TOTAL MAXIMUM DAILY LOAD (TMDL)

For

pH

In the

Upper Clinch Watershed (HUC 06010205)

Campbell County, Tennessee

FINAL

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DEPARTMENT OF ENVIRONMENT & CONSERVATION

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LIST OF ABBREVIATIONS

AMD	Acid Mine Drainage
CCC	Criteria Continuous Concentration
CFR	Code of Federal regulations
CFS	Cubic Feet per Second
CMC	Criteria Maximum Concentration
DEM	Digital Elevation Model
DWPC	Division of Water Pollution Control
EPA	Environmental Protection Agency
GIS	Geographic Information System
HUC	Hydrologic Unit Code
ITRC	Instream Total Recoverable Concentration
LA	Load Allocation
LDC	Load Duration Curve
LSPC	Loading Simulation Program in C^{++}
MGD	Million Gallons per Day
MOS	Margin of Safety
MRLC	Multi-Resolution Land Characteristic
NHD	National Hydrography Dataset
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
RM	River Mile
TDEC	Tennessee Department of Environment & Conservation
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WCS	Watershed Characterization SYstem
WLA	Waste Load Allocation

SUMMARY SHEET

Total Maximum Daily Load (TMDL) for pH in the Upper Clinch River Watershed (06010205)

Impaired Waterbody Information

State: Tennessee
Counties: Campbell
Watershed: Upper Clinch River (HUC 06010205)
Constituents of Concern: pH

Impaired Waterbodies Addressed in This Document:

Waterbody ID	Waterbody	Miles Impaired
TN06010205064 – 0110	THOMPSON CREEK	5.14

Designated Uses:

The designated use classifications for waterbodies in the Upper Clinch River Watershed include fish and aquatic life, irrigation, livestock watering & wildlife, and recreation.

Water Quality Targets:

Derived from *State of Tennessee Water Quality Standards, Chapter 1200-4-3, General Water Quality Criteria, 2007 Version*:

> The pH value shall lie within the range of 6.0 to 9.0 and shall not fluctuate more than 1.0 unit in this range over a period of 24 hours.

TMDL Scope:

Waterbodies identified on the Final 2008 303(d) list as impaired due to pH due to abandoned mining. Only limited data were available for Thompson Creek. Additional monitoring is recommended to either confirm impairment or allow for delisting.

Analysis/Methodology:

Net alkalinity was used as a surrogate for pH. The net alkalinity TMDL for impaired waterbodies in the Upper Clinch River Watershed was developed using a load duration curve methodology to assure compliance with the target net alkalinity of 10.8 mg/L (see Appendices B & C), which will provide a pH within the criteria range of 6.0 – 9.0. A duration curve is a cumulative frequency graph that represents the percentage of time during which the value of a given parameter is equaled or exceeded. Load duration curves are developed from flow duration curves and can illustrate existing water quality conditions (as represented by loads calculated from monitoring data), how these conditions compare to desired targets, and the region of the waterbody flow regime represented by these existing loads.

The TMDLs, WLAs, and LAs for net alkalinity are summarized in the following table.

Critical Conditions:

Water quality data collected over a period of 10 years for load duration curve analysis were used to assess the water quality standards representing a range of hydrologic and meteorological conditions.

Seasonal Variation:

The 10-year period used for LSPC model simulation period for development of load duration curve analysis included all seasons and a full range of flow and meteorological conditions.

Margin of Safety (MOS):

Implicit (conservative modeling assumptions).

Summary of TMDLs, WLAs, & LAs expressed as daily loads for Impaired Waterbodies in the Upper Clinch River Watershed (HUC 06010205)

Impaired Waterbody Name	Impaired Waterbody ID	Constituent	TMDL	WLAs	LAs
			[lbs/day]	[lbs/day]	[lbs/day/ac]
Thompson Creek	TN06010205064 – 0110	Net Alkalinity	58.1 x Q	NA	1.04×10^{-2} x Q

Notes: NA = Not Applicable.
Q = Mean Daily In-stream Flow (cfs).

a. For development of net alkalinity TMDLs, an implicit MOS was incorporated through the use of conservative modeling assumptions (see Section 7.5).

pH TOTAL MAXIMUM DAILY LOAD (TMDL)
UPPER CLINCH RIVER WATERSHED (HUC 06010205)

1.0 INTRODUCTION

Section 303(d) of the Clean Water Act requires each state to list those waters within its boundaries for which technology based effluent limitations are not stringent enough to protect any water quality standard applicable to such waters. Listed waters are prioritized with respect to designated use classifications and the severity of pollution. In accordance with this prioritization, states are required to develop Total Maximum Daily Loads (TMDLs) for those water bodies that are not meeting designated uses. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions, so that states can establish water quality based controls to reduce pollution from both point and non-point sources and restore and maintain the quality of their water resources (USEPA, 1991a).

2.0 WATERSHED DESCRIPTION

The Upper Clinch River Watershed (HUC 06010205) is located in the northern portion of Eastern Tennessee (Figure 1), primarily in Campbell, Claiborne, Grainger, Hancock, and Union Counties. The Upper Clinch River Watershed lies within two Level III ecoregions (Ridge and Valley, Central Appalachians) and contains five Level IV ecoregions as shown in Figure 2 (USEPA, 1997):

- **The Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f)** form a heterogeneous region composed predominantly of limestone and cherty dolomite. Landforms are mostly low rolling ridges and valleys, and the solids vary in their productivity. Landcover includes intensive agriculture, urban and industrial, or areas of thick forest. White oak forests, bottomland oak forests, and sycamore-ash-elm riparian forests are the common forest types, and grassland barrens intermixed with cedar-pine glades also occur here.
- **The Southern Sandstone Ridges (67h)** ecoregion encompasses the major sandstone ridges, but these ridges also have areas of shale and siltstone. The steep, forested chemistry of streams flowing down the ridges can vary greatly depending on the geologic material. The higher elevation ridges are in the north, including Wallen Ridge, Powell Mountain, Clinch Mountain, and Bays Mountain. White Oak Mountain in the south has some sandstone on the west side, but abundant shale and limestone as well. Grindstone Mountain, capped by the Gizzard Group sandstone, is the only remnant of Pennsylvanian-age strata in the Ridge and Valley of Tennessee.
- **The Southern Dissected Ridges and Knobs (67i)** contain more crenulated, broken, or hummocky ridges, compared to smoother, more sharply pointed sandstone ridges. Although shale is common, there is a mixture and interbedding of geologic materials. The ridges on the east side of Tennessee's Ridge and Valley tend to be associated with the Ordovician-age Sevier shale, Athens shale, and Holston and Lenoir limestones. These can include calcareous shale, limestone,

siltstone, sandstone, and conglomerate. In the central and western part of the ecoregion, the shale ridges are associated with the Cambrian-age Rome Formation: shale and siltstone with beds of sandstone. Chestnut oak forests and pine forests are typical for the higher elevations of the ridges, with areas of white oak, mixed mesophytic forest, and tulip poplar on the lower slopes, knobs, and draws.

- The **Cumberland Mountains (69d)**, in contrast to the sandstone-dominated Cumberland Plateau (68a) to the west and southwest, are more highly dissected, with narrow-crested steep slopes, and younger Pennsylvanian-age shales, sandstones, siltstones, and coal. Narrow, winding valleys separate the mountain ridges, and relief is often 2000 feet. Cross Mountain, west of Lake City, reaches 3534 feet in elevation. Soils are generally well-drained, loamy, and acidic, with low fertility. The natural vegetation is a mixed mesophytic forest, although composition and abundance vary greatly depending on aspect, slope position, and degree of shading from adjacent land masses. Large tracts of land are owned by lumber and coal companies, and there are many areas of stripmining.
- The **Cumberland Mountain Thrust Block (69e)** is mostly forested and contains high, steep ridges, hills, coves, narrow valleys, and the Pine Mountain Overthrust Fault. Forests are usually more mesophytic than in the Cumberland Mountains (69d) but forest composition is highly variable and controlled by aspect, slope position, past usage, and degree of topographic shading. Components of the bird, amphibian, small mammal, and plant assemblages are also distinct from Ecoregion 69d. The Cumberland Mountain Thrust Block (69e) is mostly underlain by Pennsylvanian shale, siltstone, sandstone, conglomerate, and coal. Sedimentation from coal mines, coal washing, and logging as well as acidic mine drainage have decreased the biological integrity and productivity of surface waters. Small streams are common and have high gradients, waterfalls, many riffles, few pools, and cobble or boulder substrates. Nutrient and alkalinity levels are lower, thermal regimes are cooler, and fish populations are less diverse than in Ecoregion 69d.

The Upper Clinch River Watershed, located in Anderson, Campbell, Claiborne, Grainger, Hancock, Hawkins, and Union Counties, Tennessee, has a drainage area of approximately 707 square miles (mi^2) in Tennessee. The entire watershed, including portions of Tennessee and Virginia, drains approximately 1,944 mi^2. Watershed land use distribution is based on the Multi-Resolution Land Characteristic (MRLC) databases derived from Landsat Thematic Mapper digital images from the period 1990-1993. Although changes in the land use of the Upper Clinch River Watershed have occurred since 1993 as a result of development, this is the most current land use data available. Land use in the Upper Clinch River Watershed is summarized in Table 1 and shown in Figure 3. Predominant land use in the Tennessee portion of the Upper Clinch River Watershed is forest (86.5%) followed by pasture (11.5%). Urban areas represent approximately 1.0% of the total drainage area of the watershed.

