FINAL DRAFT

Metals TMDL for Buckhannon River, West Virginia

U.S. Environmental Protection Agency
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Philadelphia, PA 19103

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EXECUTIVE SUMMARY

Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not meeting designated uses under technology-based controls. The TMDL process establishes allowable loading of pollutants and other quantifiable parameters for a waterbody based on the relationship between the pollution sources and the instream water quality conditions. This report summarizes the results of the analysis and recommends loadings for the main stem of the Buckhannon River between Hampton and Alexander.

The Buckhannon River is located in Upshur, Randolph, and Barbour Counties, West Virginia. The Buckhannon River has been listed by the West Virginia Department of Environmental Protection (WVDEP) on the 1998 303(d) list of water-quality-limited waters (WVDEP 1998). WVDEP has listed the stream in violation of standards for pH and metals. The portion of the Buckhannon River upstream of Beans Mill is designated by the state as B-2 waters (Trout Water). The relevant water quality criteria are 0.5 mg/L iron (chronic expressed as 4-day average), 0.75 mg/L aluminum (acute), and pH between 6.0 and 9.0. Downstream of Beans Mill the river is designated as a B-3 water (Warm Water Fishery). Here the relevant water quality criteria are 1.5 mg/L iron (chronic expressed as 4-day average), 0.75 mg/L aluminum (acute), and pH between 6.0 and 9.0. This report addresses the analysis of metals loading and load reductions required to meet existing water quality standards. The analysis performed in the development of the Buckhannon River TMDL identified no impairments under current conditions for pH. Analysis of the pH and acid loading is provided in a separate report (USEPA 1998 draft). This report discusses the development of a TMDL for metals for the main stem of the Buckhannon River. Several tributaries of the Buckhannon River are listed for pH and/or metals (WVDEP 1998). These listings are not specifically addressed in this report. TMDLs for these additional waters will be addressed as the analysis is completed.

The development of a TMDL requires an analysis of the evaluation of the various loads from all potential sources within the watershed. The instream conditions are then examined under various loading conditions. Typically, the analysis of loads and instream conditions is performed through the use of computer models. For this study the approach was designed to address both point sources (permitted discharge points) and nonpoint sources (forest, agriculture, residential, industrial, and reclaimed lands). The modeling needed to consider the variation of discharges from both point and nonpoint sources. The model selected for analysis of the TMDL was the Hydrologic Simulation Program—FORTRAN (HSPF) Version 11.0. This program is capable of continuous simulation, representing a time series of flow and runoff events. In addition, the instream portions of the model allow for the evaluation of stream flow, transport, and metals adsorption and desorption.

An evaluation of the available monitoring data was performed to characterize the condition of the river, the frequency of potential violations of water quality standards, the river conditions under which violations occurred, and the relevant processes that might need to be simulated. Historic reports, monitoring studies and compliance monitoring provided by the WVDEP, Anker Mines and Alton Mines, provided data on flow and stream geometry. The greatest amount of data in terms of number of locations and number of observations was collected during the 1980s. More recent data collection consisted of localized compliance monitoring and several sweeps (multiple locations with single observations collected). The most recent data collection focused on characterization of the tributary water quality. The review of data resulted in the following findings. Historic data show some exceedances of metal standards, particularly for aluminum and iron. A higher frequency of exceedances was observed immediately downstream of the confluence with Tenmile Creek. Examination of the more recently collected data (1990s) shows that periodic violations of iron standards continue to occur; however, the majority of the elevated concentrations are in the Buckhannon River upstream of Beans Mill. This is due to the more stringent iron criterion for B-2 waters. The pH is generally between 6 and 9.

Insufficient data were available to fully describe the time-varying conditions and the critical conditions. A long-term comprehensive study would be required to determine the circumstances that lead to an exceedance of the water quality criteria. Daily flow, stream gage, water quality measurements, and NPDES discharge information would be required to characterize the critical conditions that lead to an exceedance. It appears that elevated concentrations occur under a wide range of flow conditions due to variations in runoff, discharges, and instream flows. For this reason, a multi-year, continuous simulation was run to capture a wide range of flow conditions and the corresponding metals concentrations.

The model was developed based on the 1993 Multiresolution Landscape Characterization (MRLC) land use coverage, the instream characteristics described in previous studies, and the monitoring records of the point source discharges in the watershed. The setup of the model was based on literature values and review of the locally derived monitoring data. The hydrologic calibration was developed for the stream gaging station of the Buckhannon River at Hall, West Virginia. The model was applied to the existing conditions based on actual monitored flows from the point sources and rainfall data representing the period from January 1, 1994 to December 31, 1995. This base run was used for comparison with observed conditions. The next case considered conditions when the point sources discharge at their permit limits. This was used as the base condition for development of the TMDL allocation. The base run was examined for potential locations in violation of water quality criteria. The critical point identified for allocation was the Buckhannon River upstream of Beans Mill. The allocation was required only for iron since aluminum was predicted to meet water quality standards for the area of concern. Discharge levels and contributions from landuse types were adjusted to develop a loading combination that resulted in the achievement of water quality standards based on the numeric iron criteria. The allocation can be reached by controlling nonpoint source runoff and surface loading from abandoned mines and reclaimed areas. Control of nonpoint sources in the three subwatersheds encompassing the Left Fork varies between 22% in subwatershed 18 to 55% in subwatershed 20. The loading reduction varies between 9,954 lb/yr for watershed 20 and 3,925 lb/yr for watershed 21. All existing permits are expected to stay at their current levels. The recommended TMDL can be achieved through restoration or remining of abandoned areas and continued diversion and storage of runoff from reclaimed areas, identification of potential seeps, and eventual control through reforestation and passive treatment.

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1.0 INTRODUCTION

1.1 Background

Concentrations of metals in surface waters can become elevated due to natural processes and human activities. The U.S. Environmental Protection Agency's Water Quality Planning and Management Regulations (40 CFR 130) requires states to develop Total Maximum Daily Loads (TMDLs) for waters for which implementation of technology-based limits will not result in achievement of water quality standards. The TMDL process establishes allowable loadings of pollutants based on the relationship between pollution sources and instream water conditions. By following the TMDL process, states can establish water-quality-based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources (USEPA 1991).

1.2 Purpose of the Study

The objective of this study was to develop a TMDL for the impacted portion of the main stem of the Buckhannon River (Figure 1.1). The West Virginia Department of Environmental Protection (WVDEP) has identified the Buckhannon River as being impacted by periodic pH and metals problems, in the portion of the main stem above Hampton and below Alexander (16.74 miles), as reported on the draft 1998 303(d) list of water-quality-limited waters (WVDEP, 1998). This report addresses the development of TMDLs for the metal-related impairments of the Buckhannon River.

1.3 Selection of TMDL Endpoints

One of the major components of a TMDL is the establishment of instream endpoints, which are used to evaluate the attainment of acceptable water quality. Instream endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. The endpoints allow for a comparison between predicted instream conditions and conditions that are expected to restore beneficial uses; the endpoints are usually based on either the narrative or numeric criteria available in state water quality standards.

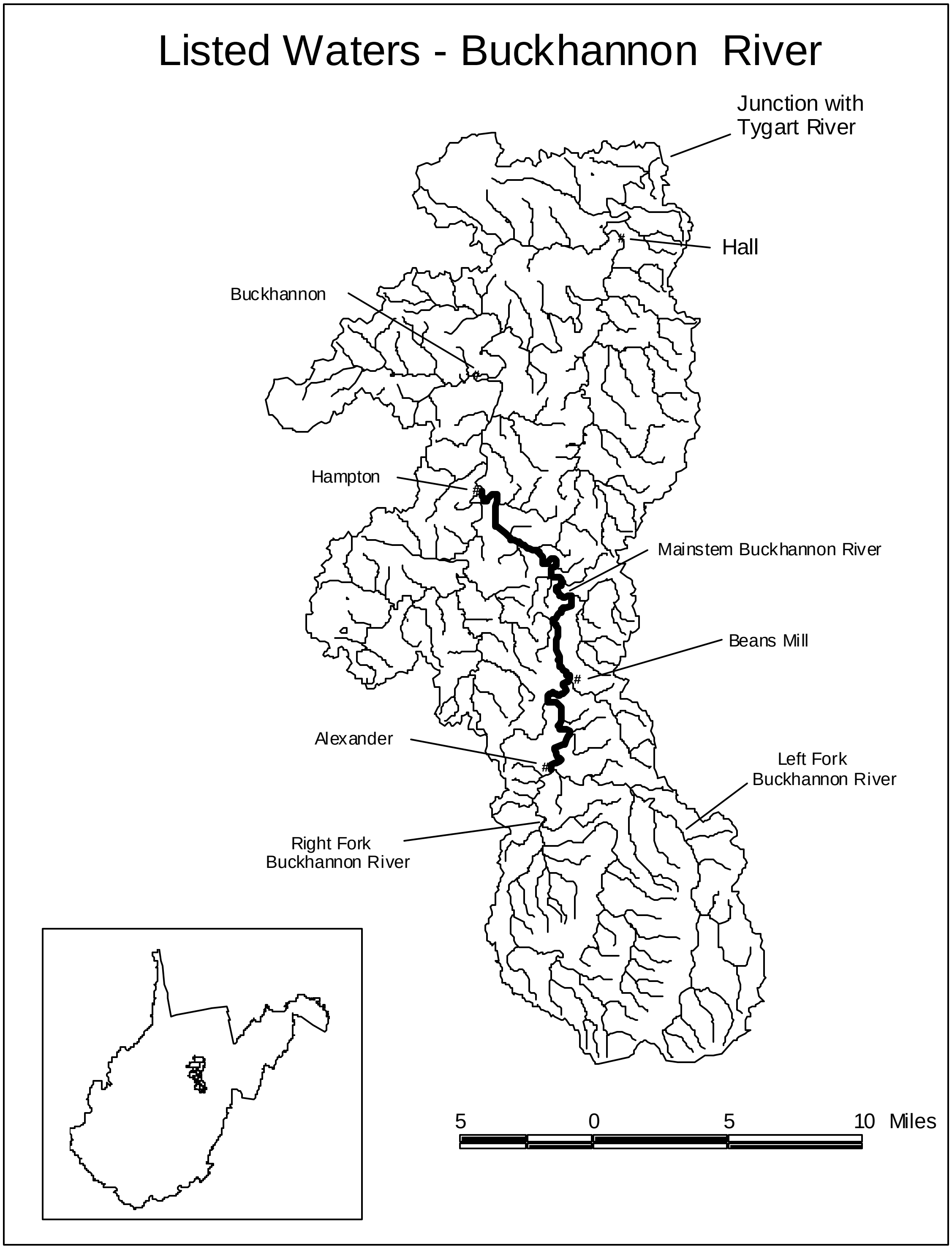

Figure 1.1. Buckhannon River listed mainstem segment

For the Buckhannon River TMDL, the applicable endpoints and associated target values can be determined directly from the West Virginia water quality standards. Elevated levels of aluminum and iron have been identified as potentially detrimental to aquatic life. The Buckhannon River below Beans Mill is designated as a B-3 water (Warm Water Fishery). Above Beans Mile, the Buckhannon River is considered to be a B-2 water (Cold Water Trout Stream). This listing also pertains to other listed waters such as the Right Fork of the Buckhannon River. The relevant West Virginia State water quality standards are shown in Table 1.1. One significant change in the standards is the elimination of the Acute Aquatic Life criterion for aluminum (0.087 mg/L). This change was approved by the West Virginia legislature on March 14, 1998. The aquatic life criterion for manganese was revised on July 1, 1998. The revision will result in no numeric aquatic life criteria for manganese although the human health criterion (1.0 mg/L, not to exceed) will continue to apply to water supplies. This change was also approved by the West Virginia legislature on March 14, 1998. Allocated loads from the TMDL will be distributed such that the acute criteria will not be exceeded and the 4-day average concentration will not exceed the chronic standards more than once every 3 years.

