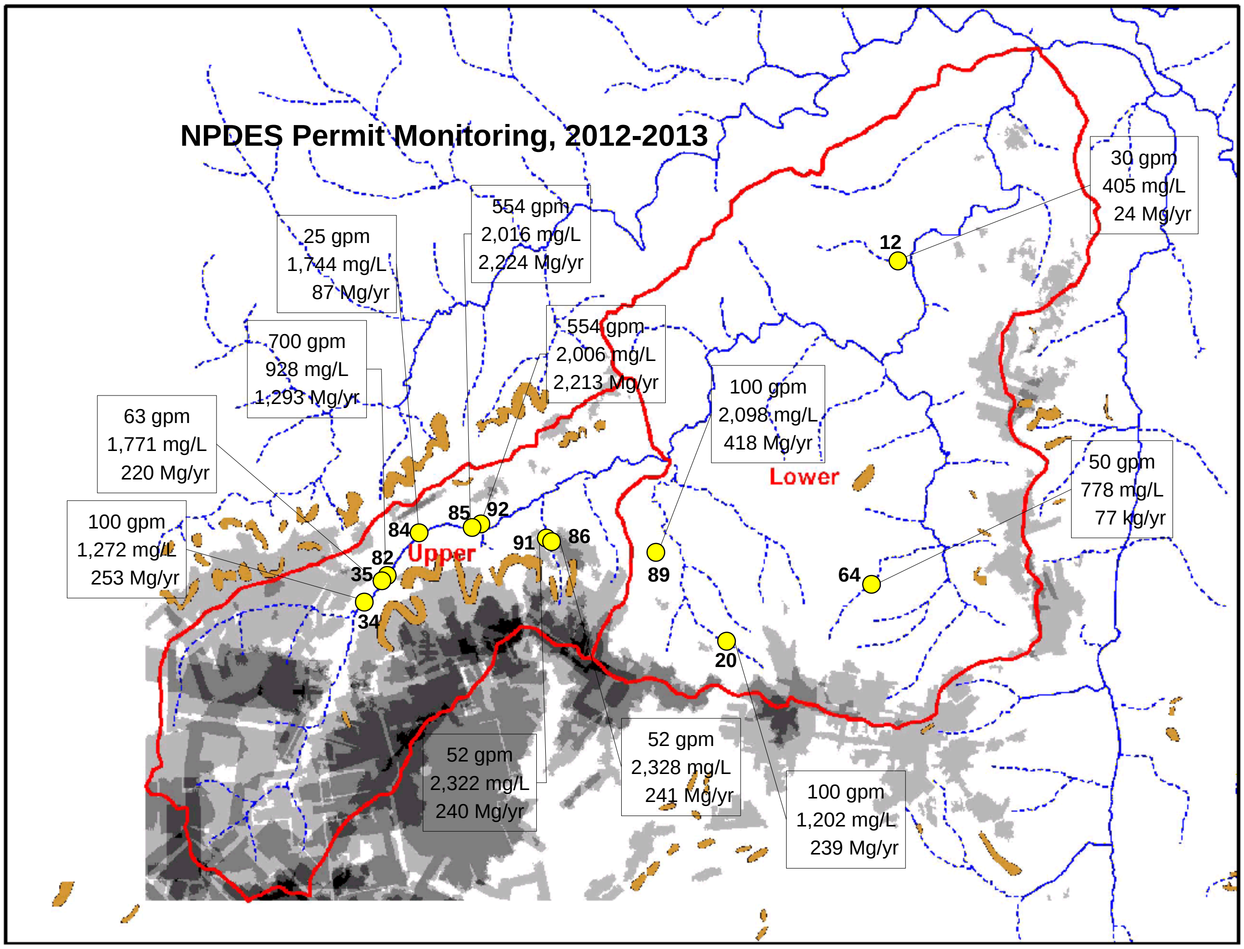


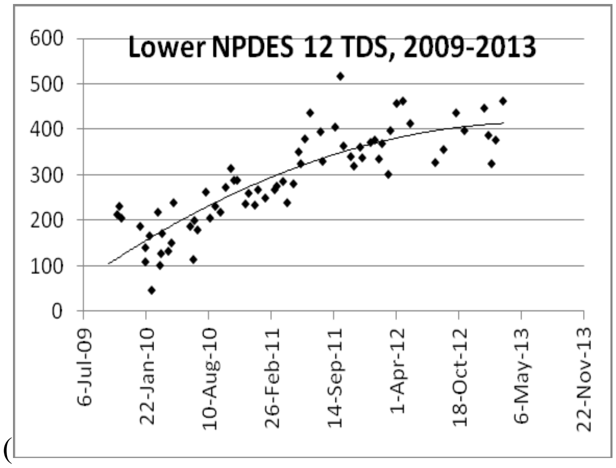
Figure 4.13 NPDES discharge median TDS (mg/L), TDS load (10^3 Mg/yr), and stream flow (gpm**) for one year in the S. F. Pound River watershed.**[35]

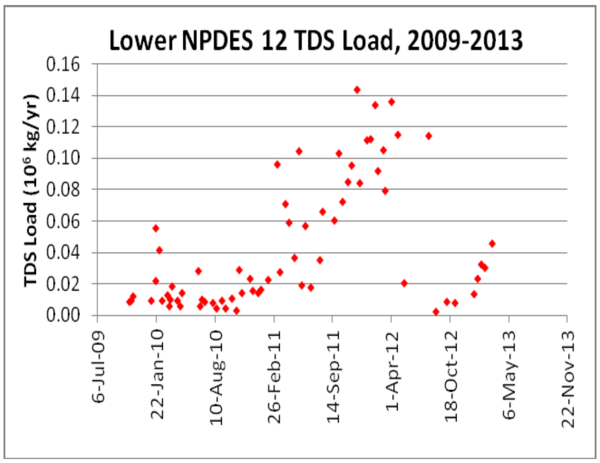
NPDES discharges 12, 91 and 92 were chosen for detailing water quantity and TDS changes over time because discharge 12 is in the lower watershed and 91 and 92 are in the upper watershed. They were all sampled in 2012 and 2013, but their records began at different times with the earliest record being from NPDES station 92. Presumably the record start date is the date permitted mining began above each discharge.

35 Source: SFP_NPDES_v5.vsd

TDS Loads in Bull and Pound Watersheds

In the lower watershed, from 2009 to 2013, flow was variable at NPDES 12 (**Figure 4.14**) while TDS concentration exhibited the same upward trend (Figure 4.15, left) observed in the mainstem of the upper watershed (**Figure 4.19**). TDS load had a median of 0.024 x 10^6 kg/yr r and varied with flow being highest in 2011 and early 2012.





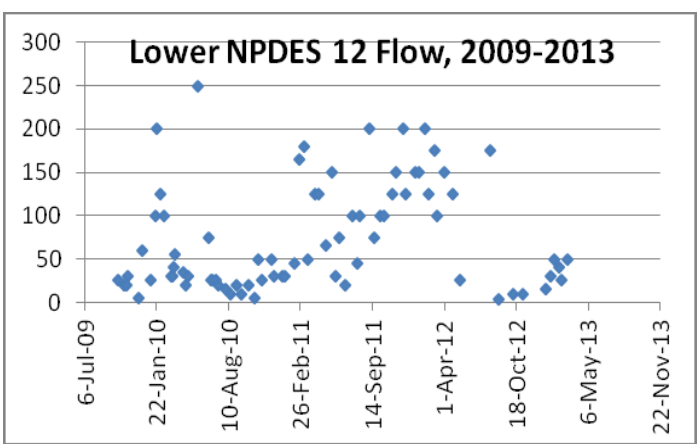


Figure 4.14 NPDES #12 flow (gpm**) in the lower watershed from 2009 to 2013.** [36]

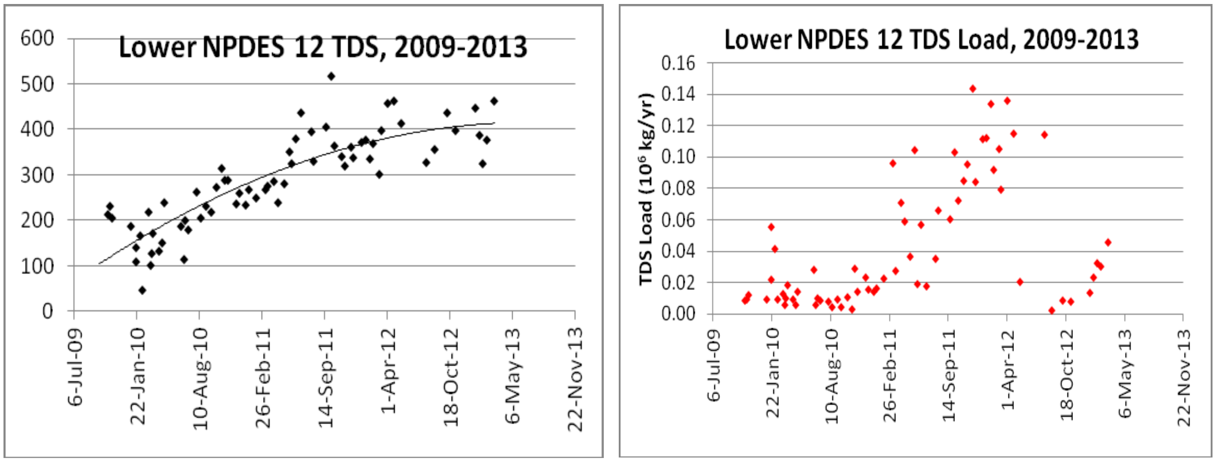


Figure 4.15 NPDES #12 TDS concentration (mg/L, left) and load (10^6 kg/yr, right) in the lower watershed. [37]

In the upper watershed at NPDES 92 where the record is longer, the discharge flow trended upward over the period (**Figure 4.16**) as did the TDS load reaching a median of 2.208 x 10^6 kg/yr in the most recent 12 months (**Figure 4.17**). The reason for the increase compared to NPDES 12 is partly the much larger median TDS concentration, 2,006 mg/L, but especially the flow, which was 18 times larger.