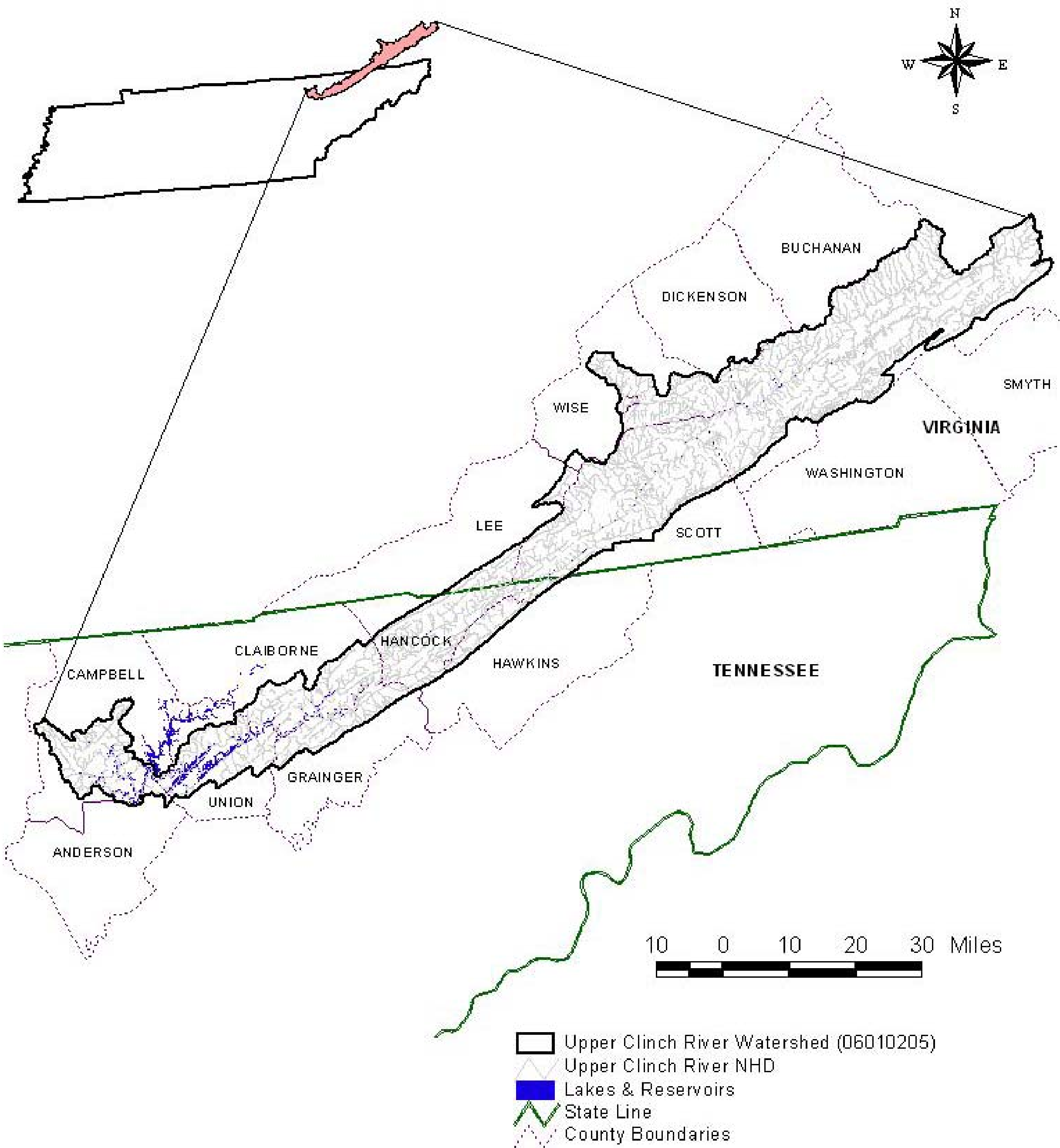

Figure 1 Location of Upper Clinch River Watershed

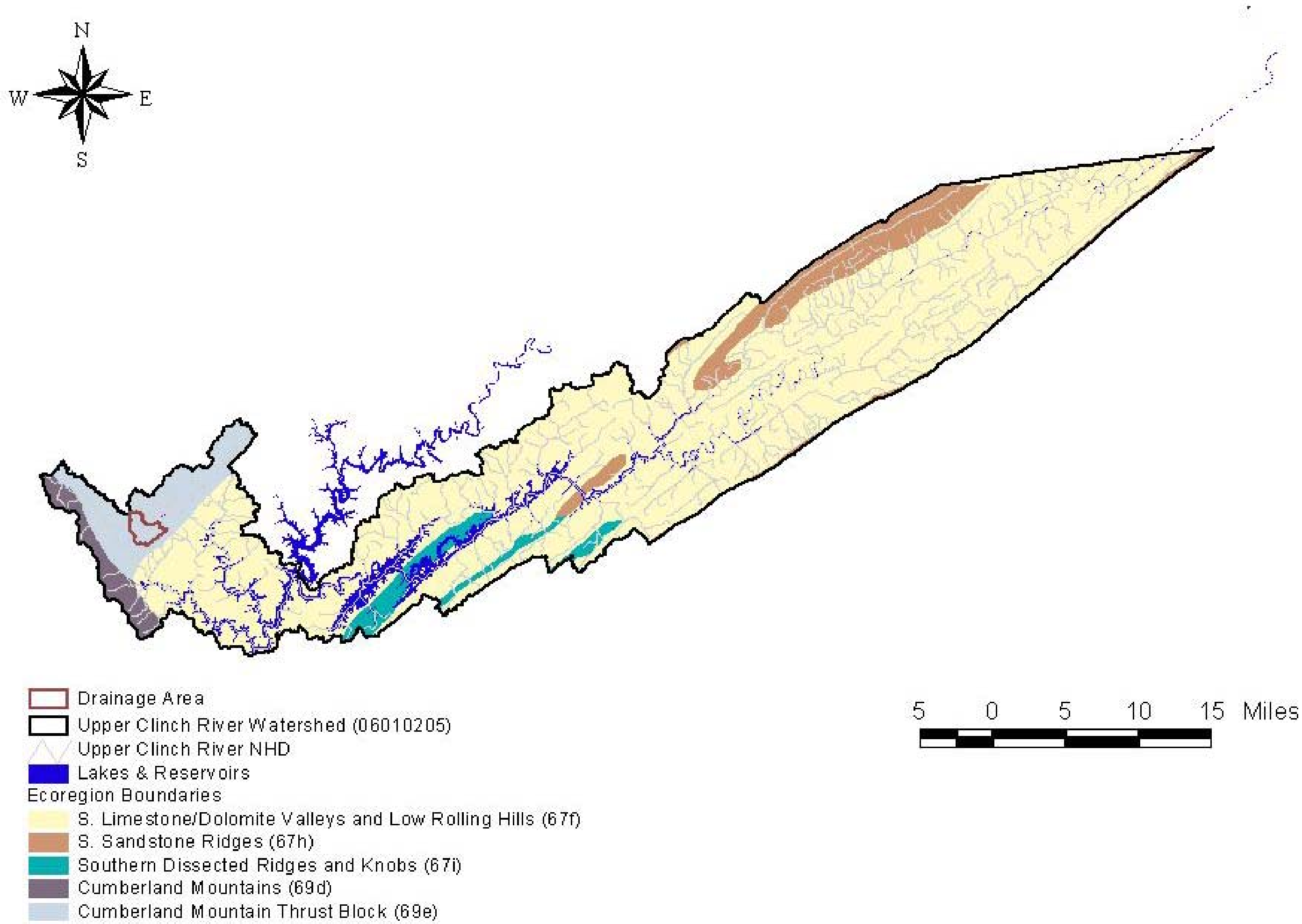

Figure 2 Upper Clinch River Watershed Ecoregion Designation

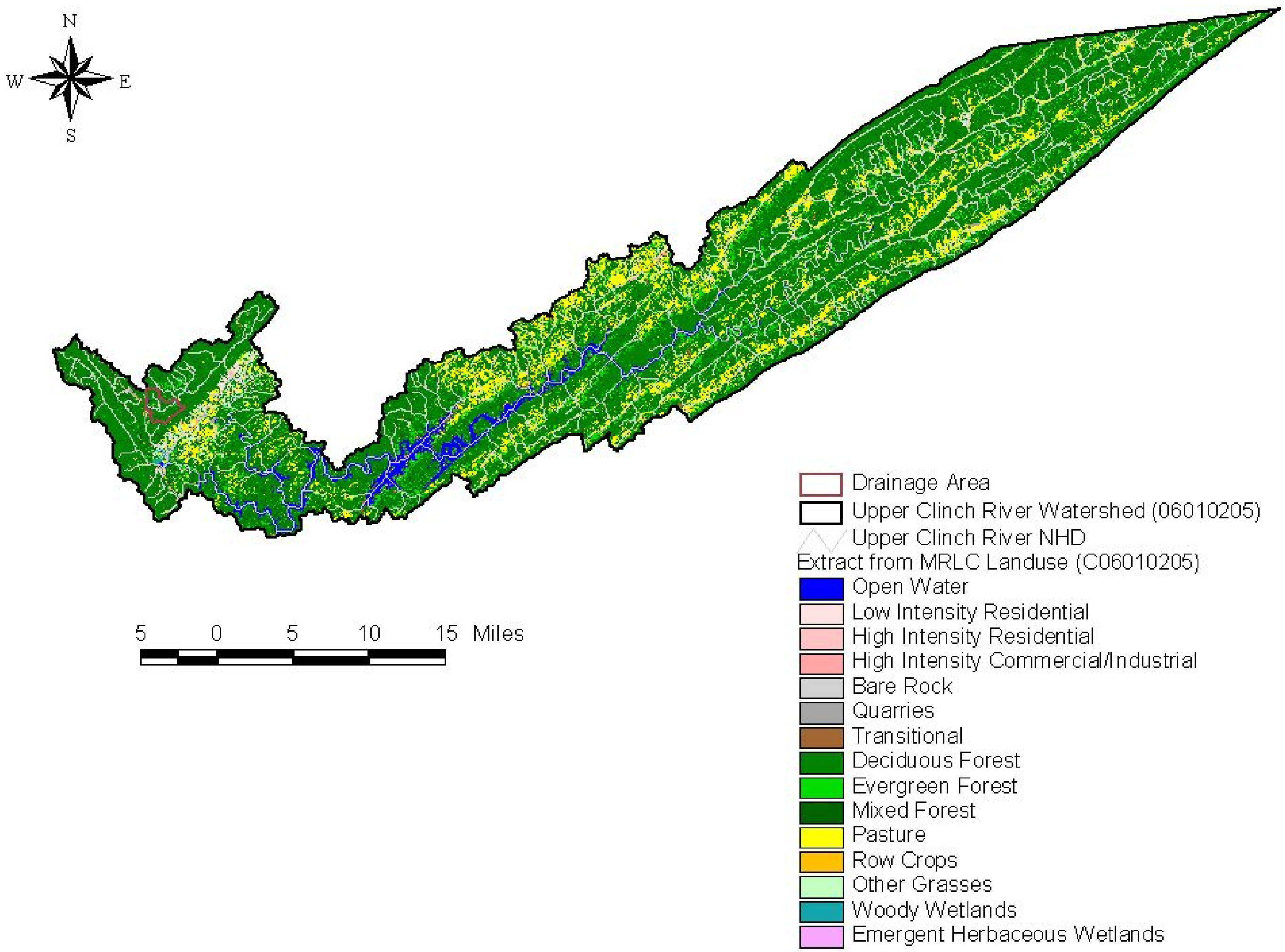

Figure 3 Upper Clinch River Watershed Land Use Distribution

Table 1. MRLC Land Use Distribution – Upper Clinch River Watershed (Tennessee portion)

Land Use	Area	
	[acres]	[%]
Bare Rock/Sand/Clay	3	0.0
Deciduous Forest	259,752	57.4
Emergent Herbaceous Wetlands	286	0.1
Evergreen Forest	41,039	9.1
High Intensity Commercial/Industrial/ Transportation	1,655	0.4
High Intensity Residential	339	0.1
Low Intensity Residential	2,370	0.5
Mixed Forest	66,446	14.7
Open Water	18,338	4.1
Other Grasses (Urban/recreational)	2,105	0.5
Pasture/Hay	51,888	11.5
Quarries/Strip Mines/ Gravel Pits	432	0.1
Row Crops	4,875	1.1
Transitional	2,377	0.5
Woody Wetlands	409	0.1
Total	**452,313**	**100.0**

3.0 PROBLEM DEFINITION

The State of Tennessee's final 2008 303(d) list (TDEC, 2008) was approved by the U.S. Environmental Protection Agency (EPA), Region IV in June of 2008. The list identified one waterbody in the Upper Clinch River Watershed as not supporting designated use classifications due, in part, to pH associated with abandoned mines and resource extraction. Information regarding formation of acid mine drainage (AMD) is contained in Appendix A. An excerpt from the 2008 303(d) list is presented in Table 2. Impaired segments in the Upper Clinch River Watershed are shown in Figure 4.

Table 2 2008 303(d) List – Upper Clinch River Watershed

Waterbody ID	Impacted Waterbody	County	Miles/Acres Impaired	Cause	Pollutant Source
TN06010205064 –0110	Thompson Creek	Campbell	5.14	Low pH	Abandoned Mining

Assessment information for waterbodies impaired due to low pH in the Upper Clinch River Watershed is available in the EPA/TDEC Assessment Database (ADB) and is referenced to the waterbody IDs in Table 2. ADB information may be accessed at: http://gwidc.memphis.edu/website/dwpc/ . According to the ADB, pH levels were measured at several locations on Thompson Creek in 2005 and all measurements were below 6.0. However, this monitoring data could not be located at the time of preparation of this TMDL.

The designated use classifications for waterbodies in the Upper Clinch River Watershed include fish and aquatic life, irrigation, livestock watering & wildlife, and recreation.