Table 1.1. West Virginia water quality standards for aluminum, iron, and manganese.

Pollutant	**Acute Criteria**		**Chronic Criteria**	
	B - 2	**B - 3**	**B - 2**	**B - 3**
pH	between 6 - 9	between 6 - 9	between 6 - 9	between 6 - 9
Aluminum, Total (mg/L)	0.75	0.75	None	None
Iron, Total (mg/L)	None	None	0.5	1.5
Manganese, Total (mg/L)	None	None	1.0[a]	1.0[a]

[a]Water supply designations only. Not to exceed.

2.0 SOURCE ASSESSMENT

2.1 Discussion of Instream Water Quality

This section focuses on the analysis of aluminum, iron, and manganese observations in the main stem of the Buckhannon River. The primary data used in this section were from the Montorin Stream Survey Report (WVDEP 1987) and an internal report produced by the WVDEP in 1991. The objective of the data evaluation was to characterize the type, frequency, and severity of water quality violations. The data analysis was also used to identify potential sources and to characterize the relationship between point source discharges and instream response at monitoring stations. The analysis was also designed to evaluate potential critical conditions and potential design flow conditions, that represent baseflow condition where violations are most likely to occur. It is assumed that if violations do not occur under these conditions, then violations will not occur under various flow conditions.

2.2 Instream Water Quality Monitoring Data

Instream water quality data for the Buckhannon River presented in this report were obtained from a number of different sources. Table 2.1 is a summary of data sources, type, frequency of sampling, the total number of observations and the sampling period. It can be seen that the available data in the 1990s consisted mainly of single sweeps (i.e., 1997, 1998) of the water quality of the Buckhannon River and its tributaries. Data from WVDEP were the most comprehensive and were therefore used to evaluate the Buckhannon River water quality conditions. Also, the water quality sweep conducted in 1987 provided a comprehensive overview of water quality throughout the watershed. The WVDEP 1997 and 1998 data sets focused primarily on tributary monitoring stations and were used in the characterization and setup for the watershed modeling component of the study. The City of Buckhannon analyzed water quality at the water treatment plant on a daily basis. The City of Buckhannon also measured water quality parameters related to drinking water standards at several upstream locations. Figure 2.1 shows the location of Buckhannon River instream sampling stations. Station identification used in this report is consistent with that of the original reports.

Table 2.1. Summary of data sources and reports for the Buckhannon River watershed.

Source	Data Type	Parameters[c]	Stations	Frequency	Date
Tygart Valley River AMD Assessment (WVDNR 1982)[b]	Instream Water Quality Buckhannon River and Tributaries	PH, Acidity, Alkalinity, SO_4, Fe, Mn	68	Single sweep	1981 and 1982
CHIA for Tenmile Creek (DOE 1987)[b]	Baseline Monitoring Data Buckhannon River	pH, Acidity, Alkalinity, Fe, Mn	7	Monthly	8/80 - 2/81
	Surface Water Data Buckhannon River	Fe, Mn	4	Monthly	2/86 - 10/86
	Water Resources Monitoring Data Buckhannon River	pH, Acidity, Alkalinity Fe, Mn, Al	9	Multiple/ Monthly	3,4,6,7,10 of 1986
Monitoring Stream Survey Report Buckhannon River (WVDEP 1987)	Water Quality Survey Buckhannon River and Tributaries	pH, Cond, Acidity, Alkalinity, Fe, SO_4, Mn, Al, ammonia, Nitrate, Nitrite	39	Single Sweep	10/87
STORET Database	Water Quality Data Buckhannon River	pH, Cond, Alkalinity, SO_4, Fe, Mn, Al	4	Multiple/Monthl y	1,2,3,4,6, of 1988
West Virginia DEP	Water Quality Data	pH, Cond, Alkalinity, SO_4, Fe, Mn, Al	15	Multiple/Weekly	3/86 - 6/88
West Virginia DEP	Water Quality Data Buckhannon River Tributaries	pH, Cond, Acidity, Al, Fe, Mn, Zn, Ca, Mg	43	Single Sweep	9/97
West Virginia DEP	Water Quality Buckhannon River Tributaries	pH, Acidity, Alkalinity, SO_4, Al, Fe, Mn	10	Single Sweep	4/98
Alton Project	Water Quality Buckhannon River and Tributaries	pH, Al, Fe, Mn, Nitrite, SO_4, Ammonia	6	Monthly	1/95 - 12/97
City of Buckhannon Water Supply	Water Quality Data	pH, Alkalinity, Hardness, Fe, Mn	8	Monthly	2/89 - 3/91
City of Buckhannon Water Supply	Water Quality Data	pH, ammonia, Alkalinity, Hardness, Fe, Mn, Turbidity	1	Daily Observations	1/96 - 5/98

[a]Alk = Alkalinity

Fe = Iron

Mn = Manganese

Al = Aluminum

SO_4 = Sulfate

Cond = Conductivity

[b] AMD - Acid Mine Drainage

[b] CHIA - Cumulative Hydrological Impact Assessment

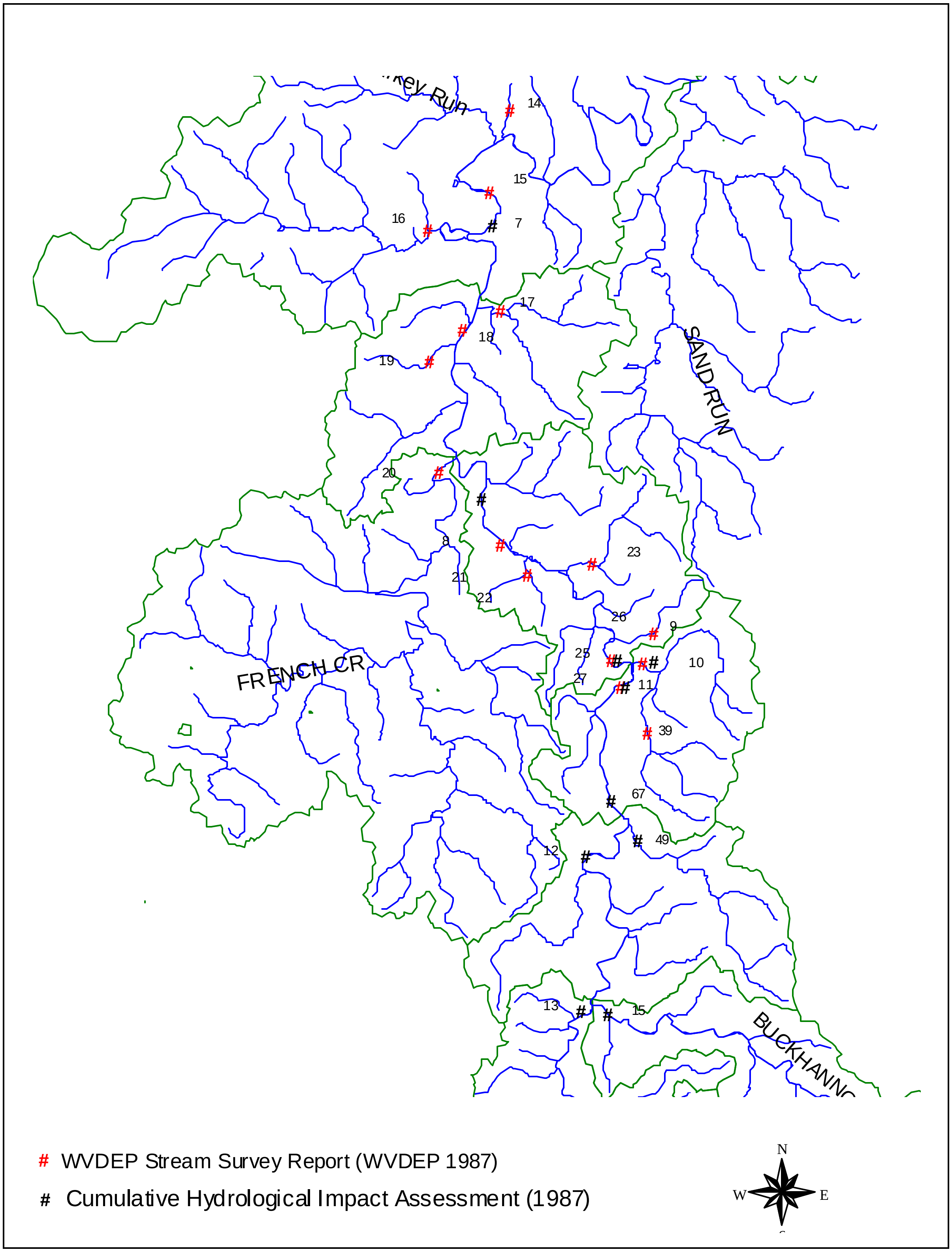

Figure 2.1. Instream monitoring locations for the WVDEP 1987 Buckhannon River survey

2.3 Assessment of Nonpoint Sources

In the Buckhannon River watershed a variety of nonpoint sources might contribute to the metal loads, including nonpoint source runoff (from areas including abandoned mine areas, reclaimed area, forest) and groundwater seepage due to natural and impacted land use conditions. To spatially analyze the metals loadings, the Buckhannon River watershed was divided into 14 subwatersheds (Figure 2.2). The land uses in each of the subwatersheds was determined using data from the USGS Land Cover Characterization Program (USGS 1997). As part of the Land Cover Characterization Program, a National Land Cover Data set is being developed. The Federal Region III Land Cover Data set (USGS 1998), which uses Multiresolution Landscape Characterization (MRLC) data, was used to determine land use coverage in Buckhannon River. A breakdown of land use types by subwatersheds is shown in Table 2.2.