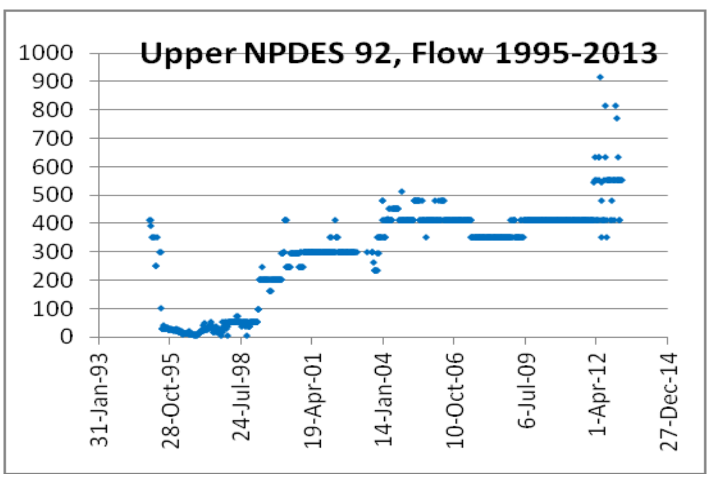


Figure 4.16 NPDES #92 flow (gpm) in the upper watershed from 1995 to 2013. [38]

36 Source: DMME SFPound IS and NP data 7_26_13_CDF_NPDES.xls[tab: NPDES WQData].
37 Source: DMME SFPound IS and NP data 7_26_13_CDF_NPDES.xls[tab: NPDES WQData].
38 Source: DMME SFPound IS and NP data 7_26_13_CDF_NPDES.xls[tab: NPDES WQData].

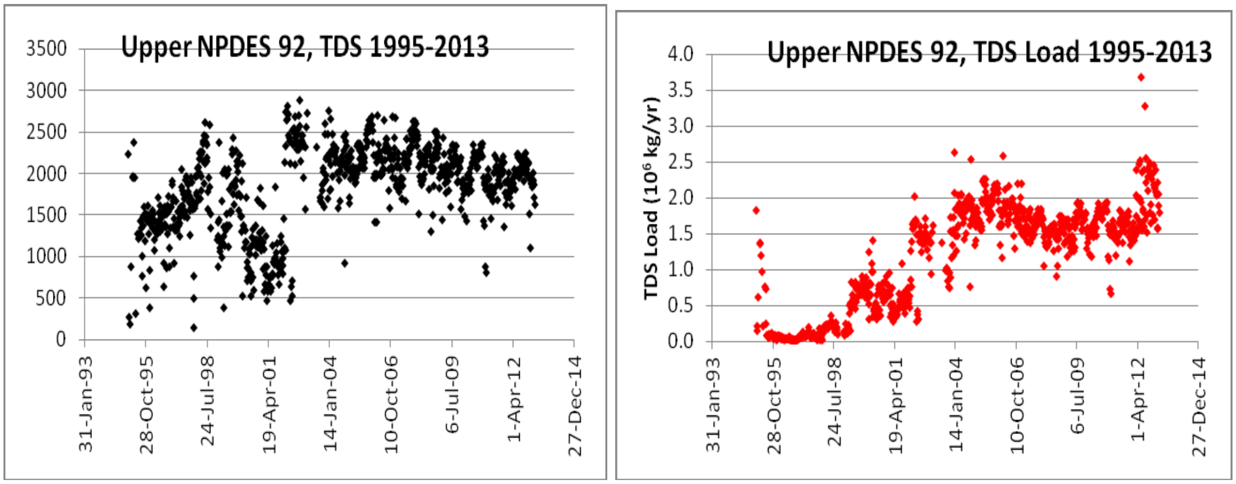


Figure 4.17 NPDES #92 TDS concentration (mg/L, left) and load (10^6 kg/yr, right) in the upper watershed.

NPDES 91 had one-tenth the flow of NPDES 92 (**Figure 4.18**), and consequently had one-tenth the TDS load. The recent TDS concentration median was somewhat larger; 2,333 mg/L (**Figure 4.19**). Over the period of record, the TDS concentrations in both NPDES 91 and NPDES 92 appear lower before about the year 2002 and higher thereafter.

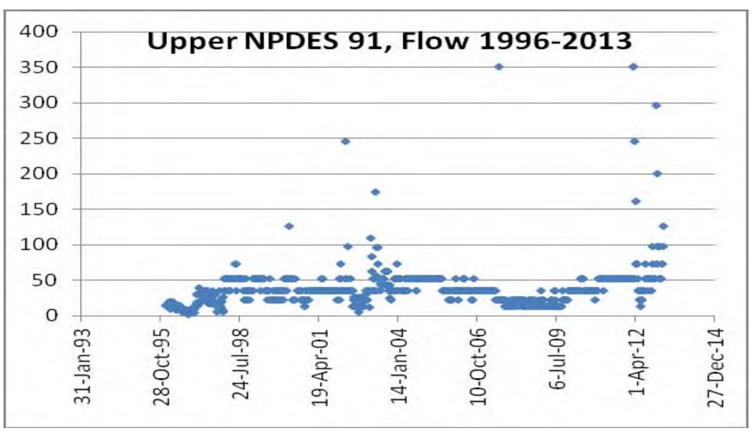


Figure 4.18 NPDES #91 flow (gpm**) in the upper watershed from 1996 to 2013.** [39]

39 Source: DMME SFPound IS and NP data 7_26_13_CDF_NPDES.xls[tab: NPDES WQData].

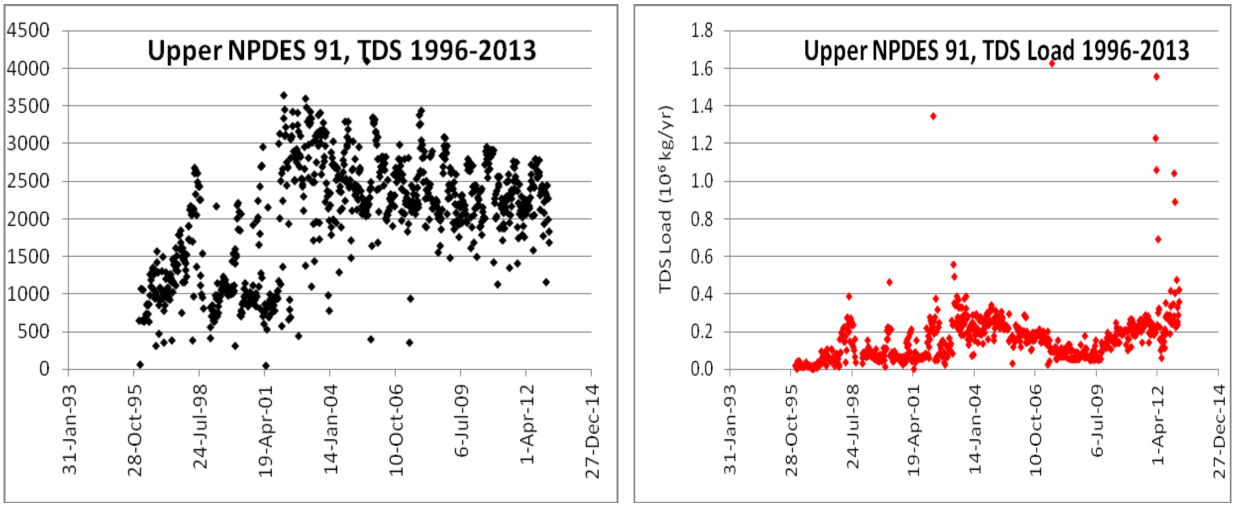


Figure 4.19 NPDES #91 TDS concentration (mg/L, left) and load (10^6 kg/yr, right) in the upper watershed.

4.5 Mining Extent, S. F. Pound

The Department of Mines, Minerals and Energy provided ArcView® shape files for mine floor space in and near the S.F. Pound River watershed. ArcView® was used to measure the aerial extent of the mining.

For purposes of analysis, the South Fork Pound River (S. F. Pound) watershed was divided hydrologically into topographically upper and lower components (**Figure 4.20**). The major difference is the upper watershed is extensively mined while the lower watershed is mined very little. Mining in the lower watershed is principally along the watershed boundary and then mainly one level deep. Below-ground mining in the upper watershed is up to four levels deep, and the area has been surface-mined as well. Because underground mining characteristics in the upper watershed in the S. F. Pound are very similar to those in the Bull Cr. watershed, relationships found in the Bull Creek watershed should apply to the upper watershed as well.

Table 4.3 Watershed footprint and mine extent in the S. F. Pound River watershed.[40]

	Upper Watershed				Lower Watershed				Total	
Number of Mine Levels	**Mined Foot-print (acres)**	**Total Mine Floor (acres) [a]**	**% of Water-shed Mined**	**Ratio Mine Floor to Water-shed**	**Mined Foot-print (acres)**	**Total Mine Floor (acres) [a]**	**% of Water-shed Mined**	**Ratio Mine Floor to Water-shed**	**Mined Foot-print (acres)**	**Total Mine Floor (acres)**
0 (area	1,297	0			6,821	0			8,118	0

40 Source: Mine_param_totals.xls[Totals].

unmined)										
1	1,258	1,258			459	459			1,717	1,717
2	727	1,454			100	200			827	1,654
3	509	1,526			18	54			527	1,580
4	58	234			2	7			60	241
Mine Footprint	**2,552**[b]		**66%**		**578**[b]		**8%**		**3,130**[b]	
Total Mine Floor		**4,472**		**1.2**		**720**		**0.1**		**5,191**
Watershed Area	**3,849**[c]				**7,399** [c]				**11,189** [c]	

a .. = Number of Mine Levels multiplied by Mined Footprint.
b .. Total of footprint in Levels 1 – 4.
c .. sum of "0 (area unmined)" and "Mine Footprint".