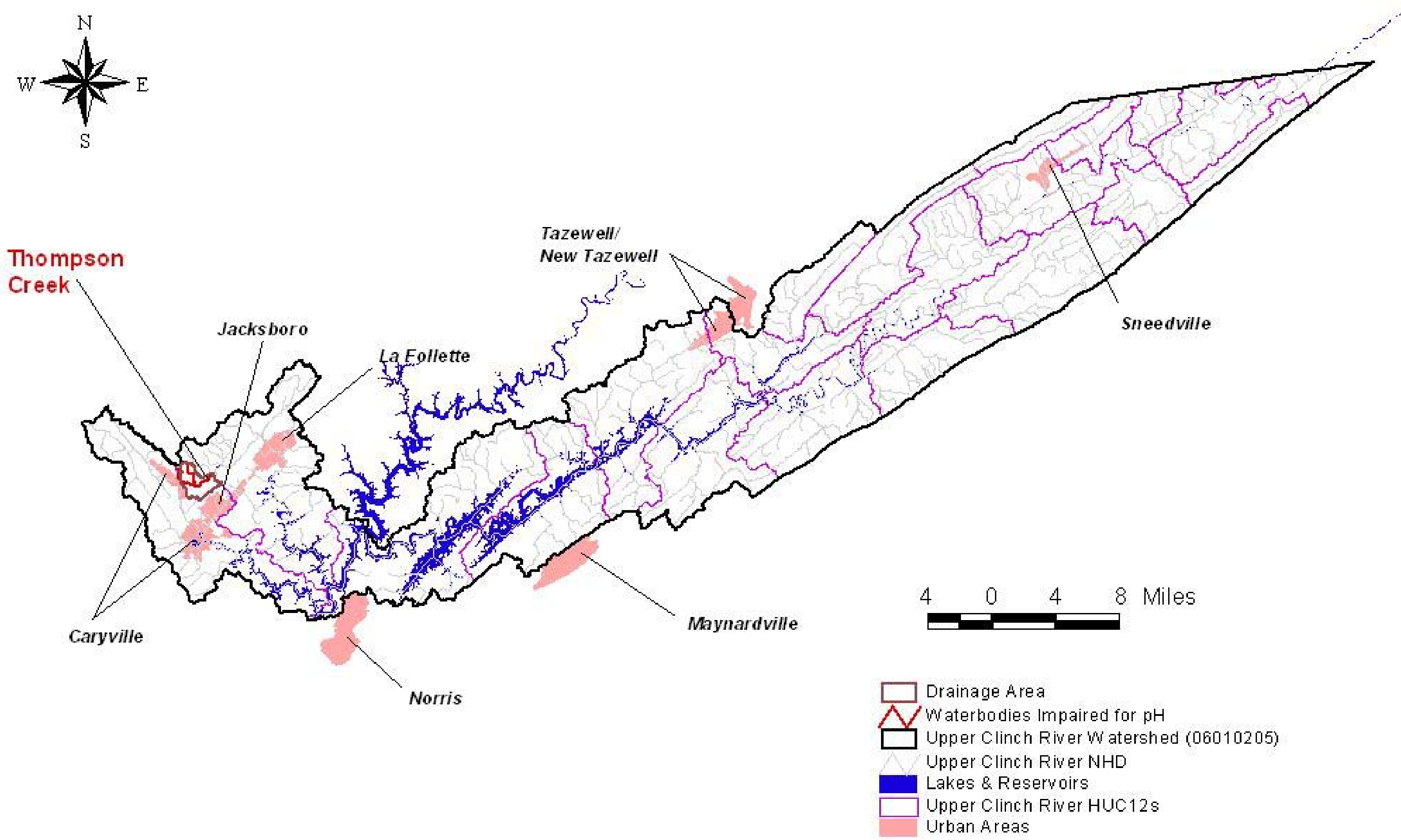

Figure 4 Upper Clinch River Watershed pH-Impaired Segments

4.0 TARGET IDENTIFICATION

The allowable instream range of pH for the Upper Clinch River Watershed, is established in *State of Tennessee Water Quality Standards, Chapter 1200-4-3 General Water Quality Criteria, 2007 Version* (TDEC, 2007) for applicable use classifications. The Fish & Aquatic Life criteria pH range for "all other wadeable streams" of 6.0 to 9.0 is the most stringent for the waterbodies covered by this TMDL.

According to the Pennsylvania Department of Environmental Protection (PDEP, 1998), the "acidity or net alkalinity of a solution, not the pH, is probably the best single indicator of the severity of AMD." In order to facilitate analysis of existing pollutant loads and load reductions required to restore the Upper Clinch River Watershed to fully supporting all of its designated use classifications, net alkalinity will be used as a surrogate parameter for TMDL development. For the purposes of this TMDL, the following terms are defined:

Acidity	The quantitative capacity of a water to react with a strong base to a designated pH. Expressed as milligrams per liter calcium carbonate.
Total Alkalinity	A measure of the ability of water to neutralize acids. Expressed as milligrams per liter calcium carbonate.
Net Alkalinity	The total alkalinity minus the acidity. Expressed as milligrams per liter calcium carbonate.

Since there is no specified numerical criterion for net alkalinity, a net alkalinity of 10.8 mg/l $CaCO_3$, was selected as the numerical target for this TMDL based on analysis of all available monitoring data for Tennessee (see Appendix B). In order to characterize net alkalinity (as $CaCO_3$) over the range of flow conditions encountered in the watershed, the target net alkalinity (as $CaCO_3$) is expressed by means of a target load duration curve. The target load duration curve, developed in Appendix C, is shown in Figure 5. In order to meet Tennessee Water Quality Standards for pH, this TMDL requires that net alkalinity (as $CaCO_3$) loads of streams in the Upper Clinch River Watershed meet, or exceed, the loads per unit area specified in the target load duration curve.

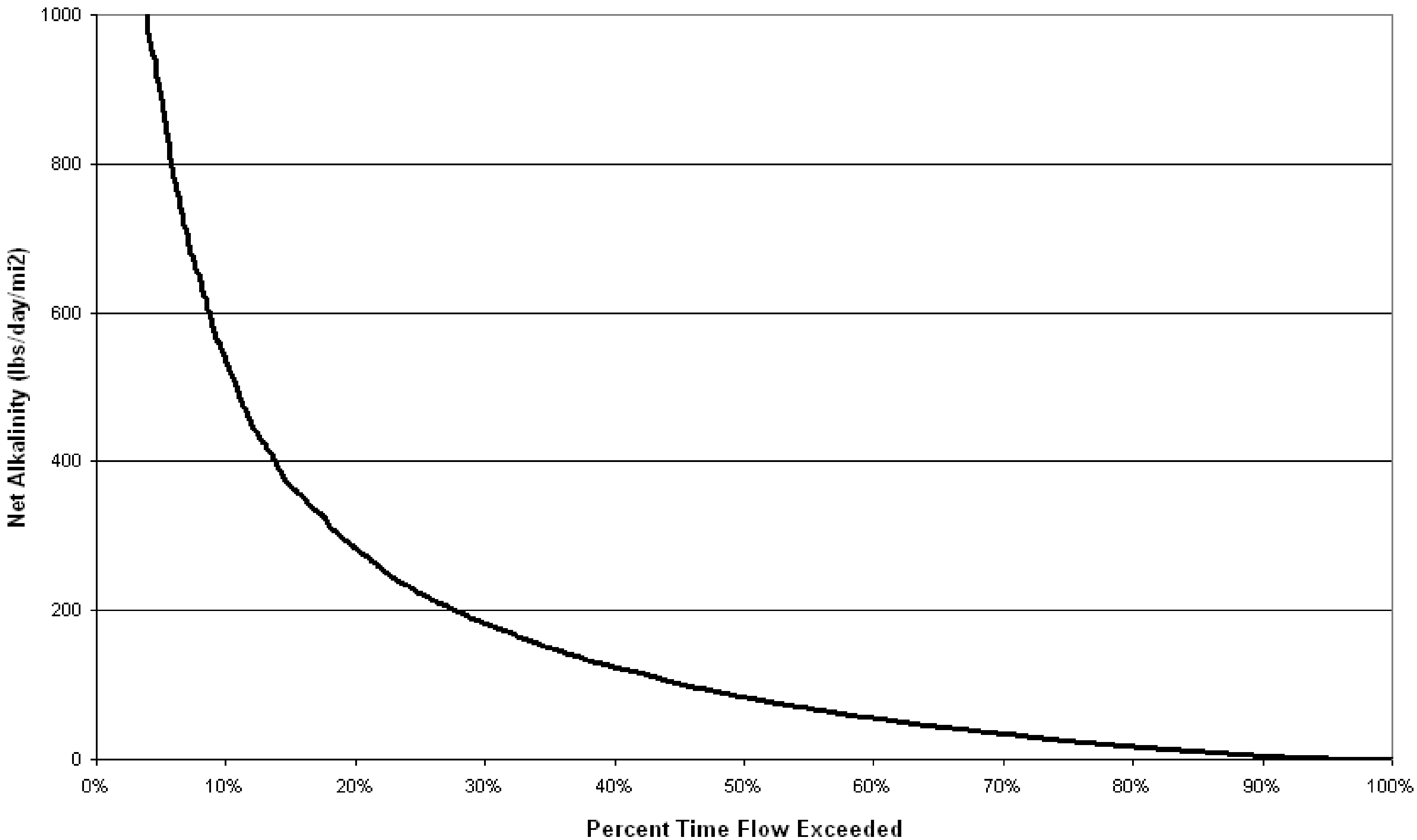

Figure 5 Target Net Alkalinity Load Duration Curve

5.0 WATER QUALITY ASSESSMENT AND DIFFERENCE FROM TARGET

Water quality monitoring of the Upper Clinch River Watershed was conducted by Division of Water Pollution Control (DWPC) personnel from the Knoxville Environmental Field Office (EFO) during the period from 6/14/05 through 8/16/05. The following monitoring station is located on the impaired segment in the Upper Clinch River watershed (see Figure 6).

- HUC-12 06010205_0105:
  - THOMP001.0CA – Thompson Creek, u/s of Rocky Ford

The water quality data collected at the monitoring site are shown in Table 3 below. All pH values were within the target range (6.0 – 9.0).

Table 3 Monitoring Data for Thompson Creek

Thompson Creek			36 21' 31"N	
Mile 1.0			84 12' 8"W	
Test	*Units*	*6/14/05*	*6/28/05*	*8/16/05*
pH	--	6.75	7.12	6.78
Conductivity	uMHO	108.0	95.0	102.0
Dissolved Oxygen	mg/L	8.24	8.23	8.00
Flow	cfs			
Temperature	Celsius	22.1	21.3	21.0
Acidity	mg/L	7.0	3.0	5.0
Total Alkalinity	mg/L	14.0	17.0	21.0
Sulfate	mg/L	32.0	27.0	28.0
Total Hardness	mg/L	69	35	44
TSS	mg/L	10U	10U	10U
Turbidity	NTU	9.6	24.7	2.4
Aluminum	ug/L	100U	584	268
Iron	ug/L	800	1290	261
Manganese	ug/L	569	198	48
Nickel	ug/L	10U	10U	10U
Zinc	ug/L	9	6	1U

As mentioned in Section 3.0, information contained in the ADB suggests that additional monitoring data (in which pH levels were below the target level of 6.0) was collected for Thompson Creek in 2005. However, this monitoring data was not available at the time of preparation of this TMDL.

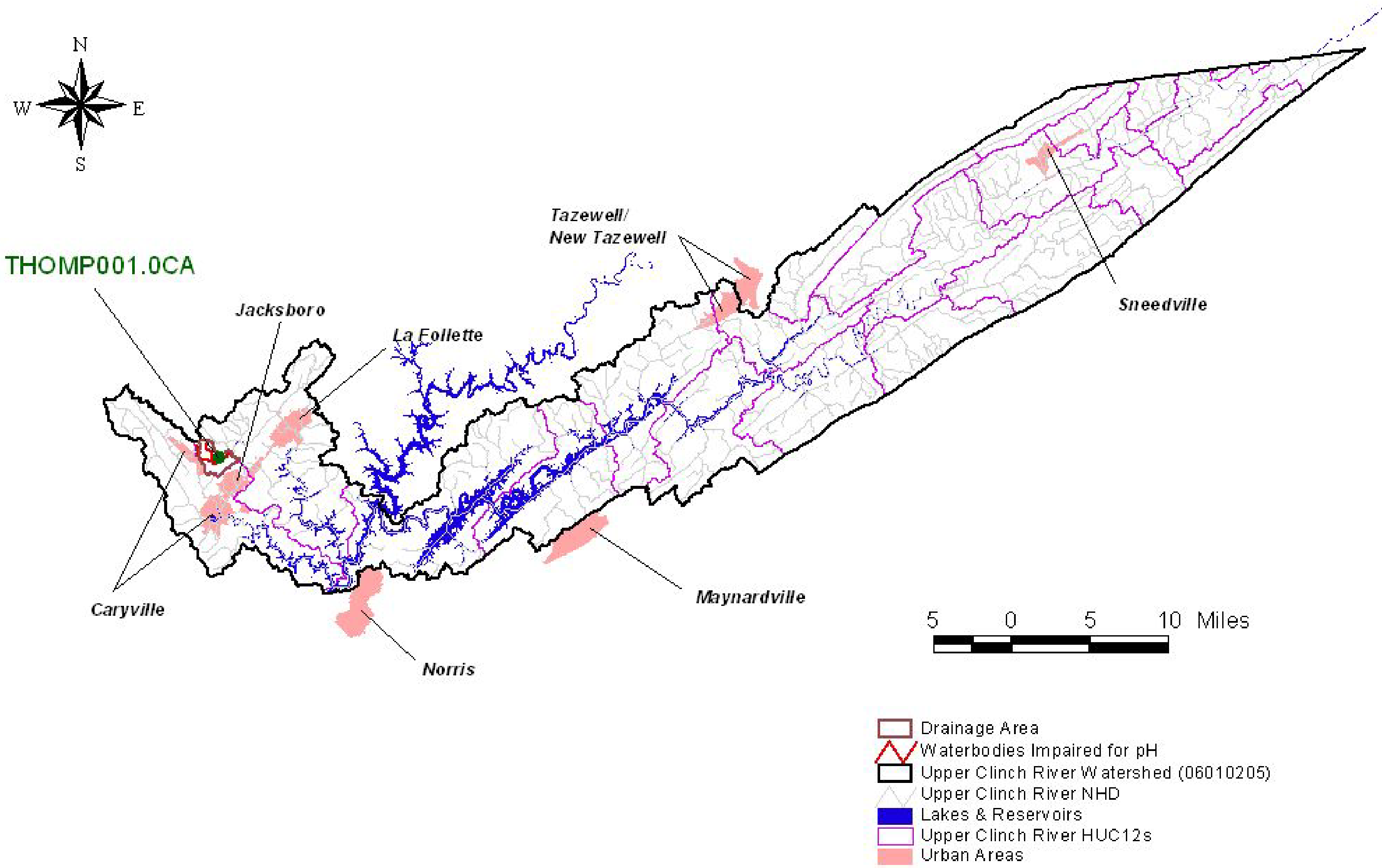

Figure 6 Upper Clinch River Watershed Monitoring Stations

6.0 SOURCE ASSESSMENT

An important part of the TMDL analysis is the identification of individual sources, or source categories, of low pH and high metals in the watershed and the amount of pollutant loading contributed by each of these sources. Sources are broadly classified as either point or non-point sources. A point source can be defined as a discernable, confined, and discrete conveyance from which pollutants are or may be discharged to surface waters. Non-point sources include all other sources of pollution.