Table 2.2. Landuse distribution by subwatersheds.

Watershed	Commercial/ Industrial (acres)	Abandoned Mining (acres)[a]	Reclaimed Mining (acres)	Forest (acres)	Agriculture (acres)
0502001-009	10.5	0.0	805.2	6444.5	272.3
0502001-010	275.4	15.68	0.4	6139.3	3567.7
0502001-011	5.1	0.0	296.1	9086.7	418.2
0502001-012	0.5	0.9	12.0	4940.2	493.7
0502001-013	108.7	33.8	416.8	18291.1	6984.2
0502001-014	956.1	68.3	140.1	17247.4	10645.5
0502001-015	111.6	0.9	21.3	22749.5	8188.6
0502001-016	6.5	0.0	74.9	8457.0	1391.2
0502001-017	26.7	22.6	9.3	15541.7	369.5
0502001-018	15.6	91.32	92.3	11940.2	329.2
0502001-019	17.6	14.7	200.5	20210.9	3561.3
0502001-020	0.2	0.0	28.7	4373.3	57.8
0502001-021	0.2	36.29	214.5	6782.3	122.7
0502001-022	1.1	18.69	37.1	11230.1	608.0
Total	1535.8	303.2	2349.2	163434.2	37009.9

[a] Treatment of abandoned mines as nonpoint sources is for this TMDL only and does not constitute determination by the EPA that abandoned mines are point or nonpoint sources for the purposes of CWA 301, 309, 402, or 404.

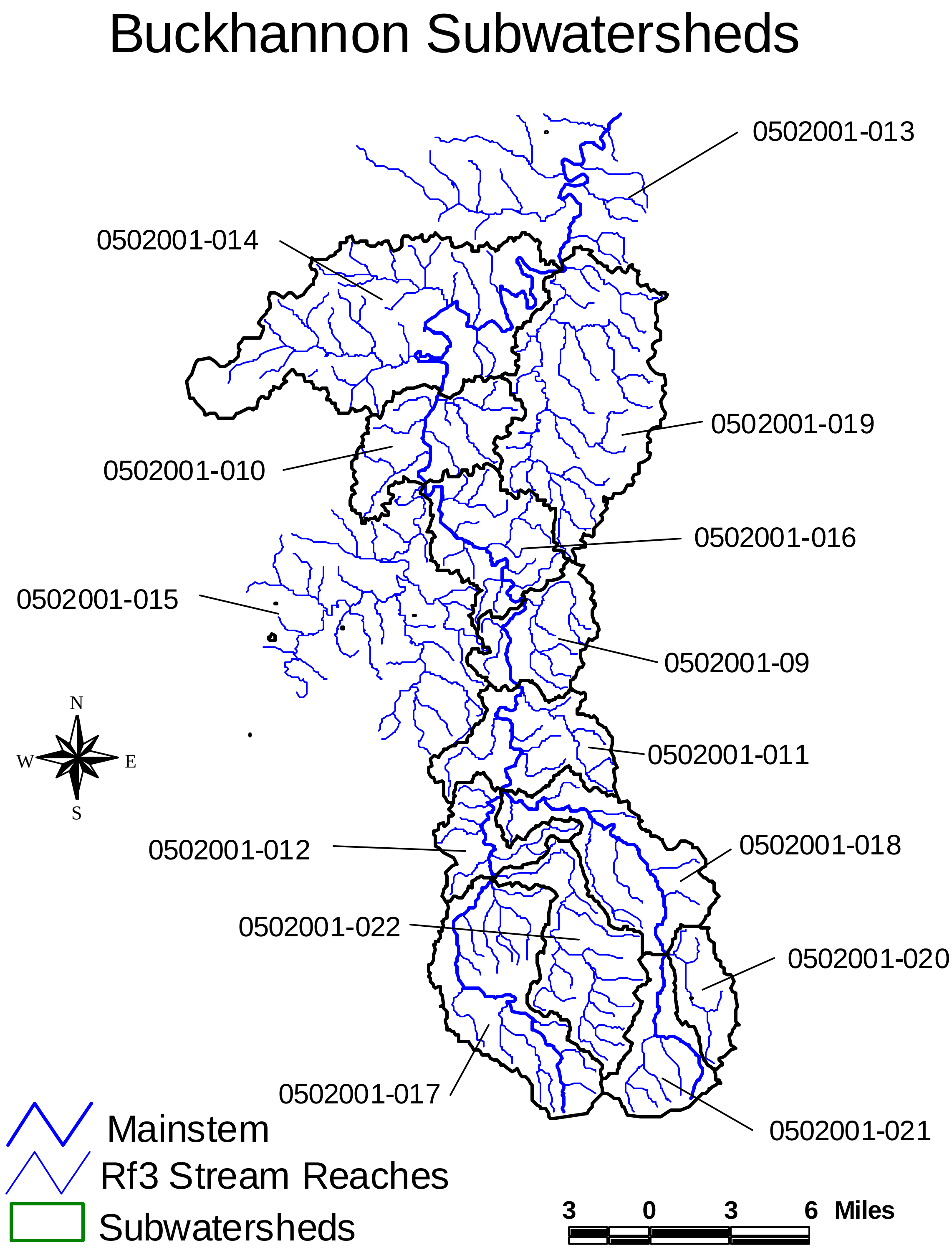

Figure 2.2. Buckhannon River subwatersheds

2.4 Assessment of Point Sources

Table 2.3 contains a list of the number of point source discharges in the Buckhannon River watershed. A complete table of point sources and their average flows and effluent concentrations is provided in the Appendix.

2.5 Observed Aluminum, Iron, and Magnesium Frequency of Exceedance

For the main stem of the Buckhannon River, frequency of standard exceedance was evaluated for the 1991 and the 1987 data collected by the WVDEP. An exceedance was considered any time the instream concentration of a pollutant exceeds the water quality standard.

Water quality data from the 1991 WVDEP report (WVDEP, 1991) was collected at 15 stations including 8 locations on the mainstem of the Buckhannon River. The number of samples taken at each station, presented in Table 2.4, varies between 35 and 64. These samples were taken over a period of 28 months. Examination of these data show that in the mainstem of the Buckhannon River, the frequency of exceedance for instream iron concentrations ranged from 0 to 7 times per station. The maximum frequency of exceedance was estimated at 10.9% for station 7 located at the city of Buckhannon. For the same period of record, aluminum frequency of exceedance ranged from 0 to 6 times with a maximum frequency of 9.4 also at station 7. The manganese criterion was not exceeded during this period except at station 9 located below the confluence with Tenmile Creek. The results of this analysis are summarized in Table 2.4. The WVDEP report included monitoring data for the same period (3/1986-6/1988) at the mouth of Tenmile Creek (station 10) which show a high frequency of exceedance. Although the frequence of exceedance at the mouth of Tenmile Creek was high for the three metals (83% for Fe, 92% for Al, and 98% for Mn), at station 9 directly downstream of Tenmile Creek the frequency of violation was 0% for Fe, 9% for Al, and 3% for Mn. This can be attributed to the dilution potential of the relatively higher flow rates of the Buckhannon river.

The more recent surveys performed by WVDEP in 1997 and 1998 focused on evaluating the condition of the tributaries. This information was used in the characterization of tributary inflows. The Alton Project also collected data for six stations on a monthly basis. These stations are located just downstream of the confluence of the Left and Right Forks of the Buckhannon River. Evaluation of the data collected from January 1995 to September 1997 showed that approximately 10% of the samples taken were above 0.5 mg/L. In the absence of four-day sampling studies, single daily measurements were used to indicate when there was the potential for exceedance of the chronic standard. Very few violations of either the aluminum standard or pH standard were observed. Analysis of the daily water quality data at the City of Buckhannon water treatment plant from 1/1/96 to 4/30/98 show no instances where the 4-day geometric mean for iron was exceeded.

Table 2.3. Number of point source discharges in the Buckhannon River watershed.

Subwatersheds	NPDES Permit Number	Facility Type	Number of Pipes
05020001-009	WV0050717	Surface Mine	7
	WV0061689	Deep Mine	4
	WV0067601	Treatment	3
	WV0067881	Surface Mine	3
05020001-010	WV0027031	Deep Mine	4
05020001-011	WV0042056	Reclaimed Surface Mine	12
	WV0024619	Deep Mine	2
05020001-013	WV0035998	Deep Mine	3
	WV0064955	Preparation Plant	2
	WV0098388	Surface Mine	1
	WV1003313	Surface Mine	1
	WV1003461	Surface Mine	1
05020001-014	WV1003291	Surface Mine	1
	WV1013858	Abandoned Deep Mine	4
05020001-015	WV0039471	Deep Mine	7
05020001-018	WV0090344	Refuse Dosposal	4
	WV0091901	Deep Mine	3
05020001-020	None		0
05020001-021	WV0053929	Preparation Plant	2
	WV0062910	Deep Mine	3
	WV1003321	Surface Mine	6
	WV1003356	Deep Mine	4
	WV1003585	Surface Mine	1
05020001-022	WV1003232	Coal Loading	8
	WV1003526	Surface Mine	1

Table 2.4. Summary of frequency of water quality criteria exceedance analysis for iron, aluminum and manganese in the main stem of the Buckhannon River (1987-1991).

Station	# Obs.	Fe		Al		Mn	
		No.	%	No.	%	No.	%
5	63	4	6.3	4	6.3	0	0
6	64	2	3.1	2	3.1	0	0
7	64	7	10.9	6	9.4	0	0
8	64	1	1.6	5	7.8	0	0
9	64	0	0.0	6	9.4	2	3.1
11	64	0	0.0	3	4.7	0	0
67	35	1[a]	2.8[a]	2	5.7	0	0
12	64	1[a]	1.6[a]	1	1.6	0	0

[a] Evaluated based on 0.5 mg/l standard.

Station	Location
5	Buckhannon River at Carrolton
6	Buckhannon River at Hall
7	Buckhannon River at Buckhannon
8	Buckhannon River at Sago
9	Buckhannon River below Tenmile Creek
10	Buckhannon River at Mouth of Tenmile Creek
11	Buckhannon River above Tenmile Creek
67	Buckhannon River at Beans Mill
12	Buckhannon River at Alton

3.0 MODELING PROCEDURES: LINKING THE SOURCES TO THE ENDPOINTS

Establishing the relationship between the instream water quality target and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses to flow and loading conditions.