The S. F. Pound River watershed totals 11,189 acres, which is 31% larger than the 7,731 acres in the Bull Creek watershed (compare **Table 3.7** and **Table 4.3**). However, the upper S. F. Pound watershed has a footprint of 3,849 acres; half the size of the Bull Creek watershed.

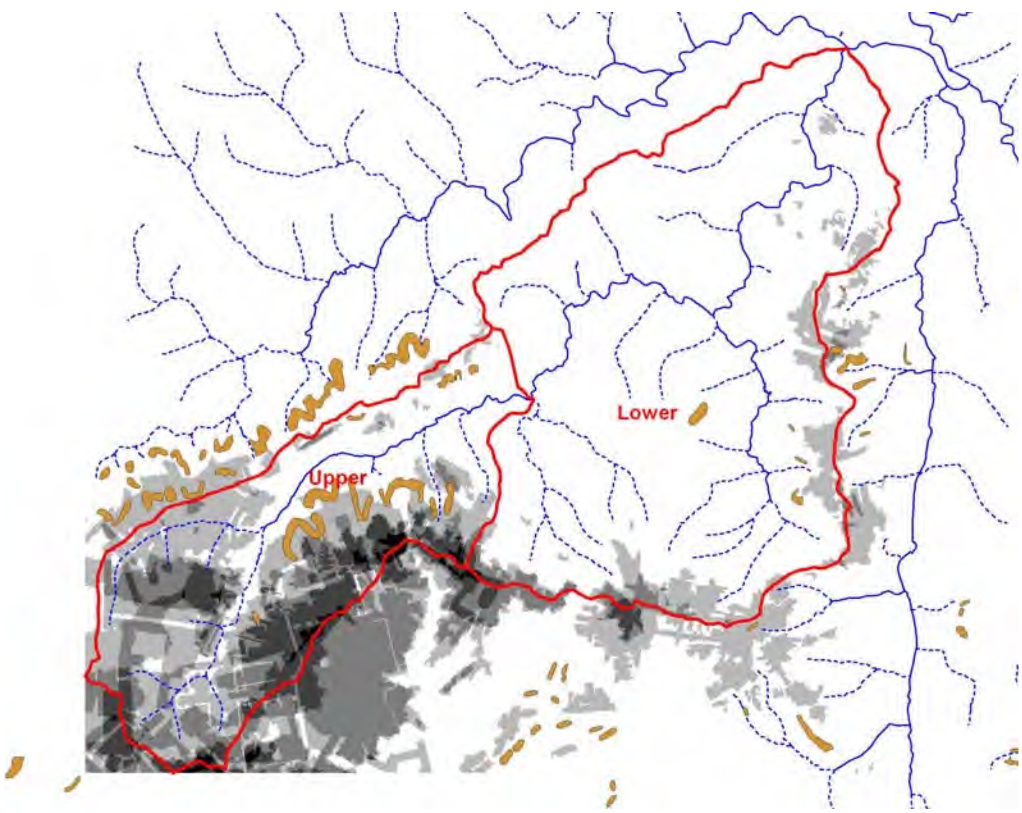


Figure 4.20 Underground and surface mining in the S. F. Pound River watershed.[41]

4.6 Hydrologic Islands, S. F. Pound

The upper watershed of the S. F. Pound watershed appears to consist of five hydrologic islands (**Figure 4.21**). The measures for the hydrologic islands are presented in **Table 4.4**. As in the Bull Creek watershed, the hill units were divided based on suspected contiguity of underground mine drainage. For example, the S. F. Pound mainstem has not been undermined for most of its length and so divides the area into two parts. Island #8 is essentially un-mined. Island #9 has been thoroughly mined at one level. Islands #10, 11 and 12 have been extensively mined underground, but islands #11 and #12 also contain prominent abandoned surface mines.

41 Source: SFP_Monitoring.vsd.

Table 4.4 Hydrologic island topography in the upper S. F. Pound River watershed.[42]

Island	Island Footprint (acres)	Top Elevation (ft)	Bottom Elevation (ft)	Relief (ft)	Standard Island Volume (10^9 ft^3)	Mine Footprint (acres)
#8	571	2200	1800	400	10	66
#9	213	2600	2000	600	6	165
#10	1,013	3600	2000	1,600	71	891
#11	1,438	3600	1850	1,750	110	1,189
#12	613	2700	1750	950	25	242
Sum:	3,849	3600	1750	1,850	221	2,552

Note: 1 acre = 43,560 square feet

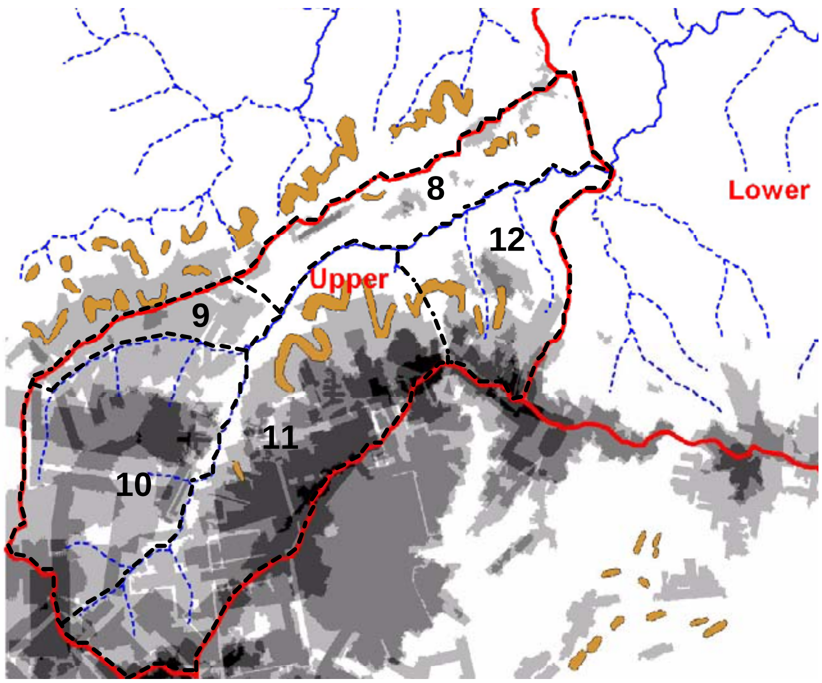


Figure 4.21 Hydrologic islands in the upper S. F. Pound River watershed.[43]

4.1 Comparison of Bull Creek and S. F. Pound Watersheds

4.1.1 Hydrologic Island Relationships

Relationships were developed in the Bull Creek watershed between hydrologic island footprint and spring flow/TDS load (**Figure 3.18**). They are used here to estimate the flow and TDS load of springs in the four most extensively mined hydrologic islands, #9 through #12, in the upper S. F. Pound watershed

42 Source: SFP_Island Dimensions_8_23_13.xls.
43 Source: SFP_Islands v2.vsd.

(**Table 4.5**). In the S. F. Pound, island #8 has very little mining and should produce low-TDS springs. The spring discharge in Bull Cr. island #7 with similar island parameters approximates its load and flow.

Table 4.5 Comparison of hydrologic islands.[44]

Watershed and Island	Foot-print (acre)	Relief (ft)	Island Volume (x10^9 ft^3)	Mining	Median Spring Flow (gpm)	Median TDS conc. (mg/L)	Median TDS Load (Mg/yr)	*Load x Flow* Median TDS Load (Mg/yr)
S.F. Pound #8	571	400	10	minimal	**0.02**	*475*	**8**	
Bull Cr. #1+2	1,154	1,007	51	UG	1.70	1,017	1,538[a]	1,382[e]
S.F. Pound #9	213	600	6	UG	**0.02±0.53**[b]	*(1,511)*[d]	**27**[c]	*45*[e]
S.F. Pound #10	1,013	1,600	71	UG	**1.30±0.54**[b]	*(897)*[d]	**1,042**[c]	*1,062*[e]
Bull Cr. #3	874	1,022	39	UG+Surf.	1.04	625	607[a]	858[e]
S.F. Pound #11	1,438	1,750	110	UG+Surf.	**1.98±0.69**[b]	*(893)*[d]	**1,580**[c]	*944*[f]
S.F. Pound #12	613	950	25	UG+Surf.	**0.66±0.49**[b]	*(905)*[d]	**534**[c]	*432*[f]

a .. Sum of Raw Median TDS load; **Table 3.5**.
UG, UG+Surf. .. underground mining, and underground plus surface mining.
b .. Estimated Median Flow (**gpm**) = 0.0016*(footprint acres) – 0.3248, 95% C.I.; **Figure 3.18**.
c .. Estimated Median TDS Load (Mg/yr) = 1.2681*(footprint acres) – 243.52; **Figure 3.18**.
d .. Back-calculated: Median TDS concentration (mg/L) = footprint est. Median TDS Load (Mg/yr) / (footprint est. flow*0.8935911).
e .. Estimated using non-HMBC *Load x Flow* relationship: Median Load (Mg/yr) = 794.45*(Footprint est. flow, **gpm***0.8935911); **Figure 3.9**.
f .. Estimated using HMBC *Load x Flow* relationship: Median Load (Mg/yr) = 387.62*(Footprint est. flow, **gpm***0.8935911); **Figure 3.9**.
Load x Flow Median TDS Load .. The TDS load based on the basic flow-dependent load relationship for all non-HMBC springs presented in **Figure 3.9**.

Hydrologic island #1+2 from the Bull Creek watershed has been extensively mined underground matching the nature of mining in S. F. Pound islands #9 and #10. Island #10 is similar in footprint size to #1+2 while #9 is much smaller. But their footprints are in the Bull Cr. range developed to predict flow and TDS load. However, the S. F. Pound hydrologic islands have greater relief and therefore have about 40% larger hill volume than the Bull Creek islands. This suggests they could have larger groundwater reservoirs although no significant relationship was found between hill volume and flow in Bull Cr. Still spring volume, and TDS load which is proportional to flow, may be somewhat under-predicted in these taller islands.