6.1 Point Sources

There are 29 facilities in the Upper Clinch River Watershed that have NPDES permits authorizing the discharge of wastewater due to mine operations. Twenty-one of these facilities are coal mining operations, although only 3 of the permits remain active. Eight of the inactive permits are located in the same HUC12 as Thompson Creek. However, none of the facilities are located in the Thompson Creek subwatershed.

6.2 Non-point Sources

There are a number of abandoned surface mining sites in the Upper Clinch River Watershed that are susceptible to the formation of acid mine drainage as discussed in Appendix A. In the 2008 303(d) List (ref.: Table 2), abandoned mining was identified as the source of low pH and high metals in several impaired waterbodies in Tennessee.

7.0 DEVELOPMENT OF TOTAL MAXIMUM DAILY LOAD

The TMDL process quantifies the amount of a pollutant that can be assimilated in a waterbody, identifies the sources of the pollutant, and recommends regulatory or other actions to be taken to achieve compliance with applicable water quality standards based on the relationship between pollution sources and in-stream water quality conditions. A TMDL can be expressed as the sum of all point source loads (Waste Load Allocations), non-point source loads (Load Allocations), and an appropriate margin of safety (MOS) that takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$\text{TMDL} = \Sigma\ \text{WLAs} + \Sigma\ \text{LAs} + \text{MOS}$$

The objective of a TMDL is to allocate loads among all of the known pollutant sources throughout a watershed so that appropriate control measures can be implemented and water quality standards achieved. 40 CFR §130.2 (i) states that TMDLs can be expressed in terms of mass per time (e.g. pounds per day), toxicity, or other appropriate measure.

7.1 Expression of TMDLs, WLAs, & LAs

In this document, the TMDL is a daily load expressed as a function of mean daily flow (daily loading function). WLAs & LAs are also expressed as daily loading functions in lbs/day/acre.

7.2 TMDL Analysis Methodology

TMDLs for the Upper Clinch River Watershed were developed using load duration curves for analysis of impaired waterbodies. A load duration curve (LDC) is a cumulative frequency graph that illustrates existing water quality conditions (as represented by loads calculated from monitoring data), how these conditions compare to desired targets, and the portion of the waterbody flow zone represented by these existing loads. Load duration curves are considered to be well suited for analysis of periodic monitoring data collected by grab sample. LDCs were developed at monitoring site locations in impaired waterbodies and daily loading functions were expressed for TMDLs, WLAs, LAs, and MOS.

7.3 TMDL Representation

In general, waterbodies become impaired due to excessive loading of particular pollutants that result in concentrations that violate instream water quality standards. A TMDL establishes the maximum load that can be assimilated by the waterbody, without violating standards, and allocates portions of this load to point and non-point sources. This normally involves reductions in loading from existing levels, with WLAs & LAs of zero load reduction as the ideal.

The use of net alkalinity as a surrogate parameter, however, requires a different approach. Existing levels of net alkalinity in impaired subwatersheds may be negative, while target values are positive. The concept of a “maximum net alkalinity load” does not appropriately represent the desired target condition with respect to AMD caused impairment. Net alkalinity targets can be achieved by reducing acidity, increasing total alkalinity, or some combination of both.

7.4 Critical Conditions and Seasonal Variation

The ten-year period from October 1, 1997 to September 30, 2007 was used to simulate flow. This 10-year period contained a range of hydrologic conditions that included both low and high streamflows. Critical conditions and seasonal variation are accounted for in the load duration curve analyses by using the entire period of flow and water quality data available for the impaired waterbody. However, in the Thompson Creek subwatershed, only limited water quality data were collected. The data were not representative of all seasons and flow ranges.

7.5 Margin of Safety

There are two methods for incorporating an MOS in the analysis: a) implicitly incorporate the MOS using conservative model assumptions to develop allocations; or b) explicitly specify a portion of the TMDL as the MOS and use the remainder for allocations.

For development of net alkalinity TMDLs, an implicit MOS was incorporated through the use of conservative modeling assumptions. These include: 1) the use of a 10-year continuous simulation that incorporates a wide range of meteorological events, 2) the use of the load duration curve, which addresses pollutant loading over the entire range of flow, and 3) the use of a positive net alkalinity target of 10.8 mg/L based on analysis of all available monitoring data for Tennessee (see Appendix B).

7.6 Determination of Total Maximum Daily Loads

Daily loading functions were calculated for impaired segments in the Upper Clinch River Watershed using LDCs to evaluate compliance with the maximum target concentrations according to the procedure in Appendix C. These TMDL loading functions for impaired segments and subsequent subwatersheds are shown in Table 4. Note that for net alkalinity, the TMDL represents the minimum loading rather than the maximum loading.

7.7 Determination of WLAs, & LAs

WLAs and LAs were determined according to the procedures in Appendix C. These allocations represent the available loading after application of the explicit MOS. For waterbodies with no active mining operations (such as Thompson Creek), there is no WLA and the LA for pH is equal to the TMDL for pH. The TMDLs, WLAs, and LAs for net alkalinity in the Upper Clinch River Watershed are summarized in Table 4.

Table 4. TMDLs, WLAs, & LAs expressed as daily loads for Impaired Waterbodies in the Upper Clinch River Watershed (HUC 06010205)

Impaired Waterbody Name	Impaired Waterbody ID	Constituent	TMDL	WLAs	LAs
			[lbs/day]	[lbs/day]	[lbs/day/ac]
Thompson Creek	TN06010205064 – 0110	Net Alkalinity	58.1 x Q	NA	1.04×10^{-2} x Q

Notes: NA = Not Applicable.
Q = Mean Daily In-stream Flow (cfs).

a. For development of net alkalinity TMDLs, an implicit MOS was incorporated through the use of conservative modeling assumptions (see Section 7.5).

8.0 IMPLEMENTATION PLAN

Monitoring conducted in 2005 has identified only one waterbody in the Upper Clinch River Watershed as impaired due to low pH and/or high metals. This condition is a result of AMD from land disturbance caused by current and past coal mining activities. It should be noted that the stream water quality documented during sampling conducted for this TMDL is not typical of the more severe acid mine drainage situations. Acid mine drainage has one or more of four major components: high acidity (low pH < 6 or alkalinity < 20 mg/L), high metal concentrations (> 500 μg/L), elevated sulfate levels (> 74 mg/L), and excessive suspended solids and/or siltation.

Required LAs will be implemented in several steps to reduce acidity and/or increase total alkalinity so as to result in an increase of instream net alkalinity. In order to meet Tennessee Water Quality Standards for pH, this TMDL requires that net alkalinity (as $CaCO_3$) loads of streams in the Upper Clinch River Watershed meet, or exceed, the daily loading functions specified in Table 4.

Step 1: Conduct water quality testing for Thompson Creek to confirm the status of this waterbody as impaired by pH. Only limited monitoring data was available for this waterbody.

Step 2: Conduct additional water and minespoil testing to identify specific AMD sites and delineate actual areas of acid production at each site.

Step 3: Once sites have been identified, remediation plans will be developed utilizing primarily passive treatment schemes (versus treatment by chemical addition) to provide a long-term solution to stream impairment. Remediation measures that have proved successful include, but are not limited to:

- Regrading of spoil
- Isolation of acid producing material from water contact
- Anoxic limestone drains
- Constructed wetlands.

The Abandoned Mine Lands Section of the DWPC has expertise in the development of AMD remediation plans and has completed a number of reclamation projects on abandoned mines in the Tennessee coalfield. A number of these projects have included measures designed to remediate acid production caused by land disturbance due to past mining. One reclamation project was completed at the Three Sisters site in the North Chickamauga Creek subwatershed in 2000 at a cost of $95,000.

The Mining Section issues NPDES permits for discharges of wastewater from coal and non-coal mines and, where applicable, Mining Law permits to non-coal facilities in Tennessee. This section of the DWPC has worked with a number of permitted mine sites, offering considerable technical advice in the remediation of problems similar to those found in the Upper Clinch River Watershed.

Step 4: Conduct follow-up water quality testing of impaired waterbodies in the Upper Clinch River Watershed to verify the effectiveness of remediation measures. Parameters should include flow, pH, acidity, and total alkalinity.

9.0 PUBLIC PARTICIPATION

In accordance with 40 CFR §130.7, the proposed pH TMDL for the Upper Clinch River Watershed was placed on Public Notice for a 35-day period and comments solicited. Steps that were taken in this regard include:

1) Notice of the proposed TMDL was posted on the Tennessee Department of Environment and Conservation website. The announcement invited public and stakeholder comment and provided a link to a downloadable version of the TMDL document.

2) Notice of the availability of the proposed TMDL (similar to the website announcement) was included in one of the NPDES permit Public Notice mailings which is sent to approximately 90 interested persons or groups who have requested this information.

10.0 FURTHER INFORMATION

Further information concerning Tennessee's TMDL program can be found on the Internet at the Tennessee Department of Environment and Conservation website:

www.state.tn.us/environment/wpc/tmdl.htm

Technical questions regarding this TMDL should be directed to the following members of the Division of Water Pollution Control staff:

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APPENDIX A

Acid Mine Drainage

Acid Mine Drainage Formation

The following information regarding acid mine drainage formation was taken from the U.S. Department of Interior, Office of Surface Mining (OSM) website at www.osmre.gov/amdform.htm. The first section on the Chemistry of Pyrite Weathering is reproduced below. Discussion of subsequent sections can be found on the OSM website.

The formation of acid drainage is a complex geochemical and microbially mediated process. The acid load ultimately generated from a minesite is primarily a function of the following factors:

- Chemistry
- Microbiological Controls
- Depositional environment
- Acid/base balance of the overburden
- Lithology
- Mineralogy
- Minesite hydrologic conditions

Chemistry of Pyrite Weathering

A complex series of chemical weathering reactions are spontaneously initiated when surface mining activities expose spoil materials to an oxidizing environment. The mineral assemblages contained in the spoil are not in equilibrium with the oxidizing environment and almost immediately begin weathering and mineral transformations. The reactions are analogous to "geologic weathering" which takes place over extended periods of time (i.e., hundreds to thousands of years) but the rates of reaction are orders of magnitude greater than in "natural" weathering systems. The accelerated reaction rates can release damaging quantities of acidity, metals, and other soluble components into the environment. The pyrite oxidation process has been extensively studied and has been reviewed by Nordstrom (1979). For purposes of this description, the term "pyrite" is used to collectively refer to all iron disulfide minerals.

The following equations show the generally accepted sequence of pyrite reactions:

$2\ FeS_2 + 7\ 0_2 + 2\ H_2O \rightarrow\rightarrow 2\ Fe^{2+} + 4\ SO_4^{2-} + 4\ H^+$ (Equation 1)

$4\ Fe^{2+} + O_2 + 4\ H^+ \rightarrow 4\ Fe^{3+} + 2\ H_2O$ (Equation 2)

$4\ Fe^{3+} + 12\ H_2O \rightarrow 4\ Fe(OH)_3 + 12\ H^+$ (Equation 3)

$FeS_2 + 14\ Fe^{3+} + 8\ H_2O \rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+$ (Equation 4)

In the initial step, pyrite reacts with oxygen and water to produce ferrous iron, sulfate and acidity. The second step involves the conversion of ferrous iron to ferric iron. This second reaction has been termed the "rate determining" step for the overall sequence.