3.1 Model Framework Selection

The development of a TMDL typically employs the use of models to support evaluation of pollutant loading (source characterization), the instream conditions, and the response of the receiving water to the changes in source loadings. The selection of the appropriate modeling approach requires consideration of the following:

- Expression of standards
- Dominant processes
- Scale of analysis

The relevant standards are discussed in Section 1.3 and shown in Table 1.1. Numeric standards, such as those applicable here, require the evaluation of the magnitude, frequency, and duration of the numeric criteria. In the case of metals, the West Virginia standards are expressed as total metals. This dictates that the methodology predict the total metals concentration in the water column of the receiving water. Thresholds of a numeric measure (i.e., mg/L) are evaluated for frequency of exceedance. Acute standards typically require evaluation over short time periods, and violations may occur under variable flow conditions. Chronic criteria require the evaluation of the response over a 4-day averaging period. Continuous simulation data can be processed to allow evaluation of the predicted chronic condition. Critical conditions may require the evaluation of the standard, depending on the particular expression, under a range of different flow conditions.

The simulation model(s) must consider the dominant processes of the pollutants of concern. The dominant processes can be considered in two primary categories— loading and instream. Loading processes include the simulation of nonpoint source loadings including inputs from land based activities (e.g., reclaimed mines, forest). The key features of the nonpoint source-based loading component is rainfall-induced runoff and erosion, as well as interflow/groundwater discharge into the stream system. The loading component also includes the input from point source discharges, as defined by permit limits and discharge monitoring information. The instream processes include transport of total metals, sediment adsorption/desorption, and deposition/resuspension. In some cases of highly variable pH, metals speciation may be a major component of the instream metal concentration. For the fast-flowing waters of the Buckhannon River watershed, metal speciation appears to have limited impact on the overall simulation. Simulation of metals speciation also requires relatively more rigorous data collection and model parameterization.

Scale of analysis and waterbody type were considered in the selection of the overall approach. The methodology should be able to evaluate subwatersheds at the scale of 100 acres to several thousand acres. The listed waters in the Buckhannon River watershed range from small streams to the river main stem. Selection of scale should be sensitive to the locations of the key features, such as abandoned mines, and point source dischargers. At the larger watershed scale, land areas are lumped into subwatersheds for practical representation of the system commensurate with the available data. Occasionally, site-specific and localized acute problems might require more detailed segmentation or definition of detailed modeling grids. For watershed-scale streams and midsized rivers, a combination of transport models, optional adsorption/desorption, and mass balance calculation capabilities might be needed to sufficiently represent the waterbody condition at various flow conditions and to define when and where water quality standards are violated.

The suite of models selected for simulation of the Buckhannon River TMDL was based on the considerations described above, analysis of the available monitoring data, and review of the literature and past modeling experience in waters with pH and metals impairments. The recommended approach includes the use of the following loading and instream modules with various simulation options to be applied as determined by the specific application:

- *Loading module*. The Hydrologic Simulation Program—FORTRAN (HSPF) Version 11.0 was selected for the loading model. It can perform continuous simulation and generate land-based runoff and erosion. HSPF also considers inputs from steady-state or time-varying point sources, allowing for incorporation of the monitored point source discharge points. HSPF allows for the parameterization of land use categories representative of the major categories in the watershed.

- *Instream module.* Two options for hydrologic routing in the stream system were investigated. HSPF has the capability to route flows under time-varying conditions using the RCHRES module. The HSPF RCHRES component includes consideration of multiple inputs, adsorption/desorption, sediment routing, and deposition. In some cases the use of a one-or-two dimensional application of the full hydrodynamic model might be warranted. The Environmental Fluid Dynamics Code (EFDC) was considered as an option (Hamrick and Wu 1997). In other specialized cases a full chemical speciation model might be needed to explore the instream response in a localized area. In those cases the MINTEQ model can be used. For this application the HSPF with the RCHRES was considered appropriate.

3.2 Model Setup

To obtain a representation of the watershed loadings and resulting concentration of metals in the Buckhannon River, the watershed was divided into 14 subwatersheds (Figure 2.2). Areas with little potential for metals loading (forest and agriculture) were subdivided based on hydrological characteristics. Areas with instream monitoring sites or multiple discharge points were also considered in the delineation process.

The stream location and network was based on the Reach File 3 (RF3) stream reach coverage (USEPA 1994). This information was used in conjunction with 7.5-minute digital elevation models (DEMs) to delineate hydrologically correct subwatersheds. ArcView (version 3.0a) was used to estimate critical model elements such as stream slope, elevation, and length. This information, as well as the stream routing, was manually input into the HSPF (v.11) model. Stream geometry for the Buckhannon River watershed was estimated from the report *Monitoring Branch Stream Survey: Report Buckhannon River and Important Tributaries, Upshur County, West Virginia* (WVDNR, 1987).

The hydrological component of the model was developed using daily rainfall data from the Elkins WSO meteorological station. The Buckhannon and Valley Head stations were considered, but significant data gaps were found at these stations. Meteorological data from the Elkins WSO station were obtained from the EarthInfo CD-ROM. The period used for this study was from January 1, 1970, to December 31, 1995. The latitude and longitude information from the NPDES permits was used to determine specific locations for the point discharges.

Point source loads were determined from the monitoring data required on the Daily Monitoring Records (DMRs) submitted by the permit holders. The DMRs include monthly averages and maximums for flow, pH, aluminum, iron, and manganese. The metals concentrations were multiplied by the discharge flows to estimate monthly average loadings for each pipe. Discharge locations derived from the NPDES permits were used to determine the receiving stream segment for each pipe.

3.3 Model Development and Calibration

To develop a representative linkage between the sources and the instream water quality response in the Buckhannon River, model parameters were adjusted to the extent possible for both hydrology and metals. The hydrological calibration of the model was accomplished by simulating the system from 1990 to 1995. The hydrological results from the model were compared to the observed daily mean flow from the closest downstream gaging station at Hall, West Virginia on the Buckhannon River. Adjustment of the hydrologic parameters for the watershed portion of the model required a comparison of the modeled overall water balance and stream flows Slight adjustment of the soil infiltration rate provided a close match to observed data. The results of this calibration are shown in Figure 3.1.

Model testing was performed using estimated monthly point source discharges based on review of the DMRs. Water quality results from the HSPF model were compared to instream monitoring information from STORET and from NPDES DMRs. Parameters related to aluminum, iron, and manganese were adjusted by comparing average monthly loading estimates to instream monitoring data collected by the WVDEP. Parameter values were changed within a range of acceptable values, in a manner that retained consistency between relative contributions from the different land use groups.

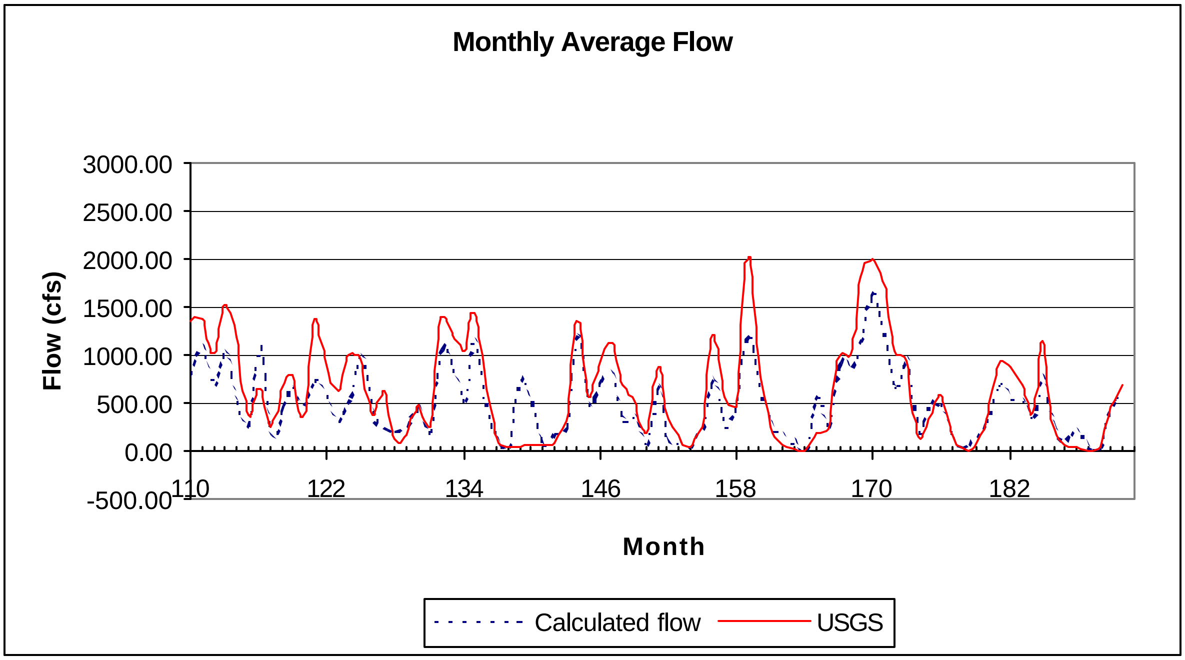

Figure 3.1. Hydrological calibration for the Buckhannon River

4.0 ALLOCATION

Total Maximum Daily Loads (TMDLs) are composed of the sum of individual waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and natural background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relation between pollutant loads and the quality of the receiving water body. Conceptually, this definition is denoted by the equation

TMDL = O WLAs + O LAs + MOS

The TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving water quality standards.

For some pollutants, TMDLs are expressed on a mass loading basis (e.g., pounds per day). In some cases the TMDL are expressed as another appropriate measure that is the relevant expression for the reduction of loadings of the specific pollutant to meet water quality standards.

4.1 Incorporating a Margin of Safety

The MOS is part of the TMDL development process. There are two basic methods for incorporating the MOS (USEPA 1991):

- Implicitly incorporate the MOS using conservative model assumptions to develop allocations or
- Explicitly specify a portion of the total TMDL as the MOS; use the remainder for allocations.

For the Buckhannon River TMDL, the MOS is incorporated implicitly into the modeling process by running a dynamic simulation to calculate the daily loadings of metals (Fe, Al, Mn). Other margins of safety used for this TMDL analysis include an increase in nonpoint source, controls especially the seeps from abandoned and reclaimed mines.

4.2 Assessing Alternatives

The evaluation of the baseline condition and management conditions was performed for the period of January 1994 to December 1995. This 2-year period represents various hydrologic conditions to capture the variability of the nonpoint source loading as well as that of the point source discharges. Although limited data were available to reach a full calibration, the model was setup with time-varying point source discharge data and adjusted to represent the existing water quality conditions.