44 SFP_Island Dimensions_8_23_13.xls

Bull Creek island #3 is slightly larger than island #12, and about 60% the size of island #11. However, the flow and load predictions should be reasonable because the S. F. Pound islands are within the island footprint range used to develop the relationships. However, as was noted for the HMBC spring in Bull Creek, abandoned surface mine features tend to produce substantially lower TDS concentrations and higher flows than areas that have only been mined underground. Thus, although the predicted flow volume may be under estimated for any springs in islands #11 and #12, the TDS load yield is still expected to be reasonable.

The "Load x Flow" estimate of load presented in the last column of **Table 4.5** is a separate estimate of the loads. This is the predicted load based upon the Bull Cr. spring volume dependence on TDS load in **Figure 3.9** on **page 14**. In the table, this separate estimate for Bull Cr. #1+2 and S. F. Pound #9 and #10 is based on the load from all non-HMBC springs. For the remaining islands the HMBC spring relationship is used. Upon comparing the values, the island-estimated load for S. F. Pound #11 appears somewhat over-estimated.

4.1.2 Mining Relationships

Relationships were developed in the Bull Creek watershed between hydrologic island footprint and flow/TDS load (**Figure 3.18**). Because the upper S. F. Pound watershed has essentially the same characteristics as the Bull Cr. watershed, the hydrologic island relationships from Bull Cr. are used here to estimate the flow and TDS load in the upper S. F. Pound watershed and the entire Bull Creek watershed (**Table 4.6**).

Table 4.6 Comparison of mining in the Bull Cr. and S. F. Pound River watersheds and estimated spring TDS load in the upper S. F. Pound watershed.

Watershed	Footprint Area (acres)	% of Footprint Mined	Mine Levels	Ratio of Mine Floor to Footprint	Spring Median Flow (gpm)	Spring Median TDS (mg/L)	Spring Median TDS Load (Mg/yr)
Bull Creek[1]	7,731	75%	4	1.2	12.045[a]	*(794)*[c]	9,560[b]
Unit A, inside	1,460	76%	3	1.0	1.70	1,017	1,538
S.F. Pound[2]	11,189	28%		0.5	NA	NA	NA
Lower Watershed	7,399	8%		0.1	NA	NA	NA
Upper Watershed	3,849	66%		1.2	5.834[a]	*(795)*[c]	4,637[b]

a .. Estimated from hydrologic island relationship: median flow (**gpm**) = 0.0016 *Footprint (acres) – 0.3248.
b .. Estimated from hydrologic island relationship: median TDS load (Mg/yr) = 1.2681*Footprint (acres) – 243.52.
c .. Estimated from estimated median TDS load (Mg/yr) divided by (median flow (**gpm**) * 0.8935911).
1 .. Footprint and mine information from **Table 3.7**.
2 .. Footprint and mine information from **Table 4.3**.

4.1.3 Water Quality Relationships

In the following **Table 4.7**, water quality and quantity in the S. F. Pound mainstem and tributaries are presented for comparison to values in NPDES discharges and dominant Bull Cr. watershed springs. While tributary loads tend to be one 100th the size of mainstem loads, NPDES loads can be as much as one 10th the size of mainstem loads. Meanwhile, mine spring loads are miniscule compared to mainstem loads.

Table 4.7 Comparison of water quality and discharge over the recent 12 months.[45]

Watershed	Map No. NPDES No., or Spring	Median Flow (gpm)	Median TDS (mg/L)	Median TDS Load (10^6 kg/yr)	TDS Load Normalized to 11,000 gpm (10^6 kg/yr)	Sample Period
SFP, Lower, mainstem[a]	**12**	**11,000**	**1,345**	29.394	29.4	2012-13
SFP, Upper, mainstem[a]	**37**	8,000	**1,783**	28.339	39.0	2012-13
SFP, Lower, tributary[a]	**60**	175	620	0.216	13.5	2012-13
SFP, Upper, tributary[a]	**61**	43	**2,843**	0.243	62.1	2012-13
SFP., Lower[b]	NPDES **20**	100	1,202	0.239	26.3	2012-13
SFP., Upper[b]	NPDES **85**	**554**	**2,016**	2.219	44.1	2012-13
Bull Cr.[c]	DownBelcher	0.85	1,035	0.002	22.6	2012-13
Bull Cr.[c]	HMBC	1.04	625	0.001	13.7	2012-13

a .. **Table 4.1** page 35.
b .. **Table 4.2** page 42.
c .. **Table 3.1** page 13.

45 DMME SFPound IS and NP data 7_26_13_CDF.xls[NPDES Extracted].

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Appendix A. Data Tables

Table A. 1 Spring TDS, flow, and physical data by sample date in the Bull Cr. watershed.[46]

Observations							Spring Statistics								
Seq	**Site**	**Date**	**TDS Concen-tration (mg/L)**	**Flow (gpm)**	**TDS Load (kg/yr)**	**4-day total Ppt (in)**	**Mean TDS conc. (mg/L)**	**Median TDS conc. (mg/L)**	**Mean TDS Load (Mg/yr)**	**Median TDS Load ($x10^6$ Mg/yr)**	**Median TDS Load Ratio**	**Eleva-tion (feet)**	**Mean Flow (gpm)**	**Median Flow (gpm)**	**Median TDS Load ($x10^6$ Mg/yr)**
1	HMBC	9/11/2012	754	1.36	913,629	0.34									913.6
2	HMBC	9/25/2012	703	0.66	413,980	0									414.0
3	HMBC	10/8/2012	715	0.63	400,601	0.37									400.6
4	HMBC	10/23/2012	595	0.70	372,712	0									372.7
5	HMBC	11/15/2012	621	0.70	390,109	0.26									390.1
6	HMBC	11/28/2012	671	1.08	648,167	0.05									648.2
7	HMBC	12/13/2012	687	1.00	616,353	0.75									616.4
8	HMBC	12/28/2012	628	0.98	547,146	0.87									547.1
9	HMBC	1/10/2013	597	1.12	596,957	0.03									597.0
10	HMBC	1/24/2013	527	1.78	840,126	0									840.1
11	HMBC	2/7/2013	484	2.66	1,148,282	0									1148.3
12	HMBC	2/21/2013	546	1.54	749,415	0.04	627	625	636	607	91	1261	1.18	1.04	749.4
13	DeelUp	9/11/2012	603	0.03	15,087	0.34									15.1
14	DeelUp	9/25/2012	634	0.01	3,399	0									3.4
15	DeelUp	10/8/2012	560	0.04	20,016	0.37									20.0

46 From TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].

16	DeelUp	10/23/2012	627	0.00	2,241	0									2.2
17	DeelUp	11/15/2012	372	0.02	5,319	0.26									5.3
18	DeelUp	11/28/2012	603	0.01	5,927	0.05									5.3
19	DeelUp	12/13/2012	650	0.01	3,485	0.75									5.9
20	DeelUp	12/28/2012	476	0.01	4,679	0.87									3.5
21	DeelUp	1/10/2013	558	0.02	7,479	0.03									4.7
22	DeelUp	1/24/2013	498	0.05	22,250	0									7.5
23	DeelUp	2/7/2013	520	0.03	15,334	0									22.3
24	DeelUp	2/21/2013	601	0.04	23,093	0.04	559	581	11	7	1	1567	0.02	0.02	15.3
25	DeelDown	9/11/2012	537	0.00	2,159	0.34									23.1
26	DeelDown	9/25/2012	519	0.01	5,426	0									2.2
27	DeelDown	10/8/2012	544	0.01	5,833	0.37									5.4
28	DeelDown	10/23/2012	536	0.01	4,311	0									5.8
29	DeelDown	11/15/2012	396	0.01	3,892	0.26									4.3
30	DeelDown	11/28/2012	503	0.01	4,944	0.05									3.9
31	DeelDown	12/13/2012	516	0.03	15,677	0.75									4.9
32	DeelDown	12/28/2012	300	0.07	19,838	0.87									15.7
33	DeelDown	1/10/2013	382	0.03	10,241	0.03									19.8
34	DeelDown	1/24/2013	309	0.11	29,545	0									10.2
35	DeelDown	2/7/2013	371	0.13	44,424	0									29.5
36	DeelDown	2/21/2013	446	0.13	53,405	0.04	447	475	17	8	1	1383	0.05	0.02	44.4
37	BurntHollow	9/11/2012	1,070	0.54	515,361	0.34									515.4
38	BurntHollow	9/25/2012	1,100	0.60	585,838	0									585.8
39	BurntHollow	10/8/2012	1,130	0.47	476,606	0.37									476.6
40	BurntHollow	10/23/2012	1,120	0.37	371,305	0									371.3
41	BurntHollow	11/15/2012	1,060	0.91	865,747	0.26									865.7

42	BurntHollow	11/28/2012	1,100	0.56	552,418	0.05									552.4
43	BurntHollow	12/13/2012	1,120	0.41	414,340	0.75									414.3
44	BurntHollow	12/28/2012	998	0.62	552,027	0.87									552.0
45	BurntHollow	1/10/2013	1,050	0.89	831,308	0.03									831.3
46	BurntHollow	1/24/2013	888	0.89	703,842	0									703.8
47	BurntHollow	2/7/2013	954	1.28	1,093,739	0									1093.7
48	BurntHollow	2/21/2013	1,010	1.39	1,250,000	0.04	1,050	1,065	684	569	85	1305	0.74	0.61	1250.0
49	CharlieUp	9/11/2012	1,060	0.13	121,242	0.34									121.2
50	CharlieUp	9/25/2012	1,080	0.07	65,625	0									65.6
51	CharlieUp	10/8/2012	1,130	0.02	23,224	0.37									23.2
52	CharlieUp	10/23/2012	1,070	0.03	25,816	0									25.8
53	CharlieUp	11/15/2012	958	0.01	9,417	0.26									9.4
54	CharlieUp	11/28/2012	1,060	0.01	11,366	0.05									11.4
55	CharlieUp	12/13/2012	1,050	0.16	145,432	0.75									145.4
56	CharlieUp	12/28/2012	934	0.27	223,677	0.87									223.7
57	CharlieUp	1/10/2013	953	0.06	52,799	0.03									52.8
58	CharlieUp	1/24/2013	772	0.45	310,434	0									310.4
59	CharlieUp	2/7/2013	866	0.67	520,027	0									520.0
60	CharlieUp	2/21/2013	946	0.56	475,925	0.04	990	1,004	165	93	14	1309	0.20	0.10	475.9
61	CharlieDown	9/11/2012	1,320	0.09	110,877	0.34									110.9
62	CharlieDown	9/25/2012	1,420	0.07	91,361	0									91.4
63	CharlieDown	10/8/2012	1,430	0.12	157,174	0.37									157.2
64	CharlieDown	10/23/2012	1,450	0.06	73,855	0									73.9
65	CharlieDown	11/15/2012	1,170	0.02	15,683	0.26									15.7
66	CharlieDown	11/28/2012	1,250	0.06	63,668	0.05									63.7
67	CharlieDown	12/13/2012	1,330	0.25	300,684	0.75									300.7