The third step involves the hydrolysis of ferric iron with water to form the solid ferric hydroxide (ferrihydrite) and the release of additional acidity. This third reaction is pH dependent. Under very acid conditions of less than about pH 3.5, the solid mineral does not form and ferric iron remains in solution. At higher pH values, a precipitate forms, commonly referred to as “yellowboy.”

The fourth step involves the oxidation of additional pyrite by ferric iron. The ferric iron is generated by the initial oxidation reactions in steps one and two. This cyclic propagation of acid generation by iron takes place very rapidly and continues until the supply of ferric iron or pyrite is exhausted. Oxygen is not required for the fourth reaction to occur.

The overall pyrite reaction series is among the most acid-producing of all weathering processes in nature.

APPENDIX B

Development of Target Net Alkalinity

Since there is no numerical criterion for net alkalinity, all available monitoring data for the State of Tennessee was examined in an effort to develop a target net alkalinity.

Of the available monitoring data for waterbodies that are not impaired for pH, 47 data points existed for which numerical values for both acidity and total alkalinity were available. (See Figure B-1.) The highest calculated net alkalinity that fell outside of the desired pH range of 6.0 to 9.0 was 10.78 mg/L as $CaCO_3$ at a pH of 9.1. Therefore, a net alkalinity of 10.8 was selected as the target net alkalinity.

Analysis was then expanded to include monitoring data for waterbodies that are not impaired for pH and for which both total alkalinity and acidity were analyzed, but for which either acidity or total alkalinity, but not both, was not detected. (See Figure B-2.) For the purpose of calculating net alkalinity, the analyte concentrations were estimated to be one half of the appropriate detection limit (10 mg/L for total alkalinity and 1 mg/L for acidity). Of the 211 data points, only 3 points (or 1.4%) exceeded the target net alkalinity value of 10.8 mg/L $CaCO_3$ but were not within the required pH range.

Available monitoring data for waterbodies that are included on the 303(d) List as impaired for pH were also compared to the target net alkalinity. Of 41 data points for which numerical values for both acidity and total alkalinity were available, only 2 points (or 4.9%) exceeded the target net alkalinity value of 10.8 mg/L $CaCO_3$ but was not within the required pH range. These data points were for North Suck Creek on 5/21/2005 (pH 5.14, net alkalinity 16.9) and South Suck Creek on 9/9/2004 (pH 5.2, net alkalinity 29.96). When analysis was expanded to include data points for which both acidity and total alkalinity were analyzed, but for which either acidity or total alkalinity, but not both, was not detected, only 3 points (or 2.0%) exceeded the target net alkalinity value of 10.8 mg/L $CaCO_3$ but were not within the required pH range. These data points were the previously mentioned points for North and South Suck Creek and a data point for North Suck Creek on 3/22/2005 (pH 5.8, net alkalinity 18.5).

Therefore, based on analysis of all available monitoring data for the State of Tennessee, selection of a target net alkalinity of 10.8 mg/L as $CaCO_3$ should provide a pH within the criteria of 6.0 to 9.0 standard pH units for waterbodies with a designated use of Fish & Aquatic Life.

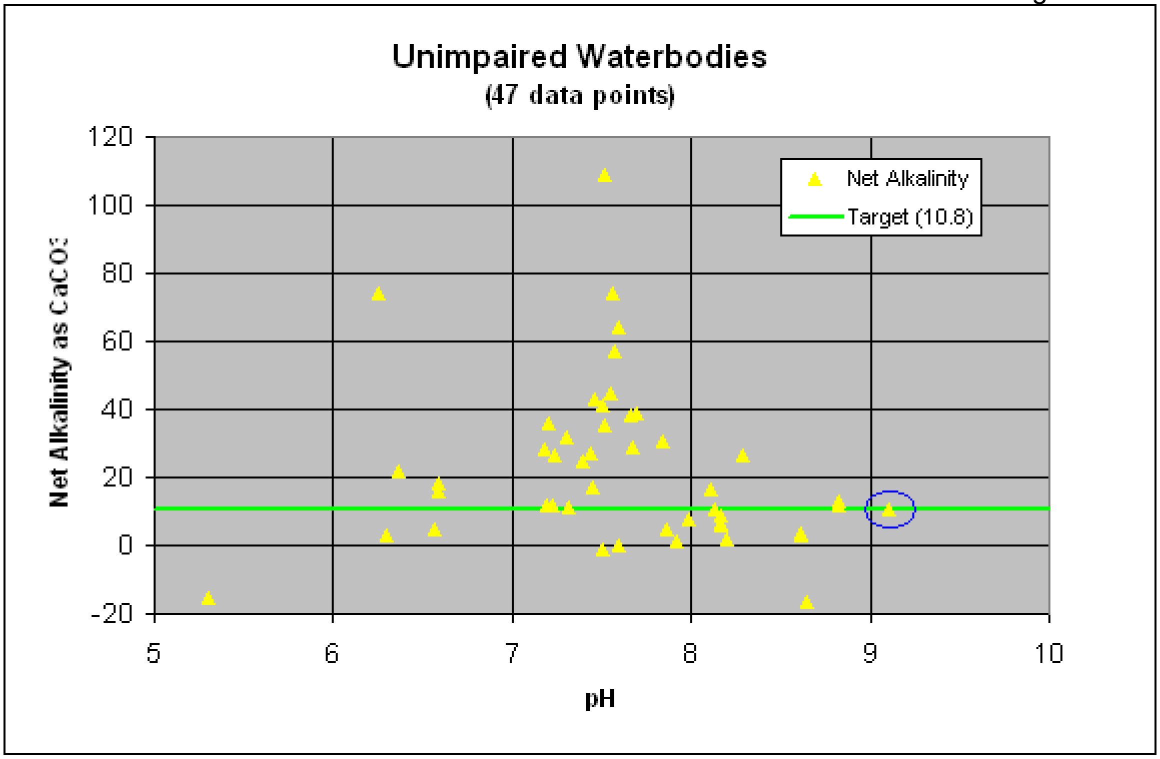

Figure B-1 pH and Net Alkalinity for Unimpaired Waterbodies in Tenneessee
(no non-detects for either acidity or total alkalinity)

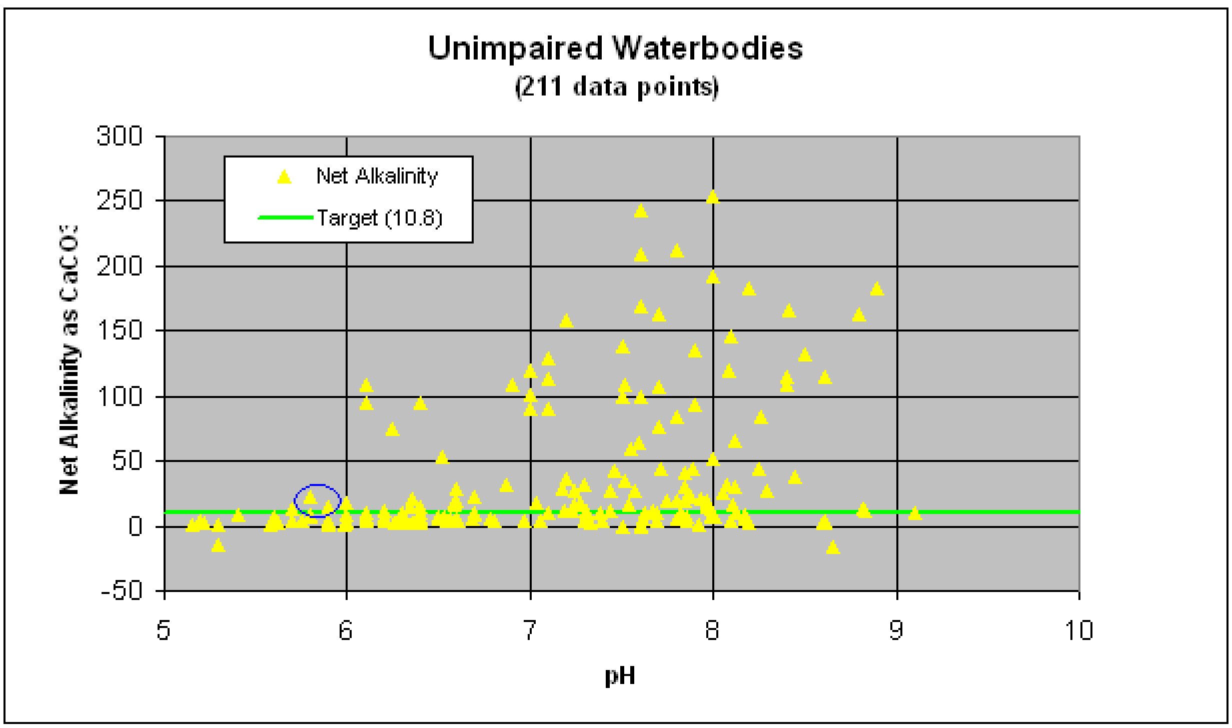

Figure B-2 pH and Net Alkalinity for Unimpaired Waterbodies in Tenneessee
(acidity or total alkalinity was not detected; 0.5 x detection limit used for non detects)

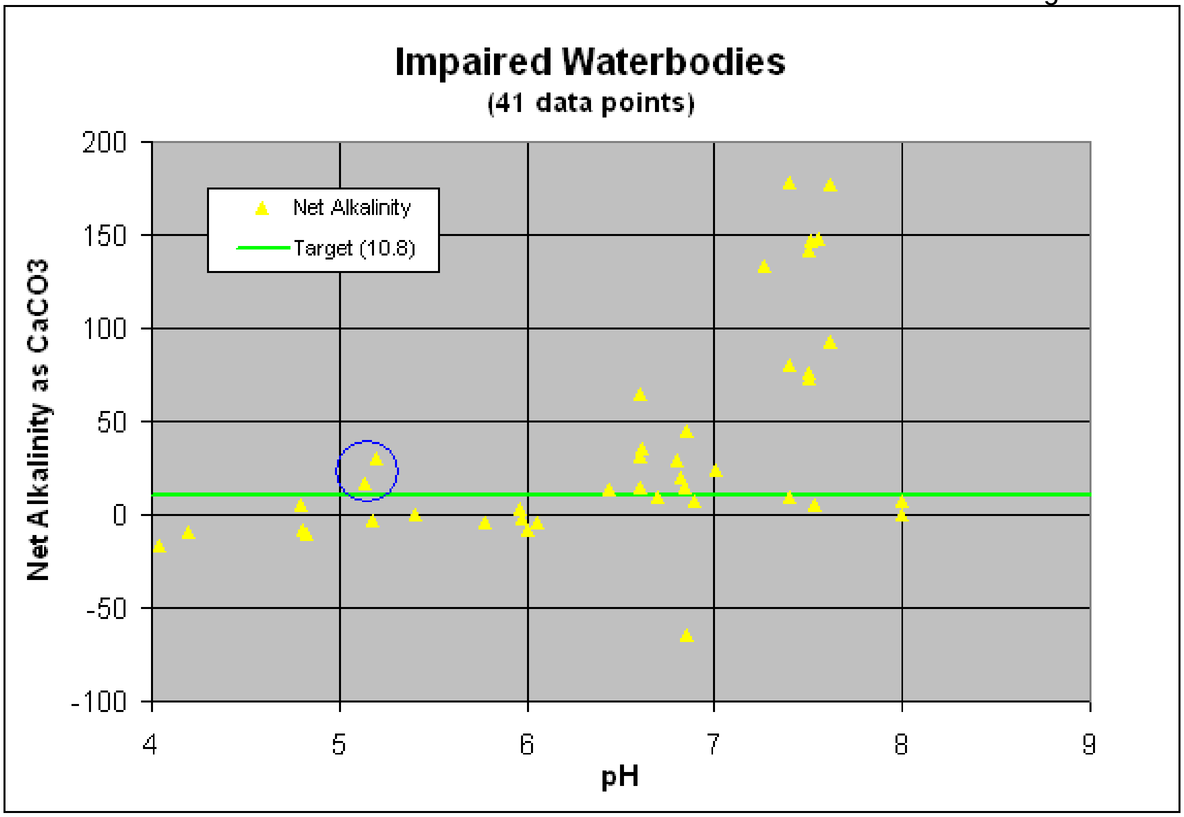

Figure B-3 pH and Net Alkalinity for Impaired Waterbodies in Teneessee
(no non-detects for either acidity or total alkalinity)