Baseline conditions were used for comparing alternative management scenarios. The baseline condition assumed that all facilities are discharging at their permitted concentrations and at an average flow determined from reported monitoring data. Management condition scenarios describe the watershed and receiving streams with the waste load and load allocations in place. Both baseline and management scenarios made the assumption that the allocations specified in the Tenmile Creek TMDL had been implemented. Comparison between baseline condition and management condition analyses allow for evaluation of source control needs and therefore the TMDL allocation.

4.2.1 Baseline Condition

Model formulation for the Buckhannon River watershed were summarized by stream reach in terms of percent of time of violation of water quality standards. The relevant subwatersheds and associated reach numbers are shown in Figure 4.1. Tables 4.1, 4.2, and 4.3 present a summary of model results showing that for the area of concern (reaches 9, 10, 11, 13, 14, and 18) the only reach violating the standards is the portion of the Buckhannon main stem above Beans Mill (reach 11). For total iron, this reach violates the 0.5 mg/L (4-day average) 5.4% of the time. The prepared allocation will focus on this reach and upstream sources. The two main tributaries contributing to reach 11 are the Right Fork (reaches 12, 17, and 22) and the Left Fork (reaches 18, 20, and 21).

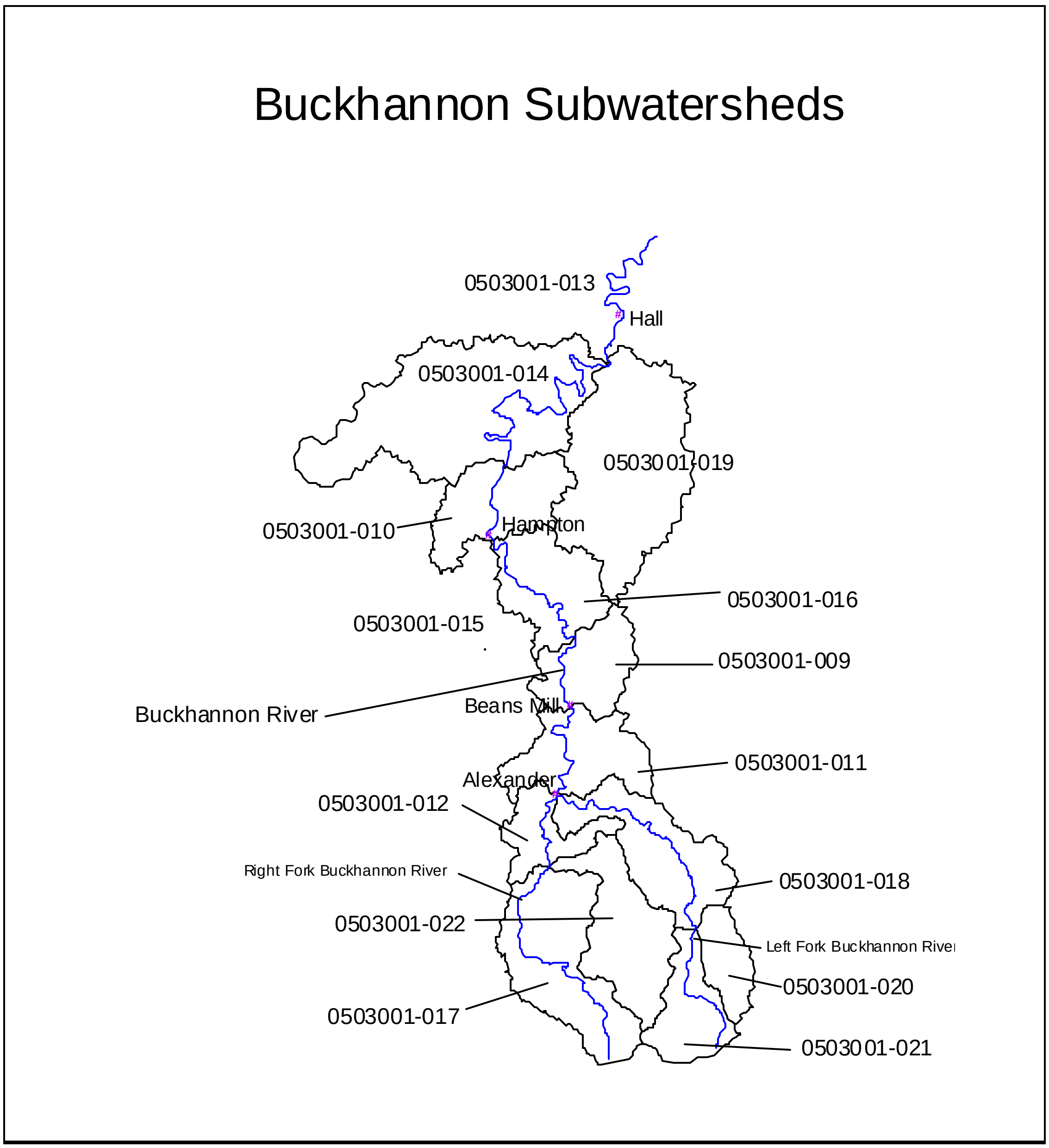

Figure 4.1. Buckhannon River subwatersheds and associated reach numbers

Modeling results show that inflows to reach 11 from the Right Fork do not violate the standards for iron, aluminum, and magnesium. Most of the loading that contributes to impairment of reach 11 comes from the Left Fork. Based on an evaluation of the contributing sources and the location of predicted impairments, the allocation will focus on the sources draining to the Left Fork of the Buckhannon River (reaches 18, 20, and 21).

Table 4.1. Summary of aluminum exceedances in the Buckhannon watershed derived from 1994-95 simulation results under baseline conditions.

Reach Name	Reach Numbers	Threshold (mg/L)	Number of Exceedances	Number of Days Exceeded	Percent Exceedances
Mainstem below Beans Mill	009, 010, 013, 014, 015, 016, 019	0.75	2	2	0.27
Main stem above Beans Mill	011	0.75	0	0	0
Right Fork of the Buckhannon	018, 020, 021	0.75	0	0	0
Left Fork of the Buckhannon	012, 017, 022	0.75	12	12	1.64

Table 4.2. Summary of iron exceedances in the Buckhannon watershed derived from 1994-95 simulation results under baseline conditions.

Reach Name	Reach Numbers	Threshold (mg/L)	Number of Exceedances	Number of Days Exceeded	Percent Exceedances
Main stem below Beans Mill	009, 010, 013, 014, 015, 016, 019	1.5	0	0	0
Main stem above Beans Mill	011	0.5	2	40	5.5
Right Fork of the Buckhannon	018, 020, 021	0.5	0	0	0
Left Fork of the Buckhannon	012, 017, 022	0.5	32	675	92.4

Table 4.3 Summary of manganese exceedances in the Buckhannon watershed derived from 1994-95 simulation results under baseline conditions.

Reach Name	Reach Numbers	Threshold (mg/L)	Number of Exceedances	Number of Days Exceeded	Percent Exceedances
Main stem below Beans Mill	009, 010, 013, 014, 015, 016, 019	1.0	0	0	0
Main stem above Beans Mill	011	1.0	0	0	0
Right Fork of the Buckhannon	018, 020, 021	1.0	0	0	0

Left Fork of the Buckhannon	012, 017, 022	1.0	0	0	0

4.2.2 Source Evaluation

The summary of point sources used in this analysis was obtained from available permits and assistance provided by the WVDEP (Table 4.4). Point sources contributing to the upstream reaches are located in the Left Fork subwatershed (mainly reaches 18, 20, and 21).

Nonpoint source loadings were also derived for each watershed in terms of concentration (mg/L) and loading (lb/day). The nonpoint source loadings are highly variable and closely dependent on the hydrology and rainfall distribution. The HSPF model was used for this study, as described in Section 3.0. The land use distribution representing the essential component of the nonpoint source loading was obtained for the Buckhannon watershed from the land cover characterization program (USGS 1997). This land use coverage was augmented by information collected from the University of West Virginia (Fletcher 1998) and historic studies (WVDEP 1987) to further identify abandoned mine locations and areal extent.

Table 4.4. Point source discharge loads used for Buckhannon watershed simulation.

Reach	Point Source	Flow (cfs)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)
21	Minor NPDES 021 [a]	0.750	0.504	0.168	0.336
18	WV62910 pipe 2	1.836	1.235	0.412	0.823
18	WV91901 pipe 15	0.190	0.149	0.043	0.085
Subtotal for Right Fork Buckhannon		2.776	1.888	1.076	1.244
17	Minor NPDES 017	0.650	0.324	0.146	0.218
12	Minor NPDES 012	0.080	0.005	0.038	0.002
Subtotal for Left Fork Buckhannon		0.730	0.329	0.184	0.220
11	AML Swamp Run [b]	0.330	0.015	0.038	0.015
11	Minor NPDES 011	0.050	0.002	0.006	0.003
Subtotal for main stem above Beans Mill		0.380	0.017	0.044	0.018
9	WV50717 pipe 2	1.444	0.162	0.214	0.324
9	WV50717 pipe 4	0.056	0.024	0.031	0.024
9	WV67881 pipe 8	0.419	0.047	0.047	0.094
9	WV67601 pipe 3	1.939	0.217	0.217	0.435
10	WV27031 pipe 2	3.260	2.558	0.731	1.462
10	WV27031 pipe 4	0.282	0.221	0.063	0.126
10	WV27031 pipe 5	1.746	1.175	0.392	0.783
15	AML Bull Run	0.731	0.575	0.038	0.039
14	AML Turkey Run	1.465	5.490	0.038	0.036
13	WV64955 pipe 4	0.237	0.160	0.053	0.106
13	AML Buckhannon	2.220	2.470	0.038	0.757
13	Minor NPDES 013	0.320	0.215	0.072	0.143
Subtotal for main stem below Beans Mill		14.119	13.314	1.932	4.329
Total for Buckhannon watershed		18.004	15.547	2.781	5.811

[a] Summation of minor NPDES discharges

[b] Discharge from abandoned mine lands as identified by the Tygart Valley River Subbasin Acid Mine Drainage Assessment

Table 4.5. Summary of aluminum exceedances in the Buckhannon watershed derived from 1994-95 simulation results under managed conditions.

Reach Name	Reach Numbers	Threshold (mg/L)	Number of Exceedances	Number of Days Exceeded	Percent Exceedances
Main stem below Beans Mill	009, 010, 013, 014, 015, 016, 019	0.75	1	1	.14
Main stem above Beans Mill	011	0.75	0	0	0
Right Fork of the Buckhannon	018, 020, 021	0.75	0	0	0
Left Fork of the Buckhannon	012, 017, 022	0.75	2	2	.27

Table 4.6. Summary of iron exceedances in the Buckhannon watershed derived from 1994-95 simulation results under managed conditions.