68	CharlieDown	12/28/2012	1,100	0.15	145,477	0.87									145.5
69	CharlieDown	1/10/2013	1,100	0.08	82,568	0.03									82.6
70	CharlieDown	1/24/2013	876	0.08	63,406	0									63.4
71	CharlieDown	2/7/2013	1,060	0.43	405,404	0									405.4
72	CharlieDown	2/21/2013	1,100	0.03	32,437	0.04	1,217	1,210	129	87	13	1293	0.12	0.08	32.4
73	UpBelcher	9/11/2012	970	0.89	769,704	0.34									769.7
74	UpBelcher	9/25/2012	1,050	0.64	600,493	0									600.5
75	UpBelcher	10/8/2012	1,090	0.30	291,230	0.37									291.2
76	UpBelcher	10/23/2012	1,030	0.62	571,568	0									571.6
77	UpBelcher	11/15/2012	1,020	0.78	711,853	0.26									711.9
78	UpBelcher	11/28/2012	1,040	0.71	661,686	0.05									661.7
79	UpBelcher	12/13/2012	1,060	0.93	876,166	0.75									876.2
80	UpBelcher	12/28/2012	976	2.13	1,856,796	0.87									1856.8
81	UpBelcher	1/10/2013	1,000	0.66	588,877	0.03									588.9
82	UpBelcher	1/24/2013	921	2.16	1,774,382	0									1774.4
83	UpBelcher	2/7/2013	887	2.57	2,037,814	0									2037.8
84	UpBelcher	2/21/2013	924	2.09	1,728,144	0.04	997	1,010	1,039	741	111	1377	1.21	0.83	1728.1
85	DownBelcher	9/11/2012	960	0.58	494,120	0.34									494.1
86	DownBelcher	9/25/2012	1,070	0.87	831,844	0									831.8
87	DownBelcher	10/8/2012	1,080	0.38	364,800	0.37									364.8
88	DownBelcher	10/23/2012	1,090	0.45	438,306	0									438.3
89	DownBelcher	11/15/2012	1,050	0.78	728,098	0.26									728.1
90	DownBelcher	11/28/2012	1,080	0.23	221,968	0.05									222.0
91	DownBelcher	12/13/2012	1,070	1.25	1,199,003	0.75									1199.0
92	DownBelcher	12/28/2012	884	1.78	1,402,924	0.87									1402.9
93	DownBelcher	1/10/2013	1,020	0.82	748,311	0.03									748.3

94	DownBelcher	1/24/2013	896	1.24	990,413	0									990.4
95	DownBelcher	2/7/2013	855	6.81	5,201,451	0									5201.5
96	DownBelcher	2/21/2013	928	2.71	2,245,616	0.04	999	1,035	1,239	790	118	1232	1.49	0.85	2245.6
97	CoveHollow	9/11/2012	1,080	0.10	94,578	0.34									94.6
98	CoveHollow	9/25/2012	1,080	0.13	123,530	0									123.5
99	CoveHollow	10/8/2012	1,180	0.10	108,607	0.37									108.6
100	CoveHollow	10/23/2012	1,190	0.21	217,992	0									218.0
101	CoveHollow	11/15/2012	1,010	0.11	101,986	0.26									102.0
102	CoveHollow	11/28/2012	1,130	0.13	135,308	0.05									135.3
103	CoveHollow	12/13/2012	1,140	0.10	100,851	0.75									100.9
104	CoveHollow	12/28/2012	1,010	0.08	72,202	0.87									72.2
105	CoveHollow	1/10/2013	1,050	0.03	23,457	0.03									23.5
106	CoveHollow	1/24/2013	879	0.11	82,474	0									82.5
107	CoveHollow	2/7/2013	907	0.26	206,674	0									206.7
108	CoveHollow	2/21/2013	986	0.09	79,297	0.04	1,054	1,065	112	101	15	1260	0.12	0.10	79.3
		maximum:	1,450	6.81	5,201,451	0.87	1217.2	1210.00	1238.9	790.08	118	1,567	1.49	1.04	5,201.5
		minimum:	300	0.00	2,159	0.00	446.58	474.50	10.69	6.70	1	1,232	0.02	0.02	2.2
		average:	882	0.57	448,038	0.23	882.10	896.50	448.04	333.69		1,332	0.57	0.41	448.0
		median:	959.00	0.24	219,979.8	0.05	997.33	1010.00	165.42	101.42			0.203	0.104	220.0

Note: To calculate TDS load in Megagrams/year (Mg/yr) from mg/L***gpm**, multiply 0.8935911 times the product of TDS (mg/L) and flow (**gpm**). Multiply Mg/yr by 1,000 to convert to kg/yr. Source: TDS v Flow with Totals and Averages_MJS_6.xlsx.

Table A. 2 Spring TDS concentration (mg/L) by sample date in the Bull Cr. watershed.

Date	Cove Hollow	Down Belcher	Up Belcher	Charlie Down	Charlie Up	Burnt Hollow	Deel Down	Deel Up	HMBC	Median TDS Conc. (mg/L)	Average TDS Conc. (mg/L)
9/11/2012	1080	960	970	1320	1060	1070	537	603	754	970.0	928.2
9/25/2012	1080	1070	1050	1420	1080	1100	519	634	703	1070.0	961.8
10/8/2012	1180	1080	1090	1430	1130	1130	544	560	715	1090.0	984.3
10/23/2012	1190	1090	1030	1450	1070	1120	536	627	595	1070.0	967.6
11/15/2012	1010	1050	1020	1170	958	1060	396	372	621	1010.0	850.8
11/28/2012	1130	1080	1040	1250	1060	1100	503	603	671	1060.0	937.4
12/13/2012	1140	1070	1060	1330	1050	1120	516	650	687	1060.0	958.1
12/28/2012	1010	884	976	1100	934	998	300	476	628	934.0	811.8
1/10/2013	1050	1020	1000	1100	953	1050	382	558	597	1000.0	856.7
1/24/2013	879	896	921	876	772	888	309	498	527	876.0	729.6
2/7/2013	907	855	887	1060	866	954	371	520	484	866.0	767.1
2/21/2013	986	928	924	1100	946	1010	446	601	546	928.0	831.9
Average:	**1053.5**	**998.6**	**997.3**	**1217.2**	**989.9**	**1050.0**	**446.6**	**558.5**	**627.3**		**882.1**
Minimum:	**879**	**855**	**887**	**876**	**772**	**888**	**300**	**372**	**484**	**866**	**729.6**
Maximum:	**1190**	**1090**	**1090**	**1450**	**1130**	**1130**	**544**	**650**	**754**	**1090**	**984.3**
Median:	**1065.0**	**1035.0**	**1010.0**	**1210.0**	**1004.0**	**1065.0**	**474.5**	**580.5**	**624.5**	**1005.0**	**892.4**

Source: TDS_Monitoring_Analysis_v02_MJS.xls.

Table A. 3 Bull Cr. spring flow volume (gpm) by sample date in the Bull Cr. watershed.

Date	Cove Hollow	Down Belcher	Up Belcher	Charlie Down	Charlie Up	Burnt Hollow	Deel Down	Deel Up	HMBC	Median Flow (gpm)	Average Flow (gpm)	Total Flow (gpm)	Median Monthly Total Flow (gpm)
9/11/2012	0.098	0.576	0.888	0.094	0.128	0.539	0.005	0.028	1.356	0.128	0.412	3.71	
9/25/2012	0.128	0.870	0.640	0.072	0.068	0.596	0.012	0.006	0.659	0.128	0.339	3.05	3.38
10/8/2012	0.103	0.378	0.299	0.123	0.023	0.472	0.012	0.040	0.627	0.123	0.231	2.08	
10/23/2012	0.205	0.450	0.621	0.057	0.027	0.371	0.009	0.004	0.701	0.205	0.272	2.45	2.26
11/15/2012	0.113	0.776	0.781	0.015	0.011	0.914	0.011	0.016	0.703	0.113	0.371	3.34	
11/28/2012	0.134	0.230	0.712	0.057	0.012	0.562	0.011	0.011	1.081	0.134	0.312	2.81	3.08
12/13/2012	0.099	1.254	0.925	0.253	0.155	0.414	0.034	0.006	1.004	0.253	0.460	4.14	
12/28/2012	0.080	1.776	2.129	0.148	0.268	0.619	0.074	0.011	0.975	0.268	0.676	6.08	5.11
1/10/2013	0.025	0.821	0.659	0.084	0.062	0.886	0.030	0.015	1.119	0.084	0.411	3.70	
1/24/2013	0.105	1.237	2.156	0.081	0.450	0.887	0.107	0.050	1.784	0.450	0.762	6.86	5.28
2/7/2013	0.255	6.808	2.571	0.428	0.672	1.283	0.134	0.033	2.655	0.672	1.649	14.84	
2/21/2013	0.090	2.708	2.093	0.033	0.563	1.385	0.134	0.043	1.536	0.563	0.954	8.59	11.71
Average:	**0.120**	**1.490**	**1.206**	**0.120**	**0.203**	**0.744**	**0.048**	**0.022**	**1.183**	**0.203**	**0.571**	**5.14**	**5.14**
Minimum:	**0.025**	**0.230**	**0.299**	**0.015**	**0.011**	**0.371**	**0.005**	**0.004**	**0.627**	**0.025**	**0.025**	**0.025**	**2.26**
Maximum:	**0.255**	**6.808**	**2.571**	**0.428**	**0.672**	**1.385**	**0.134**	**0.050**	**2.655**	**0.672**	**0.672**	**0.672**	**11.71**
Median:	**0.104**	**0.846**	**0.835**	**0.083**	**0.098**	**0.608**	**0.021**	**0.016**	**1.043**	**0.170**	**0.412**	**3.706**	**4.25**

Source: TDS_Monitoring_Analysis_v02_MJS.xls.