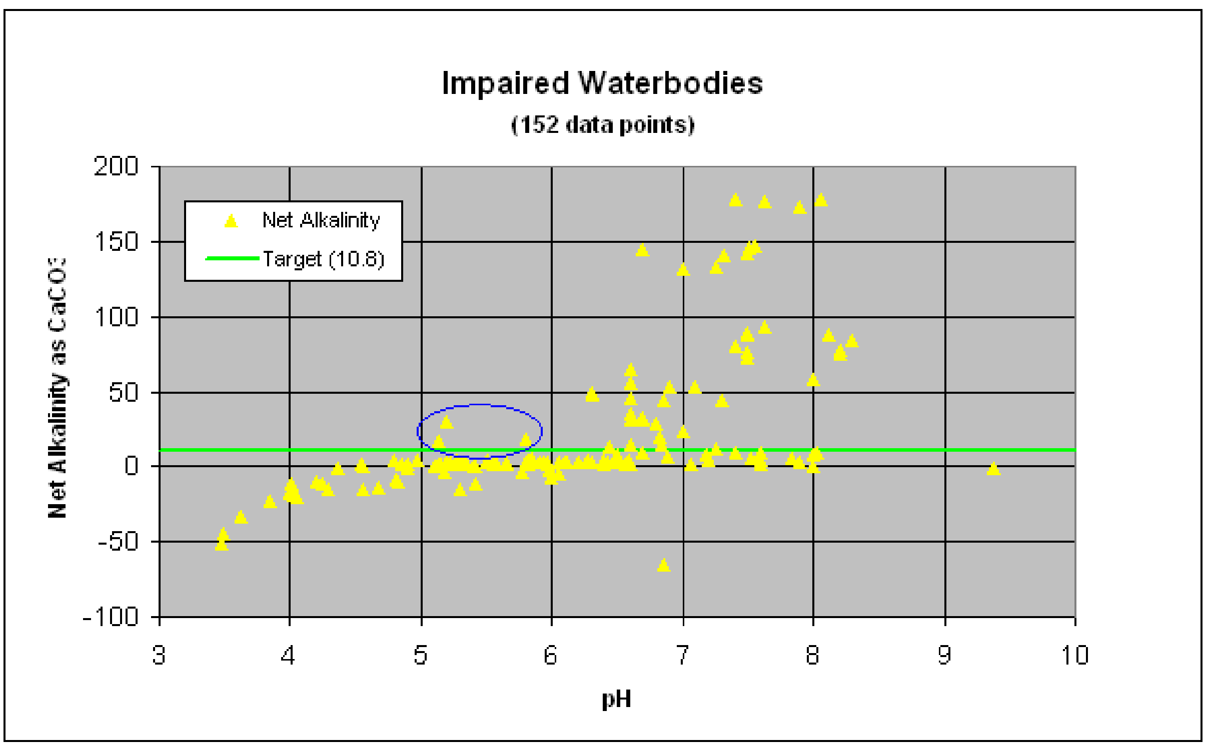

Figure B-4 pH and Net Alkalinity for Impaired Waterbodies in Teneessee
(acidity or total alkalinity was not detected; 0.5 x detection limit used for non detects)

APPENDIX C

Load Duration Curve Development
and
Determination of Daily Loading

The TMDL process quantifies the amount of a pollutant that can be assimilated in a waterbody, identifies the sources of the pollutant, and recommends regulatory or other actions to be taken to achieve compliance with applicable water quality standards based on the relationship between pollution sources and in-stream water quality conditions. A TMDL can be expressed as the sum of all point source loads (Waste Load Allocations), nonpoint source loads (Load Allocations), and an appropriate margin of safety (MOS) that takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$TMDL = \Sigma\ WLAs + \Sigma\ LAs + MOS$$

The objective of a TMDL is to allocate loads among all of the known pollutant sources throughout a watershed so that appropriate control measures can be implemented and water quality standards achieved. 40 CFR §130.2 (i) (http://www.epa.gov/epacfr40/chapt-I.info/chi-toc.htm) states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measure.

Net alkalinity TMDLs, WLAs, and LAs were developed for impaired subwatersheds and drainage areas in the Upper Clinch River Watershed using Load Duration Curves (LDCs). Daily Loads for TMDLs, WLAs, and LAs are expressed as a function of daily mean in-stream flow (daily loading function).

C.1 Development of Flow Duration Curves

A flow duration curve is a cumulative frequency graph, constructed from historic flow data at a particular location, that represents the percentage of time a particular flow rate is equaled or exceeded. Flow duration curves are developed for a waterbody from daily discharges of flow over a period of record. In general, there is a higher level of confidence that curves derived from data over a long period of record correctly represent the entire range of flow. The preferred method of flow duration curve computation uses daily mean data from U.S. Geological Survey (USGS) continuous-record stations (http://waterdata.usgs.gov/tn/nwis/sw) located on the waterbody of interest. For ungaged streams, alternative methods must be used to estimate daily mean flow. These include: 1) regression equations (using drainage area as the independent variable) developed from continuous record stations in the same ecoregion; 2) drainage area extrapolation of data from a nearby continuous-record station of similar size and topography; and 3) calculation of daily mean flow using a dynamic computer model, such as the Loading Simulation Program C++ (LSPC).

Flow duration curves for pH-impaired waterbodies in the Upper Clinch River Watershed were derived from LSPC hydrologic simulations based on parameters derived from calibration at USGS Station No. 03529500, located on the Powell River at Big Stone Gap, Virginia, in the Powell River Watershed (see Appendix D for details of calibration). For example, a flow-duration curve for Thompson Creek at RM 1.0 was constructed using simulated daily mean flow for the period from 10/1/98 through 9/30/07 (RM 1.0 corresponds to the location of monitoring station THOMP001.0CA). This flow duration curve is shown in Figure C-1 and represents the cumulative distribution of daily discharges arranged to show percentage of time specific flows were exceeded during the period of record (the highest daily mean flow during this period is exceeded 0% of the time and the lowest daily mean flow is equaled or exceeded 100% of the time).

C.2 Development of Load Duration Curves

When a water quality target concentration is applied to the flow duration curve, the resulting load duration curve (LDC) represents the allowable pollutant loading in a waterbody over the entire range of flow. The target net alkalinity load duration curve for the Upper Clinch River Watershed was developed from the flow duration curve for Thompson Creek developed in Section C.1. The target curve can be applied to all impaired waterbodies in the Upper Clinch River Watershed because it was developed on a unit drainage area basis. The net alkalinity target concentration of 10.8 mg/L was applied to each of the ranked flows used to generate the flow duration curve and the results were plotted. The net alkalinity target load corresponding to each ranked daily mean flow is:

Target Load = (10.8) x (Q/A) x (UCF)

where: Q = daily mean flow
A = drainage area
UCF = the required unit conversion factor

The target net alkalinity load duration curve, on a unit drainage area basis, is presented in Figures C-2 and C-3. Figure C-2 is presented in semi-log scale format while Figure C-3 is presented in non-log scale format. Because the calculated net alkalinity of the Upper Clinch River Watershed can be negative and negative values cannot be plotted on a log or semi-log scale format, the non-log scale format will be used for net alkalinity load duration curves in this TMDL.

Pollutant monitoring data, plotted on the LDC, provides a visual depiction of stream water quality as well as the frequency and magnitude of any exceedances. Load duration curve intervals can be grouped into several broad categories or zones, in order to provide additional insight about conditions and patterns associated with the impairment. For example, the duration curve could be divided into four zones: high flows (exceeded 0-10% of the time), moist conditions (10-40%), median or mid-range flows (40-70%), and low flows (70-100%). Impairments observed in the low flow zone typically indicate the influence of point sources, while those further left on the LDC (representing zones of higher flow) generally reflect potential nonpoint source contributions (Stiles, 2003).

Load duration curves for specific monitoring locations were developed using the following procedure (Thompson Creek is used as an example):

1. Daily loads were calculated for each of the water quality samples collected at monitoring station THOMP001.0CA (ref.: Table 3) by multiplying the sample concentration by the daily mean flow for the sampling date and the required unit conversion factor, and dividing by the subwatershed drainage area. THOMP001.0CA was selected for LDC analysis because it was the monitoring station nearest to the impaired portion of Thompson Creek with pH data available.

Note: *In order to be consistent for all analyses, the derived daily mean flow was used to compute sampling data loads, even if measured ("instantaneous") flow data was available for some sampling dates.*

Example – 6/14/05 sampling event:

Modeled Flow = 1.81 cfs
Concentration = 13 mg/L
Area = 2,007.4 acres = 3.14 mi^2
Daily Load = 2.18 x 10^{+1} *lbs net alkalinity/day/mi*^{2}
= 2.89 x 10^{-2} *lbs net alkalinity/day/acre*

2. Using the flow duration curves developed in C.1, the "percent of days the flow was exceeded" (PDFE) was determined for each sampling event. Each sample load was then plotted on the load duration curves developed in Step 1 according to the PDFE. The resulting net alkalinity load duration curve is shown in Figure C-4.

Example – 6/14/05 sampling event:

Modeled Flow = 1.81 cfs
PDFE = 66.7%

C.3 Development of WLAs, LAs, and MOS

As previously discussed, a TMDL can be expressed as the sum of all point source loads (WLAs), nonpoint source loads (LAs), and an appropriate margin of safety (MOS) that takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$TMDL = \Sigma \text{ WLAs} + \Sigma \text{ LAs} + MOS$$

C.4 Daily Load Calculations

Each of the terms in the equation above can be derived sequentially:

TMDL = (Target Concentration) x (Q) x (UCF)

where: Target Concentration = water quality criterion
Q = daily mean flow
UCF = the required unit conversion factor

Using Thompson Creek at Mile 1.0 as an example:

$TMDL_{Thompson}$ = (10.8 mg/L) x (Q) x (UCF)

$TMDL_{Thompson}$ = 5.38 x Q (lbs/day)

An implicit MOS was used for net alkalinity; therefore,

$MOS_{Thompson}$ = 0

By rearranging the equation in section C.4 and expressing on a unit area basis:

$$\Sigma \text{ LAs} = (\text{TMDL} - \text{MOS} - \Sigma \text{ WLAs}) / \text{DA}$$

where: DA = waterbody drainage area (acres)

Since there are no permitted point sources contributing at Mile 1.0, WLA = 0. Therefore:

$$LA_{Thompson} = (5.38 \times Q) / (2{,}007.44)$$

$$\mathbf{LA_{Thompson} = (2.89 \times 10^{-2}) \times Q \ (lbs/day/ac)}$$

TMDLs, WLAs, & LAs for impaired waterbodies in the Upper Clinch River Watershed are summarized in Table C-2.