Reach Name	Reach Numbers	Threshold (mg/L)	Number of Exceedances	Number of Days Exceeded	Percent Exceedances
Main stem below Beans Mill	009, 010, 013, 014, 015, 016, 019	1.5	0	0	0
Main stem above Beans Mill	011	0.5	1	1	0.14
Right Fork of the Buckhannon	018, 020, 021	0.5	0	0	0
Left Fork of the Buckhannon	012, 017, 022	0.5	18	135	18.5

Table 4.7 Summary of manganese exceedances in the Buckhannon watershed derived from 1994-95 simulation results under managed conditions.

Reach Name	Reach Numbers	Threshold (mg/L)	Number of Exceedances	Number of Days Exceeded	Percent Exceedances
Main stem below Beans Mill	009, 010, 013, 014, 015, 016, 019	1.0	0	0	0
Main stem above Beans Mill	011	1.0	0	0	0
Right Fork of the Buckhannon	018, 020, 021	1.0	0	0	0
Left Fork of the Buckhannon	012, 017, 022	1.0	0	0	0

4.3 TMDL Allocation

Analysis of the modeling results of the baseline condition, as described in Section 4.2.2., indicated the key water quality standard violations is located between Beans Mill and the upstream confluence with the Left and Right Forks. It also indicated that the majority of the metal loading is reaching the Buckhannon mainstem through the Left Fork. The scenario prepared for this allocation identifies source loading reductions for the nonpoint sources in the Left Fork watersheds (reaches 18, 20, 21).

The combined loading from the Left Fork for existing conditions (baseline) is simulated at 56,576 lb/yr of total iron. An allocation reducing this loading to 37,427 lb/yr was simulated and showed that all the mainstem reaches of the Buckhannon meet the water quality standard for iron. The control of iron from nonpoint sources is also likely to result in significant reductions of other pollutants, including aluminum and manganese. Tables 4.8 to 4.10 show the results of the simulation in terms of reductions of loads. The loading scenario consisted of controlling an overall 7.73% of the total nonpoint source iron loading to the Buckhannon River. This loading was primarily focused on the Left Fork, as summarized in Table 4.9.

Table 4.8 Comparison of NPS aluminum loads (lbs/yr) for existing and management scenarios.

Watershed	Existing	Managed	Total Reduction	Percent Reduction
5020001018	17900.78	14100.62	3800.17	21.23
5020001020	12940.87	6037.02	6903.85	53.35
5020001021	12336.50	9233.14	3103.35	25.16

Table 4.9 Comparison of NPS iron loads (lbs/yr) for existing and management scenarios.

Watershed	Existing	Managed	Total Reduction	Percent Reduction
5020001018	23312.40	18043.51	5268.89	22.60
5020001020	17973.99	8019.93	9954.06	55.38
5020001021	15291.13	11365.26	3925.86	25.67

Table 4.10 Comparison of NPS manganese (lbs/yr) loads for existing and management scenarios.

Watershed	Existing	Managed	Total Reduction	Percent Reduction
5020001018	4827.24	4287.14	540.09	11.19
5020001020	2631.72	1540.90	1090.81	41.45
5020001021	2506.28	2173.38	332.90	13.28

Table 4.11 Comparison of NPS loads (lbs/yr) for all subwatersheds.

Contaminant	Existing	Managed	Total Reduction	Percent Reduction
Al	483064.82	445501.25	37563.57	7.78
Fe	623686.59	575492.34	48194.25	7.73
Mn	152839.04	148615.94	4223.10	2.76

5.0 SUMMARY

The Buckhannon River watershed was divided into 14 subwatersheds and the HSPF model selected as the modeling framework for performing the TMDL allocations. The model was applied to the existing conditions based on actual monitored flows from the point sources and rainfall data representing the period from January 1, 1994 to December 31, 1995. This base run was used for comparison with observed conditions. The next case considered conditions when the point sources discharge at their permit limits. This was considered the base condition for development of the TMDL allocation. This base run was examined for potential locations in violation of water quality criteria. Critical points evaluated included the section of the Buckhannon upstream of Beans Mill and the section below the confluence with Tenmile Creek (due to the location of the City of Buckhannon water supply).

For this TMDL analysis, load allocations were calculated with margins of safety to meet water quality standards and established water quality goals because of uncertainty in the available data or lack of key information. The uncertainty in the data used for this study is discussed later in this section, with along recommendations for improving future TMDL analyses.

5.1 Findings

Output from the HSPF model indicated a number of violations of the aluminum and iron standards for the existing conditions using the time period of January 1994 to December 1995. Discharge and relevant land-contributing areas were adjusted to develop a loading combination that resulted in the achievement of water quality standards based on the numeric iron and aluminum criteria. The TMDL allocation was developed based on iron evaluated using the appropriate standard at multiple locations in the Buckhannon River.

The allocation can be reached by controlling nonpoint source runoff and surface loading from abandoned mines and reclaimed areas. Control of nonpoint source in the three subwatersheds encompassing the Left Fork varies between 22% for subwatershed 18 and 55% in subwatershed 20. The loading reduction varies from 9,954 lb/yr for watershed 20 to 3,925 lb/yr in watershed 21. All existing permits are expected to stay at their current levels. The recommended TMDL can be achieved through restoration or remining of abandoned areas and continued diversion and storage of runoff from reclaimed areas, identification of potential seeps, and eventual control through reforestation and passive treatment. After applying the load allocations, the HSPF model indicated that all 14 subwatersheds were meeting the iron water quality standards and the established water quality goals.

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APPENDIX

Table A.1. Summary of NPDES discharges in the Buckhannon watershed.

Permit Number	Pipe Number	Num Obs	Min	Flow rate Max	Value (gpm)	Value (cfs)
Subwatershed 05020001-009						
WV0050717	1	46	1.0	43.0	10.0	0.02
WV0050717	2	48	13.0	3460.0	648.0	1.44
WV0050717	3	1	15.0	15.0	15.0	0.03
WV0050717	4	47	1.0	300.0	47.0	0.10
WV0050717	6	4	2.0	400.0	178.0	0.40
WV0050717	8	12	1.0	13.0	3.0	0.01
WV0050717	9					0.00
WV0061689	1	44	1.0	43.0	10.0	0.02
WV0061689	2	48	1.0	350.0	49.0	0.11
WV0061689	4	3	1.0	5.0	3.0	0.01
WV0061689	21	32	1.0	118.0	9.0	0.02
WV0067601	2	34	1.0	26.0	3.0	0.01
WV0067601	3	46	15.0	3250.0	870.0	1.94
WV0067601	4	32	1.0	15.0	3.0	0.01
WV0067881	2	1	4.0	4.0	4.0	0.01
WV0067881	7	1	5.0	5.0	5.0	0.01
WV0067881	8	5	25.0	700.0	188.0	0.42
Subwatershed 05020001-010						
WV0027031	2	48	36.0	9582.0	1463.0	3.26
WV0027031	4	27	0.0	1528.0	127.0	0.28
WV0027031	5	48	52.0	3134.0	784.0	1.75
WV0027031	104					0.00
Subwatershed 05020001-011						
WV0042056	1	38	0.0	2.0	0.0	0.00
WV0042056	2	39	0.0	1.0	0.0	0.00
WV0042056	3	36	0.0	1.0	0.0	0.00
WV0042056	4	37	0.0	2.0	0.0	0.00
WV0042056	5	20	0.0	0.0	0.0	0.00
WV0042056	6	35	0.0	0.0	0.0	0.00
WV0042056	7	34	0.0	1.0	0.0	0.00
WV0042056	8	39	0.0	0.0	0.0	0.00
WV0042056	9	35	0.0	0.0	0.0	0.00
WV0042056	10	39	0.0	2.0	0.0	0.00
WV0042056	11	38	0.0	1.0	0.0	0.00
WV0042056	12	38	0.0	1.0	0.0	0.00
Subwatershed 05020001-013						
WV0024619	1	1	75.0	75.0	75.0	0.17
WV0024619	3	19	25.0	63.0	43.0	0.10
WV0035998	1	20	5.0	18.0	12.0	0.03
WV0035998	3	16	0.0	250.0	37.0	0.08
WV0035998	5	17	18.0	70.0	32.0	0.07
WV0064955	4	39	30.0	163.0	106.0	0.24
WV0064955	101	1	50.0	50.0	50.0	0.11
WV0098388	1	37	0.0	41100.0	4325.0	9.64
WV0098388	4	1	76.0	76.0	76.0	0.17

Permit	Pipe			Flow rate		
Number	Number	Num Obs	Min	Max	Value (gpm)	Value (cfs)
WV0098388	5	1	1.0	1.0	1.0	0.00
WV1003313	4	1	15.0	15.0	15.0	0.03
WV1003461	1	19	0.0	250.0	21.0	0.05
Subwatershed 05020001-014						
WV1003291	1	2	6.0	12.0	9.0	0.02
WV1013858	6	14	10.0	40.0	16.0	0.04
WV1013858	7	28	8.0	80.0	38.0	0.08
WV1013858	8	2	18.0	20.0	19.0	0.04
WV1013858	9	9	5.0	18.0	9.0	0.02
Subwatershed 05020001-015						
WV0039471	1	3	0.0	0.0	0.0	0.00
WV0039471	2	3	0.0	0.0	0.0	0.00
WV0039471	3					0.00
WV0039471	5	2	0.0	0.0	0.0	0.00
WV0039471	6	3	0.0	0.0	0.0	0.00
WV0039471	9					0.00
WV0039471	10	1	0.0	0.0	0.0	0.00
Subwatershed 05020001-018						
WV0090344	1	9	3.0	60.0	23.0	0.05
WV0090344	2	2	15.0	25.0	20.0	0.04
WV0090344	3	22	5.0	385.0	43.0	0.10
WV0090344	4	11	3.0	83.0	37.0	0.08
WV0091901	1	25	1.0	212.0	21.0	0.05
WV0091901	2	1	1700.0	1700.0	1700.0	3.79
WV0091901	15	27	1.0	290.0	85.0	0.19
Subwatershed 05020001-020						
Subwatershed 05020001-021						
WV0053929	1	27	15.0	300.0	72.0	0.16
WV0053929	2	14	1.0	30.0	8.0	0.02
WV0062910	1	26	1.0	318.0	70.0	0.16
WV0062910	2	20	11.0	2500.0	824.0	1.84
WV0062910	3	2	1835.0	2100.0	1968.0	4.39
WV1003321	1	8	3.0	20.0	10.0	0.02
WV1003321	3	5	10.0	20.0	14.0	0.03
WV1003321	4	4	5.0	23.0	10.0	0.02
WV1003321	15	5	4.0	29.0	11.0	0.02
WV1003321	16	5	4.0	41.0	13.0	0.03
WV1003321	19	1	76.0	76.0	76.0	0.17
WV1003356	1	36	1.0	88.0	20.0	0.04
WV1003356	2	35	5.0	83.0	18.0	0.04
WV1003356	3	4	5.0	20.0	14.0	0.03
WV1003356	4	6	3.0	25.0	13.0	0.03
WV1003585	1	26	7.0	370.0	72.0	0.16
Subwatershed 05020001-022						
WV1003232	1	5	3.0	30.0	12.0	0.03
WV1003232	2	7	1.0	15.0	5.0	0.01
WV1003232	3	7	1.0	15.0	4.0	0.01

Permit Number	Pipe Number	Num Obs	Min	Flow rate Max	Value (gpm)	Value (cfs)
WV1003232	4	5	3.0	45.0	15.0	0.03
WV1003232	5	4	3.0	10.0	5.0	0.01
WV1003526	1	43	1.0	40.0	15.0	0.03
WV1003526	2	44	1.0	25.0	8.0	0.02
WV1003526	3	46	2.0	50.0	27.0	0.06
WV1003526	4	38	1.0	36.0	4.0	0.01

Table A.2. Summary of pH measurements at NPDES Discharge Points in the Buckhannon Watershed.