Table A. 4 Bull Cr. spring TDS load (Mg/yr) by sample date in the Bull Cr. watershed.

Date	Cove Hollow	Down Belcher	Up Belcher	Charlie Down	Charlie Up	Burnt Hollow	Deel Down	Deel Up	HMBC	Median Load (Mg/yr)	Ave. Load (Mg/yr)	Sum Median Load (Mg/yr)	Obser-ved 4-day Ppt (inch)
9/11/2012	95	494	770	111	121	515	2	15	914	121	337	3,037	0.34
9/25/2012	124	832	601	91	66	586	5	3	414	124	302	2,722	0.00
10/8/2012	109	365	291	157	23	477	6	20	401	157	205	1,848	0.37
10/23/2012	218	438	572	74	26	371	4	2	373	218	231	2,078	0.00
11/15/2012	102	728	712	16	9	866	4	5	390	102	315	2,832	0.26
11/28/2012	135	222	662	64	11	552	5	6	648	135	256	2,306	0.05
12/13/2012	101	1,199	876	301	145	414	16	3	616	301	408	3,672	0.75
12/28/2012	72	1,403	1,857	145	224	552	20	5	547	224	536	4,825	0.87
1/10/2013	23	748	589	83	53	831	10	7	597	83	327	2,942	0.03
1/24/2013	82	990	1,774	63	310	704	30	22	840	310	535	4,817	0.00
2/7/2013	207	5,202	2,038	405	520	1,094	44	15	1,148	520	1,186	10,673	0.00
2/21/2013	79	2,246	1,728	32	476	1,250	53	23	749	476	737	6,637	0.04
Median:	**101**	**790**	**741**	**87**	**93**	**569**	**8**	**7**	**607**			**2,989**	
percent:	**3.4%**	**26.3%**	**24.7%**	**2.9%**	**3.1%**	**19.0%**	**0.3%**	**0.2%**	**20.2%**	**100.0%**		**100%**	
minimum:	**23**	**222**	**291**	**16**	**9**	**371**	**2**	**2**	**373**			**1,848**	
maximum:	**218**	**5,202**	**2,038**	**405**	**520**	**1,250**	**53**	**23**	**1,148**			**10,673**	

Source: TDS_Monitoring_Analysis_v02_MJS.xls.

Table A. 5 Mined footprint, mine floor, and un-mined footprint (acres) in the Bull Cr. watershed.

Mine Unit	Un-Mined Inside	Mined Footprint Inside	Mined Footprint Outside	Mined Footprint Total	Mined Floor Inside	Mined Floor Outside	Mined Floor Total	Mined + Un-Mined Footprint Inside
A	344.6	1,114.9	855.4	1,970.3	1,464.0	948.2	2,412.2	1,459.5
B	152.0	314.7	777.2	1,091.9	545.9	813.5	1,359.4	466.7
C	364.7	1,359.5	1,512.6	2,872.1	2,534.1	1,982.4	4,516.5	1,724.2
D	288.8	705.4	372.9	1,078.3	1,097.2	425.8	1,523.1	994.2
E	754.6	2,331.2	1,443.0	3,774.2	3,670.8	2,000.9	5,671.7	3,085.8

Note: footprint units are acres.
Source: Mine_param_totals.xls[Totals].

Table A. 6 Mine parameters in the Bull Cr. watershed.

Mine Area	Location Respect to Bull Cr Watershed	Mined Footprint (acres)	Un-Mined Footprint (acres)	Total Footprint (ac)	Mined Levels	Total Mine Floor (acres)	Percent of Footprint Mined	Ratio Mine Floor to Footprint	Median Spring Flow (gpm)	Sum Median Spring Flow (gpm)	Median TDS Load (Mg/yr)	Flow-Weighted Med.TDS Load (Mg/yr)	Sum Median TDS Load (Mg/yr)	Monitored Spring
A	inside	1115	345	1460	3	1464	76%	1.0	0.02+0.83 +0.85	1.7	7 + 741 + 790	757	1,538	Deel Up + Up Belcher + Down Belcher
	outside	855	534	1389	3	948	62%	0.7						none
	total	1970	879	2849		2412	69%	0.8						
B	inside	315	152	467	3	546	67%	1.2	0.02	0.02	8	8	8	Deel Down
	outside	777	544	1322	2	813	59%	0.6						none
	total	1092	696	1788		1359	61%	0.8						
C	inside	1359	365	1724	5	2534	79%	1.5	0.5*0.1+ 0.08+1.04	1.17	0.5*93 + 87 + 607	548	740	0.5*Charlie Up+Charlie Down + HMBC
	outside	1513	1844	3357	5	1982	45%	0.6						none
	total	2872	2209	5081		4516	57%	0.9						
D	inside	705	289	994	4	1097	71%	1.1	0.5*0.1+ 0.1+0.61	0.76	0.5*93+ 101+569	473	716	0.5*Charlie Up + Cove Hollow + Burnt Ho
	outside	373	527	900	3	426	41%	0.5						none
	total	1078	815	1894		1523	57%	0.8						
E	inside	2331	755	3086	4	3671	76%	1.2	NA	NA	NA	NA	NA	none
	outside	1443	1790	3233	4	2001	45%	0.6						none
	total	3774	2544	6318		5672	60%	0.9						
Total	inside	5825	1906	7731		9312	75%	1.2						
	outside	4961	5239	10201		6170	49%	0.6						
	total	10786	7143	17930		15482	60%	0.9						

Source: Mine Footprint Vars v02.xls.

Table A. 7 Hydrologic island parameters and related spring data in the Bull Cr. watershed.

Island #	Foot-print (acre)	Foot-print Top Eleva-tion (ft)	Foot-print Bottom Elevation (ft)	Island Relief (ft)	Standard Island Volume (10^9 ft^3)	Spring Eleva-tion (ft)	Spring Island Relief (ft)	Spring Island Volume (ft^3)	Largest Width of Valley Barrier (ft)	Small-est Width of Valley Barrier (ft)	Median Flow (gpm)	Sum Med. Flow (gpm)	Flow-Weighted Med. TDS Conc. (mg/L)	Flow-Weight Median TDS Load (Mg/yr)	Sum of Raw Median TDS Load (Mg/yr)	Associated Spring (dominant bolded)
1	359	2,172	1,427	745	12	1,377	795	12	339	339	0.83	0.83	1010	749	741	**Up Belcher**
2	795	2,185	1,178	1,007	35	1232, 1567	953	33	678	678	0.85+0.02	0.87	1025	797	797	**Down Belcher** + Deel Up
1+2	1154	2,185	1,178	1,007	51	1377, 1232, 1567	953	48	678	678	0.83+0.85+0.02	1.70	1017	1546	1538	**Up Belcher** + **Down Belcher** + Deel Up
3	874	2,240	1,218	1,022	39	1261	979	37	647	443	1.04	1.04	625	581	607	**HMBC**
4	481	2,140	1,200	940	20	1309, 1293	847	18	990	628	0.5*0.1 + 0.08	0.13	1131	131	134	0.5*Charlie Up + Charlie Down
5	324	2,095	1,065	1,030	15	1309	786	11	1102	452	0.5*0.1	0.05	502	22	47	0.5*Charlie Up
6	244	2,085	1,035	1,050	11	1260, 1305	825	9	1498	370	0.1+0.61	0.71	1065	676	670	Cove Hollow + **Burnt Hollow**
7	444	2,207	1,312	895	17	1383	824	16	647	629	0.02	0.02	475	8	8	Deel Down
sum:	3521				152			139				5.35		2,964	3003	

Source: Hydrologic Island Vars v02.xlsx.

Table A. 8 In-stream water quality stations data summary in the South Fork Pound watershed.

MapTech Map No.	Row Labels	Count of WtTds	Count of WtFlow	Count of WtPh	Average of WtTds (mg/L)	Average of WtFlow (gpm)	Average of WtPh (SU)	Average TDS Load (106 kg/yr)
1	0003655		26			922		
2	0003656		26			1543		
3	0003657		26			2477		
4	0004380	46	32	46	1138	5751	7.7	13.00
5	0004381	46	32	46	1112	6248	7.6	13.80
6	0005063	53	59	53	1786	591	7.7	2.10
7	0006928	60	60	60	1385	8148	7.7	22.42
8	0006929	60	60	60	1354	9743	7.7	26.21
9	0006930	59	60	59	309	188	7.1	0.12
10	0006931	60	60	60	1344	8519	7.7	22.75
11	0007244	56	64	64	1196	23407	8.0	55.62
12	0007245	56	64	64	1261	23627	7.8	59.19
13	0007246	56	64	64	1258	24561	7.8	61.39
14	0007696	15	15	15	425	2360	7.6	1.99
15	0007697	15	15	15	440	116	7.2	0.10
18	2620125	12	219	12	716	973	7.3	1.38
19	2620126	220	220	220	1558	4699	7.9	14.55
25	3420040	10	10	10	930	2115	7.7	3.91
26	3420065	12	12	12	774	988	7.5	1.52
27	3420066	728	770	729	1441	4220	7.8	12.08
28	3420084	200	220	200	1394	3185	7.8	8.82
29	3420085	185	232	185	881	1056	7.5	1.85
31	3420091	40	41	41	916	4902	7.7	8.92
32	3420092	41	41	41	983	6376	7.7	12.45
33	3420095	122	85	123	845	5542	7.5	9.30
34	3420096	124	96	125	894	5283	7.5	9.38
35	3420103	3		3	525		7.2	
36	3420104	3		3	497		7.3	
37	3420109	218	222	220	1570	4678	7.9	14.59
38	3420110	194	214	194	1408	3180	7.8	8.90
39	3420111	357	433	358	893	1037	7.5	1.84
41	3420175	214	219	214	1048	57	6.8	0.12
42	3420176	145	219	145	417	14	5.9	0.01
43	3420177	117	219	117	923	30	7.4	0.06
44	3420178	218	219	218	713	240	7.3	0.34
47	3420193	122	84	122	788	7981	7.5	12.49
48	3420194	122	95	122	638	5532	7.5	7.01
49	3420216	9	9	9	592	97	7.4	0.11