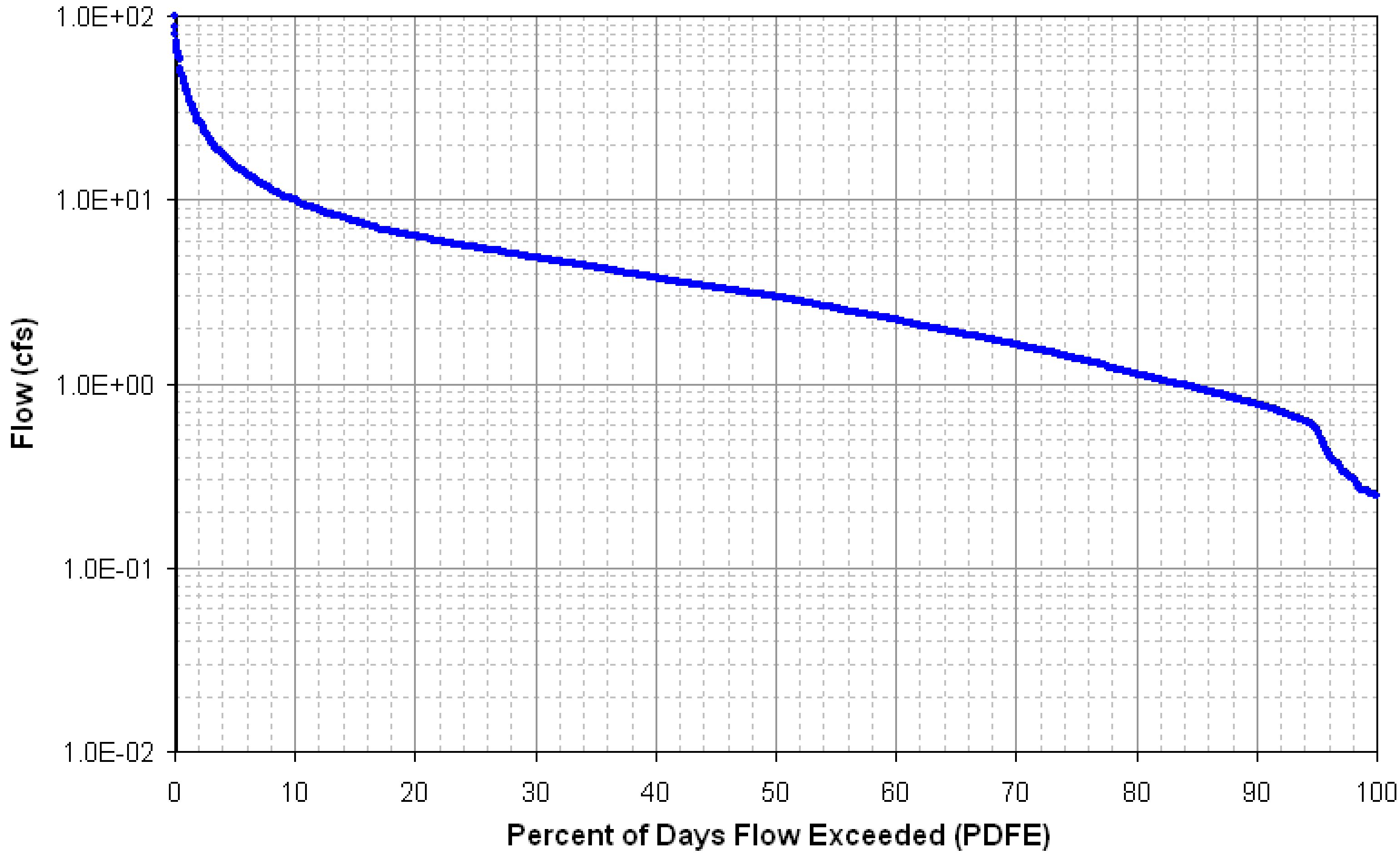

Figure C-1 Flow Duration Curve for Thompson Creek at RM1.0

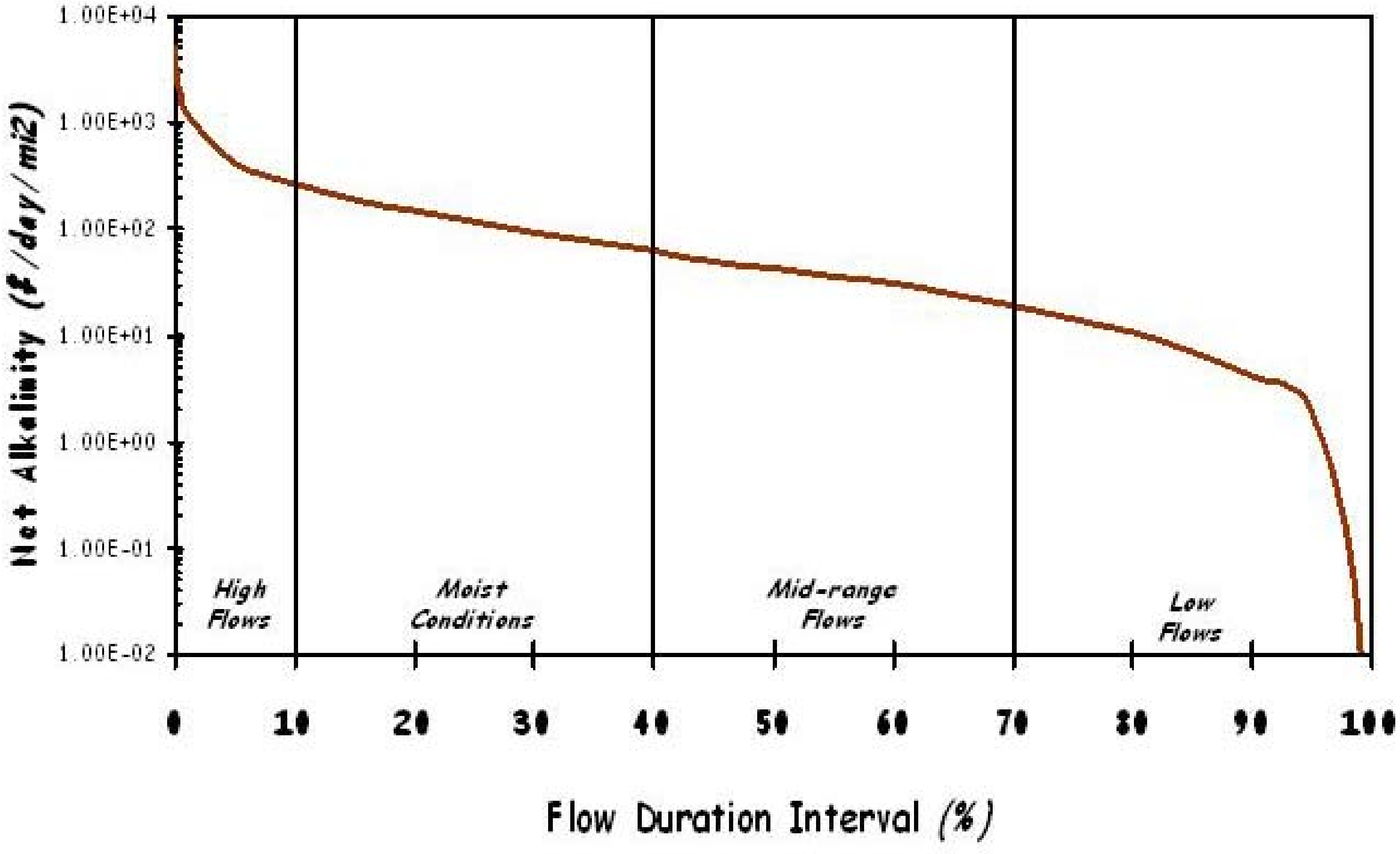

Figure C-2 Target Net Alkalinity Load Duration Curve (semi-log-scale)

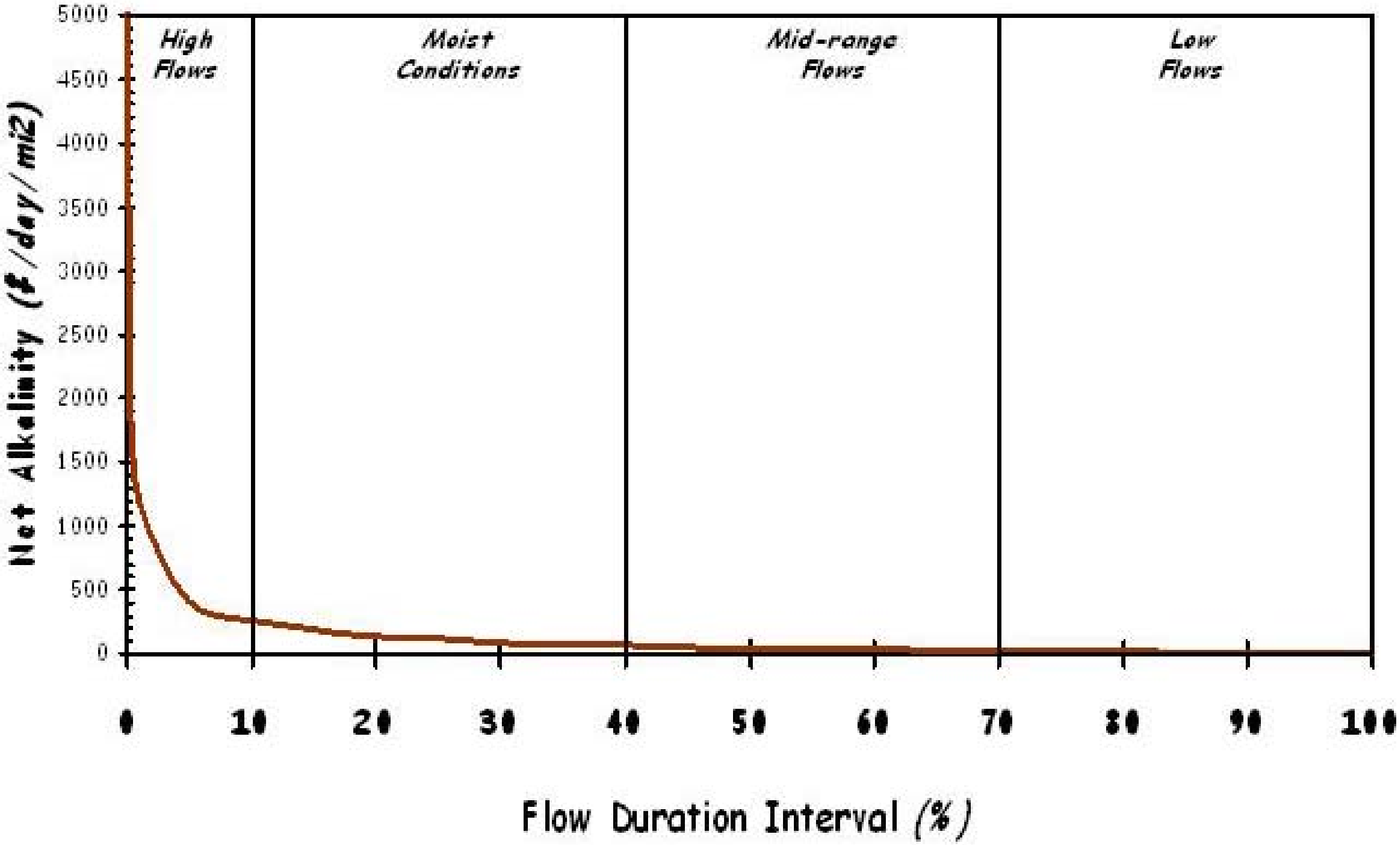

Figure C-3 Target Net Alkalinity Load Duration Curve (non-log scale)