Permit	Pipe		pH		
Number	Number	Num Obs	Min	Max	Value
Subwatershed 05020001-009					
WV0050717	1	46	6.07	8.90	7.30
WV0050717	2	48	6.50	10.00	7.96
WV0050717	3	1	7.33	7.33	7.33
WV0050717	4	47	6.08	8.70	7.08
WV0050717	6	4	7.20	8.80	7.85
WV0050717	8	12	6.00	8.70	7.36
WV0050717	9	13	6.90	8.90	7.61
WV0061689	1	44	6.24	8.90	7.56
WV0061689	2	48	6.10	7.70	6.85
WV0061689	4	3	6.00	6.90	6.40
WV0061689	21	32	6.20	9.00	7.27
WV0067601	2	34	6.00	7.40	6.47
WV0067601	3	46	6.13	8.90	7.86
WV0067601	4	32	6.00	8.10	6.68
WV0067881	2	1	8.30	8.30	8.30
WV0067881	7	1	8.70	8.70	8.70
WV0067881	8	6	8.10	9.00	8.67
Subwatershed 05020001-010					
WV0027031	2	48	6.29	8.45	7.76
WV0027031	4	27	6.81	8.84	7.65
WV0027031	5	48	6.99	8.37	7.87
WV0027031	104	1	7.21	7.21	7.21
Subwatershed 05020001-011					
WV0042056	1	40	5.00	9.00	7.25
WV0042056	2	41	5.60	8.80	7.26
WV0042056	3	38	6.20	8.00	7.09
WV0042056	4	40	5.20	8.90	7.14
WV0042056	5	41	4.90	9.00	6.80
WV0042056	6	37	4.90	9.00	7.03
WV0042056	7	37	4.80	8.90	7.17
WV0042056	8	41	5.90	8.10	7.35
WV0042056	9	38	5.60	11.70	6.84
WV0042056	10	41	6.10	7.50	6.88
WV0042056	11	39	6.60	9.00	7.62
WV0042056	12	40	5.10	9.30	7.25
Subwatershed 05020001-013					
WV0024619	1	1	7.65	7.65	7.65
WV0024619	3	19	7.73	8.18	8.01
WV0035998	1	20	4.54	7.48	6.59
WV0035998	3	16	6.01	7.58	7.05
WV0035998	5	18	3.65	7.94	7.11
WV0064955	4	39	6.46	7.89	7.41
WV0064955	101	1	7.70	7.70	7.70
WV0098388	1	37	6.77	8.13	7.46
WV0098388	4	1	6.30	6.30	6.30

Permit	Pipe		pH		
Number	Number	Num Obs	Min	Max	Value
WV0098388	5	1	6.86	6.86	6.86
WV1003313	4	1	7.80	7.80	7.80
WV1003461	1	23	6.51	8.80	7.54
Subwatershed 05020001-014					
WV1003291	1	2	6.90	7.50	7.20
WV1013858	6	14	6.53	8.12	7.48
WV1013858	7	28	2.22	8.37	7.43
WV1013858	8	2	7.82	7.83	7.83
WV1013858	9	9	7.14	8.01	7.61
Subwatershed 05020001-015					
WV0039471	1	45	6.80	9.00	7.62
WV0039471	2	44	7.00	8.50	7.67
WV0039471	3	32	6.50	8.00	7.28
WV0039471	5	42	6.50	8.50	7.60
WV0039471	6	45	6.90	9.20	7.67
WV0039471	9	1	7.40	7.40	7.40
WV0039471	10	40	6.00	7.00	6.59
Subwatershed 05020001-018					
WV0090344	1	9	6.90	7.80	7.17
WV0090344	2	4	6.60	7.90	7.20
WV0090344	3	40	6.10	8.40	7.22
WV0090344	4	11	6.60	7.30	7.04
WV0091901	1	42	6.40	8.80	7.32
WV0091901	2	1	8.30	8.30	8.30
WV0091901	15	38	6.20	7.80	7.06
Subwatershed 05020001-020					
Subwatershed 05020001-021					
WV0053929	1	47	6.20	8.30	7.15
WV0053929	2	22	6.00	9.00	7.39
WV0062910	1	46	6.60	8.60	7.66
WV0062910	2	29	6.30	8.60	7.86
WV0062910	3	13	6.70	7.40	7.05
WV1003321	1	8	6.85	8.00	7.38
WV1003321	3	5	6.58	7.03	6.75
WV1003321	4	4	6.21	7.27	6.85
WV1003321	15	5	6.71	6.99	6.83
WV1003321	16	5	6.33	6.87	6.60
WV1003321	19	1	6.20	6.20	6.20
WV1003356	1	36	6.05	8.11	7.06
WV1003356	2	35	6.14	7.93	6.74
WV1003356	3	4	6.40	7.35	6.65
WV1003356	4	6	6.28	7.10	6.58
WV1003585	1	44	6.50	8.00	7.13
Subwatershed 05020001-022					
WV1003232	1	5	6.00	7.10	6.70
WV1003232	2	7	6.00	7.20	6.74
WV1003232	3	7	6.40	7.20	6.90

Permit	Pipe		pH		
Number	Number	Num Obs	Min	Max	Value
WV1003232	4	5	6.10	7.40	6.79
WV1003232	5	4	6.10	6.90	6.58
WV1003526	1	43	3.70	8.10	6.85
WV1003526	2	44	6.00	7.90	6.73
WV1003526	3	46	6.00	7.80	6.87
WV1003526	4	36	6.00	7.70	6.67

Table A.3. Summary of Aluminum Discharges in the Buckhannon Watershed.

Permit	Pipe		Aluminum		
Number	Number	Num Obs	Min	Max	Value (mg/L)
Subwatershed 05020001-009					
WV0050717	1	46	0.08	1.08	0.38
WV0050717	2	48	0.09	1.04	0.46
WV0050717	3	1	0.15	0.15	0.15
WV0050717	4	47	0.04	1.00	0.30
WV0050717	6	4	0.58	2.01	1.16
WV0050717	8	12	0.28	0.79	0.50
WV0050717	9				
WV0061689	1	41	0.06	2.50	0.42
WV0061689	2	43	0.03	0.78	0.23
WV0061689	4	1	0.13	0.13	0.13
WV0061689	21	27	0.07	0.57	0.25
WV0067601	2				
WV0067601	3	46	0.19	26.00	1.33
WV0067601	4				
WV0067881	2	1	2.24	2.24	2.24
WV0067881	7	1	1.21	1.21	1.21
WV0067881	8	4	0.51	1.16	0.88
Subwatershed 05020001-010					
WV0027031	2				
WV0027031	4				
WV0027031	5	17	0.01	0.30	0.12
WV0027031	104				
Subwatershed 05020001-011					
WV0042056	1	39	0.14	3.59	1.14
WV0042056	2	40	0.14	2.13	0.82
WV0042056	3	37	0.10	1.47	0.52
WV0042056	4	39	0.10	20.30	1.06
WV0042056	5				
WV0042056	6				
WV0042056	7				
WV0042056	8				
WV0042056	9				
WV0042056	10	36	0.10	0.62	0.23
WV0042056	11	37	0.10	2.74	0.35
WV0042056	12	39	0.21	8.68	1.77
Subwatershed 05020001-013					
WV0024619	1				
WV0024619	3				
WV0035998	1				
WV0035998	3				
WV0035998	5				
WV0064955	4				
WV0064955	101				
WV0098388	1				
WV0098388	4				

Permit	Pipe		Aluminum		
Number	Number	Num Obs	Min	Max	Value (mg/L)
WV0098388	5				
WV1003313	4				
WV1003461	1	1	0.05	0.05	0.05
Subwatershed 05020001-014					
WV1003291	1				
WV1013858	6				
WV1013858	7				
WV1013858	8				
WV1013858	9				
Subwatershed 05020001-015					
WV0039471	1				
WV0039471	2				
WV0039471	3				
WV0039471	5				
WV0039471	6				
WV0039471	9				
WV0039471	10				
Subwatershed 05020001-018					
WV0090344	1				
WV0090344	2	4	0.24	1.00	0.62
WV0090344	3	12	0.02	1.00	0.48
WV0090344	4				
WV0091901	1	15	0.01	1.18	0.43
WV0091901	2				
WV0091901	15	10	0.01	1.00	0.39
Subwatershed 05020001-020					
Subwatershed 05020001-021					
WV0053929	1	16	0.01	1.00	0.36
WV0053929	2	8	0.01	1.00	0.41
WV0062910	1	14	0.01	1.00	0.42
WV0062910	2				
WV0062910	3	14	0.01	1.00	0.20
WV1003321	1	8	0.07	5.62	1.61
WV1003321	3	5	0.04	1.09	0.44
WV1003321	4	4	0.58	2.65	1.17
WV1003321	15	5	0.15	0.88	0.41
WV1003321	16	5	0.11	1.31	0.52
WV1003321	19	1	0.21	0.21	0.21
WV1003356	1	36	0.01	4.66	0.86
WV1003356	2	35	0.01	4.14	0.45
WV1003356	3	4	0.01	0.02	0.02
WV1003356	4	6	0.01	0.03	0.02
WV1003585	1	14	0.01	1.00	0.26
Subwatershed 05020001-022					
WV1003232	1				
WV1003232	2				
WV1003232	3				

Permit	Pipe		Aluminum		
Number	Number	Num Obs	Min	Max	Value (mg/L)
WV1003232	4				
WV1003232	5				
WV1003526	1	3	0.04	0.05	0.04
WV1003526	2	4	0.31	1.00	0.49
WV1003526	3	3	0.07	0.08	0.08
WV1003526	4	3	0.06	0.12	0.10

Table A.4. Summary of Iron discharges in the Buckhannon Watershed.