50	3420217	9	9	9	723	1133	7.5	1.63
51	3420244	131	120	131	598	1845	7.4	2.19
52	3420245	131	120	131	603	2081	7.4	2.49
55	3420257	12	12	12	774	988	7.5	1.52
56	3420258	12	12	12	630	94	7.5	0.12
57	3420263	119	96	121	529	4464	7.4	4.69
58	3420265	200	220	200	1394	3212	7.8	8.90
60	3420267	204	219	204	555	2123	7.2	2.34
61	3420268	218	220	218	2009	18	7.1	0.07
62	3420269	75	220	75	1517	3	6.6	0.01
63	3420270	294	296	294	1955	14	7.1	0.05
64	3420271	294	295	294	1953	17	7.2	0.07
65	3420272	295	295	295	1746	45	7.6	0.16
66	3420313	10	12	10	29	4	0.8	0.00
67	3420320	91	57	92	688	3498	7.5	4.78
68	3420321	96	68	96	524	4119	7.4	4.29
69	3420322	93	68	93	542	4665	7.4	5.02

Source: DMME SFPound IS and NP data 7_26_13_MJS_JDB.xls[Instream WQ Data]

Table A. 9 Mine floor and mine footprint for mine units in the Bull Cr. watershed.

Value	Location	Mine Unit	Count (of 100 sq.ft. blocks)	Mine Footprint (sq.ft.)	Floor Multiplier	Mine Floor (sq.ft.)
30	Inside	A	150116	0	0	0
31	Inside	A	360988	36098800	100	36098800
32	Inside	A	97300	9730000	200	19460000
33	Inside	A	27375	2737500	300	8212500
40	Outside	A	232560	0	0	0
41	Outside	A	337581	33758100	100	33758100
42	Outside	A	29569	2956900	200	5913800
43	Outside	A	5441	544100	300	1632300
50	Inside	B	66220	0	0	0
51	Inside	B	52388	5238800	100	5238800
52	Inside	B	68669	6866900	200	13733800
53	Inside	B	16029	1602900	300	4808700
60	Outside	B	237151	0	0	0
61	Outside	B	322719	32271900	100	32271900
62	Outside	B	15818	1581800	200	3163600
70	Inside	C	158879	0	0	0
71	Inside	C	290896	29089600	100	29089600
72	Inside	C	147024	14702400	200	29404800
73	Inside	C	100087	10008700	300	30026100
74	Inside	C	52288	5228800	400	20915200
75	Inside	C	1899	189900	500	949500
80	Outside	C	803344	0	0	0
81	Outside	C	527201	52720100	100	52720100
82	Outside	C	76653	7665300	200	15330600
83	Outside	C	38479	3847900	300	11543700
84	Outside	C	15214	1521400	400	6085600
85	Outside	C	1343	134300	500	671500
90	Inside	D	125815	0	0	0
91	Inside	D	163772	16377200	100	16377200
92	Inside	D	121670	12167000	200	24334000
93	Inside	D	16467	1646700	300	4940100
94	Inside	D	5362	536200	400	2144800

100	Outside	D	229385	0	0	0
101	Outside	D	140234	14023400	100	14023400
102	Outside	D	21364	2136400	200	4272800
103	Outside	D	841	84100	300	252300
10	Inside	E	328718	0	0	0
11	Inside	E	514399	51439900	100	51,439,900
12	Inside	E	435852	43585200	200	87170400
13	Inside	E	47984	4798400	300	14395200
14	Inside	E	17240	1724000	400	6896000
20	Outside	E	779528	0	0	0
21	Outside	E	431236	43123600	100	43123600
22	Outside	E	154456	15445600	200	30891200
23	Outside	E	40095	4009500	300	12028500
24	Outside	E	2789	278900	400	1115600

Source: Mine_param_totals.xls[Raw].

Definitions:

count = The number of 100 sqft units at this level

value = Area (first digit) plus number of mine levels (second digit);
e.g., mine levels = 0 (none), 1 (one level), 2 (2 levels), etc.

location= Inside or outside of the Bull Cr. watershed

floor multiplier = Number by which Count is multiplied to get total mine floor
e.g., 400 means the area is 4 floors deep

footprint = The sqft of ground area that has N levels of mine
e.g., area 10 has 32,871,800 sqft of area un-mined and 51,439,900 sqft mined at 1 level only.
Multiply footprint by N levels to obtain total mine floor across N levels;
e.g., multiply footprint at level 3 to obtain total mine floor in the 3 levels.

mine floor = The mine floor space at N levels summed.
Equals the mine footprint at level N multiplied by N.

Table A. 10 S. F. Pound NPDES discharge stations and data summary.[47]

MapTech Map No.	Row Labels	Count of WtTds	Count of WtFlow	Count of WtPh	Average of WtTds (mg/L)	Average of WtFlow (gpm)	Average of WtPh (SU)	Average TDS Load (106 kg/yr)
1	0003655		26			922		
1	0000261		206			0		0
2	0001239		426			0		0
5	0001737	2	337	12	1687	48	7.15	0.16
7	0004373		64			0		0.00
8	0004374		73	1		0	6.70	0.00
9	0005182	1	233	10	156	0	7.12	0.00
10	0005819	1	24	2	728	1	6.75	0.00
12	0006925	68	91	76	289	62	7.23	0.04
13	0006926		27			0		0.00
14	0006927		25			0		0.00
15	0007240	1	84	1	376	2	7.70	0.00
16	0007241		84			0		0.00
17	0007242		84			0		0.00
20	2670086	98	453	432	1098	42	7.06	0.09
25	3470010		9			0		0.00
26	3470011		10	7		4	6.23	
31	3470054		25	21		29	7.14	
32	3470055		25	10		7	7.20	
34	3470068	32	386	388	1283	54	7.50	0.14
35	3470069	100	439	350	1466	35	7.52	0.10
36	3470072		270	55		2	7.41	
37	3470100		25			0		0.00
38	3470101		25			0		0.00
39	3470102		25			0		0.00
61	3470155		310			0		0.00
62	3470156		284			0		0.00
63	3470157		284			0		0.00
64	3470158	23	438	198	755	21	7.68	0.03
65	3470159		310			0		0.00
66	3470160		310			0		0.00
67	3470161		263	4		0	7.40	0.00
69	3470189		236	85		4	7.33	
70	3470190		223	67		5	7.23	
71	3470199		270	2		0	7.50	0.00
79	3470248		224	192		22	7.51	
82	3470259	32	296	286	1069	308	7.43	0.65
83	3470264		181	107		13	7.39	

47 DMME SFPound IS and NP data 7_26_13_CDF.xls.

84	3470286	79	443	246	1548	7	7.35	0.02
85	3470287	99	439	433	2003	295	7.69	1.17
86	3470288	101	441	424	2237	38	7.26	0.17
87	3470289	4	366	216	627	12	7.29	0.01
88	3470290		432	37		2	7.22	
89	3470291	87	442	432	1392	69	6.95	0.19
91	3470293	860	872	872	2029	38	6.96	0.15
92	3470294	875	890	890	1832	301	7.68	1.10
93	3470318		194	28		7	6.52	
94	3470319		192	150		36	7.13	
95	3470326		172	36		2	7.17	
96	3470327		181	23		1	6.87	
133	3481220		10	2		1	6.75	
134	3481221		10	5		5	6.58	
152	3482127		19	19		149	7.29	
154	3482129		17			0		0.00
159	3484551		19			0		0.00
160	3485964		101	101		1179	7.51	