Permit	Pipe			Iron	
Number	Number	Num Obs	Min	Max	Value (mg/L)
Subwatershed 05020001-009					
WV0050717	1	46	0.05	0.85	0.14
WV0050717	2	48	0.05	0.52	0.23
WV0050717	3	1	0.08	0.08	0.08
WV0050717	4	47	0.15	1.29	0.44
WV0050717	6	4	0.06	0.21	0.14
WV0050717	8	12	0.33	1.67	0.78
WV0050717	9				
WV0061689	1	44	0.04	0.88	0.14
WV0061689	2	48	0.26	1.62	0.64
WV0061689	4	3	0.03	0.10	0.06
WV0061689	21	32	0.07	0.43	0.23
WV0067601	2				
WV0067601	3	46	0.04	0.48	0.12
WV0067601	4				
WV0067881	2	1	0.12	0.12	0.12
WV0067881	7	1	0.05	0.05	0.05
WV0067881	8	4	0.09	2.00	0.62
Subwatershed 05020001-010					
WV0027031	2	48	0.24	3.50	1.20
WV0027031	4	27	0.23	3.25	1.08
WV0027031	5	48	0.11	8.40	1.95
WV0027031	104				
Subwatershed 05020001-011					
WV0042056	1	39	0.05	0.90	0.37
WV0042056	2	40	0.12	1.05	0.37
WV0042056	3	37	0.22	4.56	0.72
WV0042056	4	39	0.10	1.11	0.38
WV0042056	5	40	0.05	0.25	0.07
WV0042056	6	36	0.05	1.49	0.24
WV0042056	7	36	0.05	0.29	0.07
WV0042056	8	40	0.16	2.43	0.80
WV0042056	9	37	0.05	1.55	0.26
WV0042056	10	40	0.22	2.41	0.65
WV0042056	11	38	0.45	6.22	1.62
WV0042056	12	39	0.05	0.36	0.08
Subwatershed 05020001-013					
WV0024619	1	1	1.85	1.85	1.85
WV0024619	3	19	0.06	0.45	0.26
WV0035998	1	20	0.26	4.23	0.70
WV0035998	3	16	0.10	1.24	0.35
WV0035998	5	18	0.15	0.81	0.30
WV0064955	4	39	0.39	4.48	1.56
WV0064955	101	1	0.65	0.65	0.65
WV0098388	1	37	0.03	2.80	0.63
WV0098388	4				

Permit	Pipe			Iron	
Number	Number	Num Obs	Min	Max	Value (mg/L)
WV0098388	5				
WV1003313	4				
WV1003461	1	23	0.07	2.58	0.62
Subwatershed 05020001-014					
WV1003291	1				
WV1013858	6	14	0.15	2.20	0.64
WV1013858	7	28	0.13	2.22	0.64
WV1013858	8	2	0.25	0.37	0.31
WV1013858	9	9	0.10	1.76	0.70
Subwatershed 05020001-015					
WV0039471	1	45	0.19	1.20	0.64
WV0039471	2	44	0.04	0.87	0.26
WV0039471	3	32	0.04	1.12	0.21
WV0039471	5	42	0.07	3.74	1.17
WV0039471	6	45	0.05	1.09	0.17
WV0039471	9				
WV0039471	10	40	0.12	1.08	0.33
Subwatershed 05020001-018					
WV0090344	1	9	0.25	1.24	0.58
WV0090344	2	4	0.29	0.97	0.59
WV0090344	3	40	0.07	2.32	0.62
WV0090344	4	11	0.04	0.71	0.35
WV0091901	1	41	0.06	1.33	0.35
WV0091901	2	1	0.13	0.13	0.13
WV0091901	15	38	0.14	3.00	1.60
Subwatershed 05020001-020					
Subwatershed 05020001-021					
WV0053929	1	47	0.04	2.90	0.46
WV0053929	2	22	0.04	1.41	0.50
WV0062910	1	45	0.05	0.87	0.29
WV0062910	2	29	0.01	0.87	0.24
WV0062910	3	14	0.01	2.73	0.37
WV1003321	1	8	0.29	2.17	1.17
WV1003321	3	5	0.06	1.08	0.35
WV1003321	4	4	0.26	2.35	0.89
WV1003321	15	5	0.06	0.37	0.17
WV1003321	16	5	0.06	0.68	0.29
WV1003321	19	1	0.07	0.07	0.07
WV1003356	1	35	0.13	2.85	0.99
WV1003356	2	35	0.04	2.18	0.60
WV1003356	3	4	0.48	0.79	0.56
WV1003356	4	6	0.24	0.79	0.47
WV1003585	1	44	0.05	110.00	3.38
Subwatershed 05020001-022					
WV1003232	1	5	0.08	0.97	0.30
WV1003232	2	7	0.10	0.78	0.26
WV1003232	3	7	0.15	1.32	0.43

Permit	Pipe		Iron		
Number	Number	Num Obs	Min	Max	Value (mg/L)
WV1003232	4	5	0.06	0.38	0.24
WV1003232	5	4	0.21	0.53	0.30
WV1003526	1	43	0.01	0.57	0.23
WV1003526	2	44	0.10	1.29	0.47
WV1003526	3	46	0.14	1.44	0.44
WV1003526	4	38	0.10	1.60	0.66

Table A.5 Summary of manganese discharges in the Buckhannon Watershed.

Permit	Pipe	Manganese			
Number	Number	Num Obs	Min	Max	Value (mg/L)
Subwatershed 05020001-009					
WV0050717	1	46	0.02	0.30	0.10
WV0050717	2	48	0.06	0.91	0.27
WV0050717	3	1	0.10	0.10	0.10
WV0050717	4	47	0.09	1.40	0.29
WV0050717	6	4	0.68	2.78	1.30
WV0050717	8	12	0.14	1.23	0.56
WV0050717	9				
WV0061689	1	44	0.02	0.26	0.10
WV0061689	2	48	0.13	1.95	0.51
WV0061689	4	2	0.03	0.07	0.05
WV0061689	21	30	0.01	0.40	0.14
WV0067601	2				
WV0067601	3	46	0.07	0.83	0.35
WV0067601	4				
WV0067881	2	1	1.00	1.00	1.00
WV0067881	7	1	0.83	0.83	0.83
WV0067881	8	4	0.09	0.97	0.60
Subwatershed 05020001-010					
WV0027031	2	48	0.01	0.82	0.30
WV0027031	4	27	0.02	0.38	0.10
WV0027031	5	48	0.06	0.71	0.28
WV0027031	104				
Subwatershed 05020001-011					
WV0042056	1	39	0.69	16.60	8.94
WV0042056	2	40	4.03	22.80	13.74
WV0042056	3	37	2.81	15.30	8.74
WV0042056	4	39	0.40	7.62	3.41
WV0042056	5	40	0.01	5.71	1.61
WV0042056	6	36	1.65	8.14	4.74
WV0042056	7	36	0.47	3.80	1.21
WV0042056	8	40	0.24	2.61	0.91
WV0042056	9	37	0.40	3.47	1.43
WV0042056	10	40	0.49	6.44	2.43
WV0042056	11	38	0.38	5.59	1.99
WV0042056	12	39	0.52	6.42	3.45
Subwatershed 05020001-013					
WV0024619	1	1	1.74	1.74	1.74
WV0024619	3	19	0.02	0.21	0.07
WV0035998	1	20	0.11	6.20	2.03
WV0035998	3	16	0.07	0.22	0.13
WV0035998	5	18	0.02	0.46	0.13
WV0064955	4	39	0.21	1.93	0.99
WV0064955	101	1	0.26	0.26	0.26
WV0098388	1	37	0.05	1.78	0.59
WV0098388	4				

Permit	Pipe	Manganese			
Number	Number	Num Obs	Min	Max	Value (mg/L)
WV0098388	5				
WV1003313	4				
WV1003461	1	23	0.02	0.58	0.13
Subwatershed 05020001-014					
WV1003291	1				
WV1013858	6	14	0.04	0.80	0.32
WV1013858	7	28	0.04	1.24	0.54
WV1013858	8	2	0.06	0.10	0.08
WV1013858	9	9	0.08	1.18	0.44
Subwatershed 05020001-015					
WV0039471	1	45	0.03	0.36	0.15
WV0039471	2	44	0.01	0.14	0.05
WV0039471	3	32	0.04	0.58	0.21
WV0039471	5	42	0.01	2.45	1.12
WV0039471	6	45	0.01	0.72	0.12
WV0039471	9				
WV0039471	10	40	0.02	0.68	0.13
Subwatershed 05020001-018					
WV0090344	1	9	0.07	0.34	0.14
WV0090344	2	4	0.01	0.15	0.09
WV0090344	3	40	0.06	0.89	0.36
WV0090344	4	11	0.07	0.29	0.17
WV0091901	1	42	0.02	0.46	0.13
WV0091901	2	1	0.01	0.01	0.01
WV0091901	15	37	0.01	1.01	0.27
Subwatershed 05020001-020					
Subwatershed 05020001-021					
WV0053929	1	47	0.02	0.45	0.17
WV0053929	2	22	0.01	0.59	0.18
WV0062910	1	45	0.01	0.34	0.05
WV0062910	2	28	0.01	0.12	0.05
WV0062910	3	14	0.01	0.17	0.04
WV1003321	1	8	0.07	0.68	0.33
WV1003321	3	5	0.01	0.08	0.03
WV1003321	4	4	0.01	1.82	0.49
WV1003321	15	5	0.01	0.02	0.01
WV1003321	16	5	0.01	0.12	0.04
WV1003321	19	1	0.05	0.05	0.05
WV1003356	1	36	0.07	1.46	0.41
WV1003356	2	35	0.05	0.59	0.24
WV1003356	3	4	0.22	0.26	0.24
WV1003356	4	6	0.09	0.25	0.15
WV1003585	1	44	0.02	0.43	0.16
Subwatershed 05020001-022					
WV1003232	1	5	0.02	0.24	0.09
WV1003232	2	7	0.02	0.11	0.05
WV1003232	3	7	0.03	0.21	0.08

Permit	Pipe	Manganese			
Number	Number	Num Obs	Min	Max	Value (mg/L)
WV1003232	4	5	0.02	0.14	0.07
WV1003232	5	4	0.04	0.10	0.07
WV1003526	1	40	0.01	0.32	0.07
WV1003526	2	41	0.03	0.54	0.29
WV1003526	3	43	0.02	0.80	0.10
WV1003526	4	35	0.04	0.28	0.15