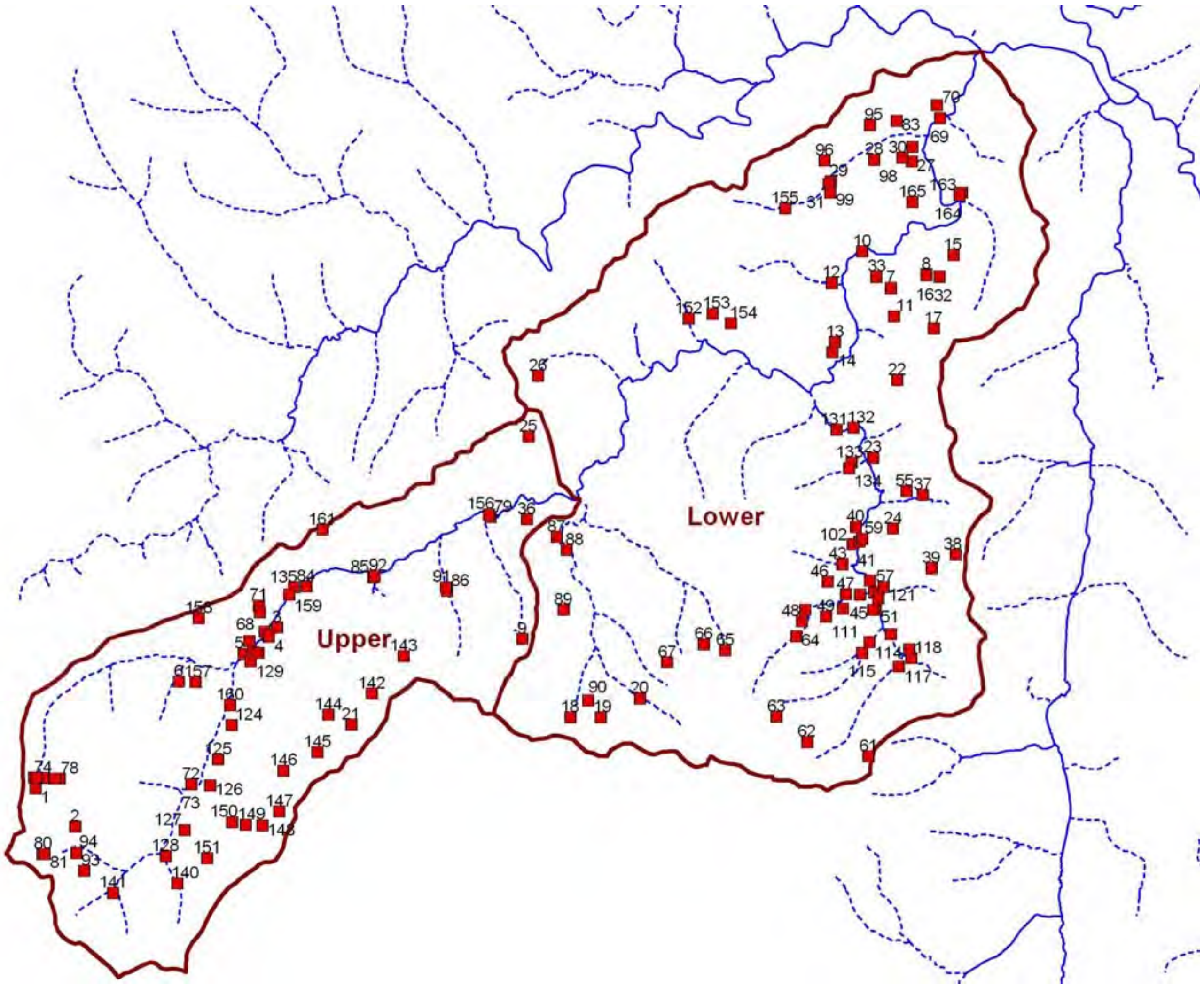

Figure A.1 NPDES monitoring stations in the S. F. Pound River watershed.[48]

[48] Source: SFP_NPDES_Mon_v1.png.

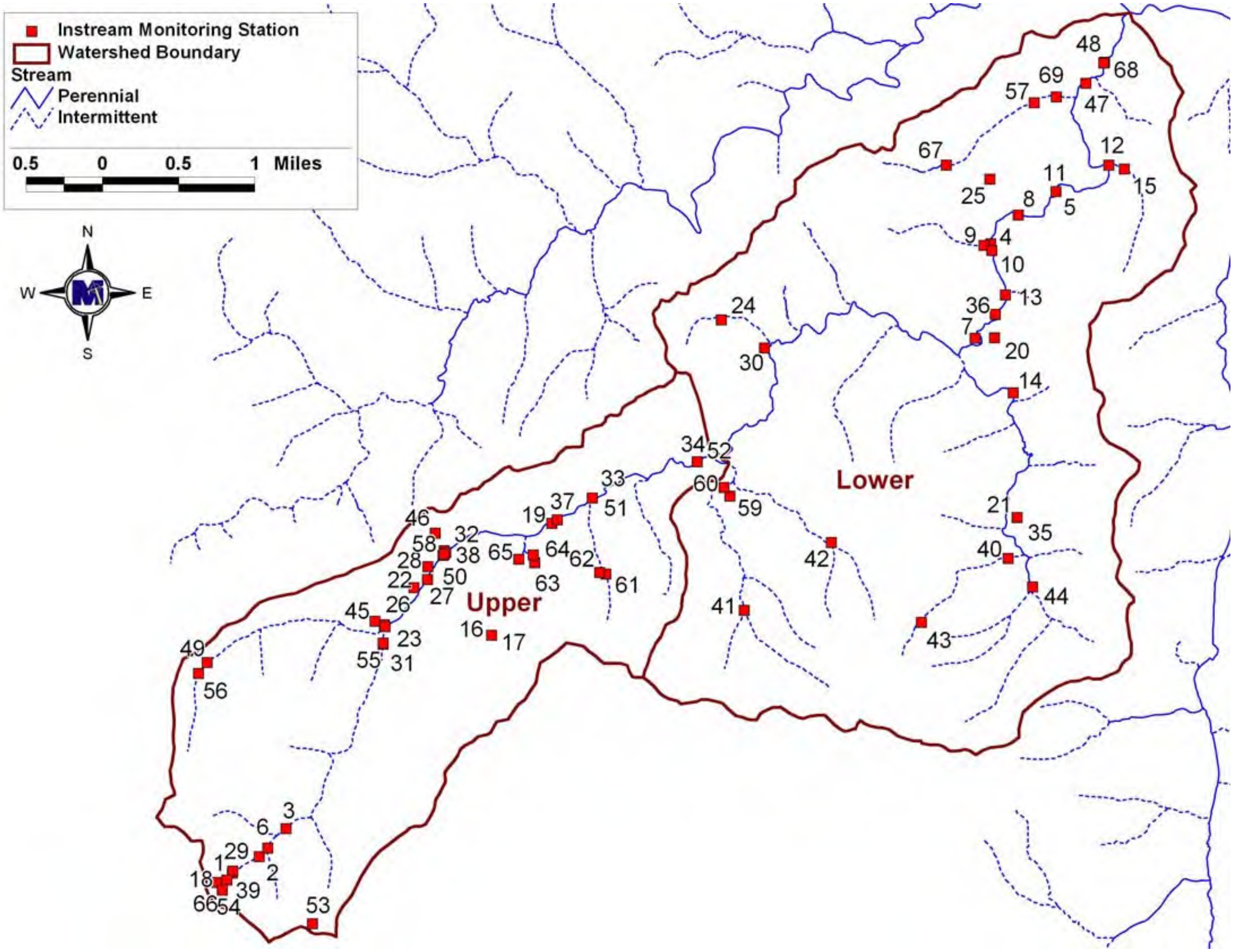

Figure A.2 In-stream water quality monitoring stations in the S. F. Pound River watershed.[49]

49 Source: SFP_Instream_mon_v1.jpg

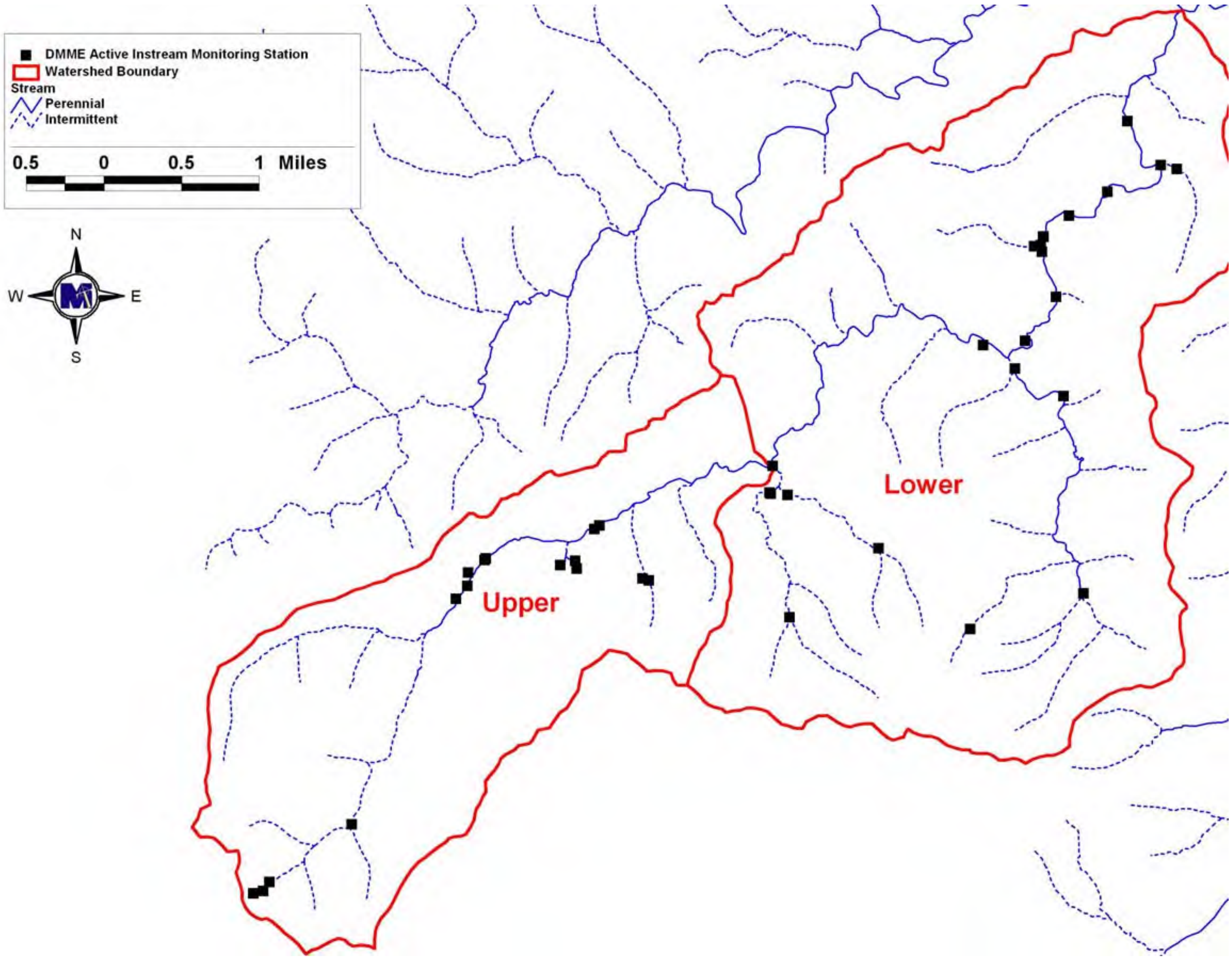

Figure A.3 Recent in-stream water quality sampling stations in the S. F. Pound River watershed.