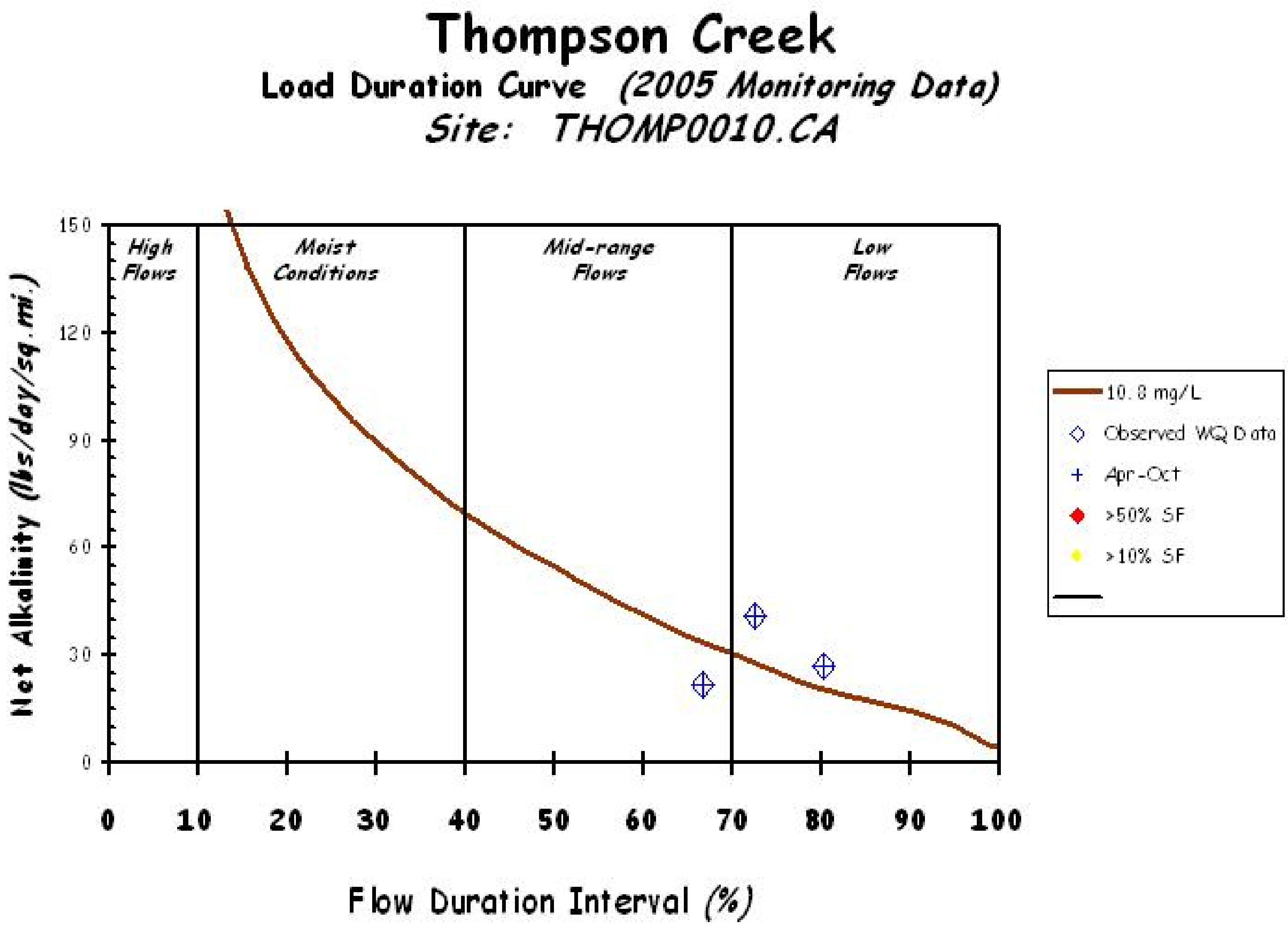

Figure C-4 Net Alkalinity Load Duration Curve for Thompson Creek at Mile 1.0

Table C-1. Net Alkalinity Load Calculations for Thompson Creek – Mile 1.0

Sample	Flow		PDFE[a]	Net Alkalinity	
Date	(cfs)	(cfs/mi^2)	(%)	(mg/L)	(lbs/day/mi^2)
6/14/05	1.81	0.577	66.7	7	2.18E+01
6/28/05	1.11	0.354	80.4	14	2.67E+01
8/16/05	1.50	0.477	72.6	16	4.12E+01
90th Percentile Concentration				**16**	
a	Percent of Days Flow Is Exceeded				

Table C-2. TMDLs, WLAs, & LAs expressed as daily loads for Impaired Waterbodies in the Upper Clinch River Watershed (HUC 06010205)

Impaired Waterbody Name	Impaired Waterbody ID	Constituent	TMDL	WLAs	LAs
			[lbs/day]	[lbs/day]	[lbs/day/ac]
Thompson Creek	TN06010205064 – 0110	Net Alkalinity	58.1 x Q	NA	$1.04 \times 10^{-2} \times Q$

Notes: NA = Not Applicable.
Q = Mean Daily In-stream Flow (cfs).
a. For development of net alkalinity TMDLs, an implicit MOS was incorporated through the use of conservative modeling assumptions (see Section 7.5).

APPENDIX D

Hydrodynamic Modeling Methodology

D.1 Model Selection

The Loading Simulation Program C++ (LSPC) was selected for TMDL analyses of pH-impaired waters in the Upper Clinch River Watershed. LSPC is a watershed model capable of performing flow routing through stream reaches. LSPC is a dynamic watershed model based on the Hydrologic Simulation Program – Fortran (HSPF).

D.2 Model Set Up

The Upper Clinch River Watershed was delineated into subwatersheds in order to facilitate model hydrologic calibration. Boundaries were constructed so that subwatershed "pour points" coincided with HUC-12 delineations, impaired waterbodies, and water quality monitoring stations. Watershed delineation was based on the NHD stream coverage and Digital Elevation Model (DEM) data. This discretization facilitates simulation of daily flows at water quality monitoring stations.

Several computer-based tools were utilized to generate input data for the LSPC model. The Watershed Characterization System (WCS), a geographic information system (GIS) tool, was used to display, analyze, and compile available information to support hydrology model simulations for the Upper Clinch River subwatersheds. This information includes land use categories, point source dischargers, soil types and characteristics, population data (human and livestock), and stream characteristics.

An important factor influencing model results is the precipitation data contained in the meteorological data file used in the simulation. Weather data from the Knoxville meteorological station were available for the time period from January 1970 through September 2007. Meteorological data for a selected 11-year period were used for all simulations. The first year of this period was used for model stabilization with simulation data from the subsequent 10-year period (10/1/97 – 9/30/07) used for TMDL analysis.

D.3 Model Calibration

Hydrologic calibration of the watershed model involves comparison of simulated streamflow to historic streamflow data from U.S. Geological Survey (USGS) stream gaging stations for the same period of time. A USGS continuous record station located nearby in the Powell River Watershed with a sufficiently long and recent historical record was selected as a basis of the hydrology calibration. The USGS station was selected based on similarity of drainage area, Level IV ecoregion, land use, and topography. The calibration involved comparison of simulated and observed hydrographs until statistical stream volumes and flows were within acceptable ranges as reported in the literature (Lumb, et al., 1994).

Initial values for hydrologic variables were taken from an EPA developed default data set. During the calibration process, model parameters were adjusted within reasonable constraints until acceptable agreement was achieved between simulated and observed streamflow. Model parameters adjusted include: evapotranspiration, infiltration, upper and lower zone storage, groundwater storage, recession, losses to the deep groundwater system, and interflow discharge.

The results of the hydrologic calibration for Powell River at Big Stone Gap, VA, USGS Station 03529500, drainage area 108.1 square miles, are shown in Table D-1 and Figure D-1 and D-2.

Table D-1. Hydrologic Calibration Summary: Powell River at Big Stone Gap, VA (USGS 03529500)

Simulation Name:	35329500	**Simulation Period:**	
	Powell River	**Watershed Area (ac):**	69168.15
Period for Flow Analysis			
Begin Date:	**10/01/02**	**Baseflow PERCENTILE:**	2.5
End Date:	**09/30/07**	*Usually 1%-5%*	
Total Simulated In-stream Flow:	**112.58**	Total Observed In-stream Flow:	**119.91**
Total of highest 10% flows:	**43.89**	Total of Observed highest 10% flows:	**47.04**
Total of lowest 50% flows:	**21.33**	Total of Observed Lowest 50% flows:	**21.39**
Simulated Summer Flow Volume (months 7-9):	**14.27**	Observed Summer Flow Volume (7-9):	**12.73**
Simulated Fall Flow Volume (months 10-12):	**21.33**	Observed Fall Flow Volume (10-12):	**25.38**
Simulated Winter Flow Volume (months 1-3):	**37.41**	Observed Winter Flow Volume (1-3):	**39.11**
Simulated Spring Flow Volume (months 4-6):	**39.58**	Observed Spring Flow Volume (4-6):	**42.69**
Total Simulated Storm Volume:	**101.81**	Total Observed Storm Volume:	**105.51**
Simulated Summer Storm Volume (7-9):	**11.61**	Observed Summer Storm Volume (7-9):	**9.12**
Errors (Simulated-Observed)		*Recommended Criteria*	Last run
Error in total volume:	**-6.12**	10	
Error in 50% lowest flows:	**-0.31**	10	
Error in 10% highest flows:	**-6.69**	15	
Seasonal volume error - Summer:	**12.08**	30	
Seasonal volume error - Fall:	**-15.99**	30	
Seasonal volume error - Winter:	**-4.35**	30	
Seasonal volume error - Spring:	**-7.29**	30	
Error in storm volumes:	**-3.50**	20	
Error in summer storm volumes:	**27.25**	50	

Criteria for Median Monthly Flow Comparisons	
Lower Bound (Percentile):	25
Upper Bound (Percentile):	75

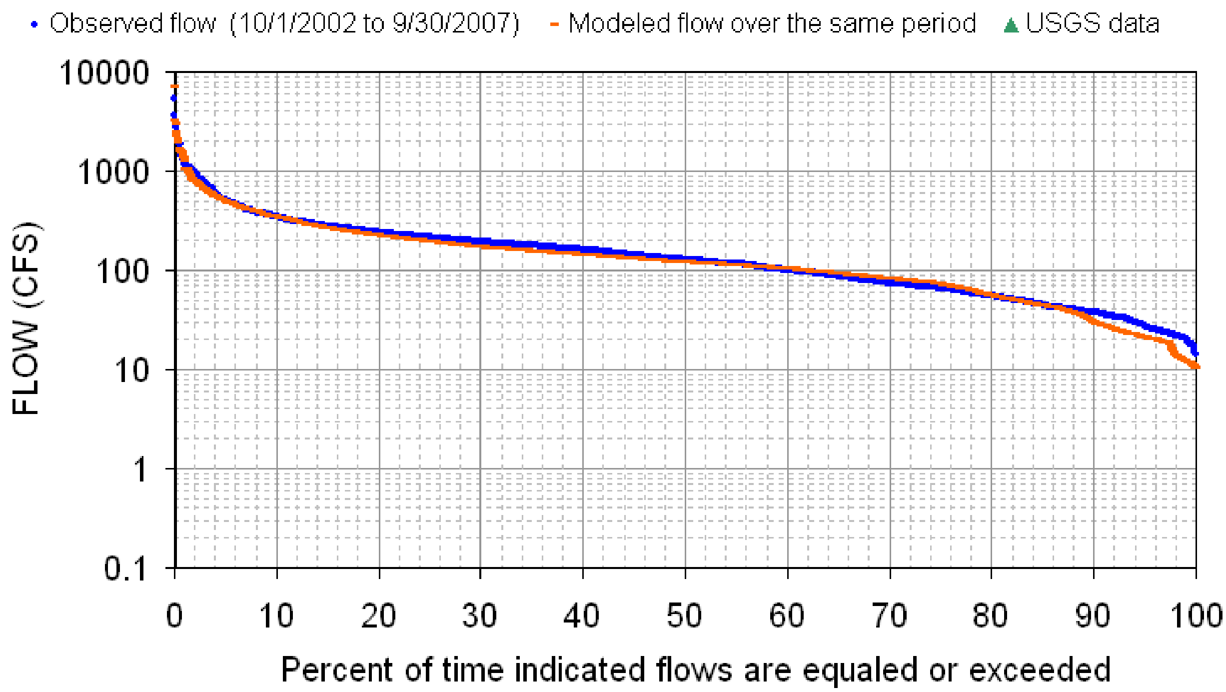

Figure D-1. Hydrologic Calibration: Powell River, USGS 03529500 (WYs 2003-2007)

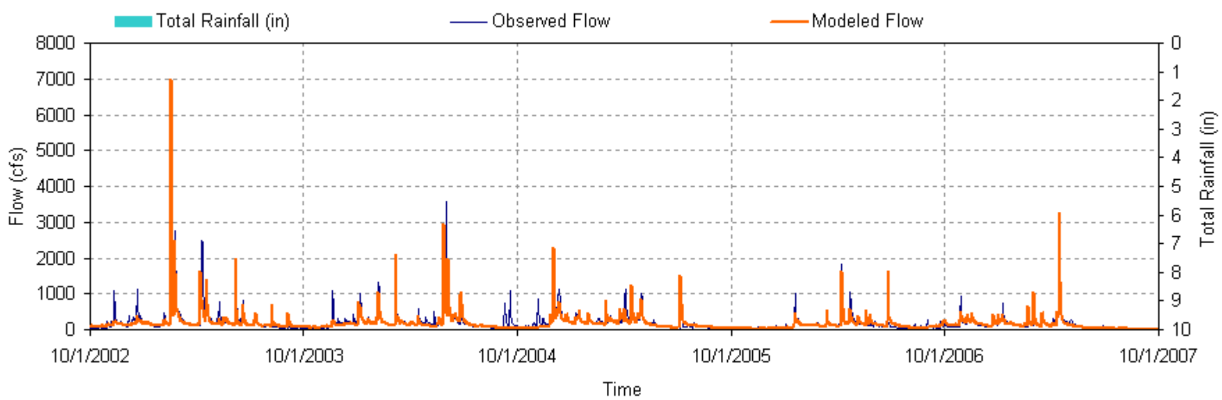

Figure D-2. 5-Year Hydrologic Comparison: Powell River, USGS 03529500

APPENDIXE

Public Notice Announcement

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF WATER POLLUTION CONTROL

PUBLIC NOTICE OF AVAILABILITY OF PROPOSED TOTAL MAXIMUM DAILY LOAD (TMDL) FOR pH IN THE UPPER CLINCH RIVER WATERSHED (HUC 06010205), TENNESSEE

Announcement is hereby given of the availability of Tennessee's proposed Total Maximum Daily Load (TMDL) for pH in the Upper Clinch River watershed, located in eastern Tennessee. Section 303(d) of the Clean Water Act requires states to develop TMDLs for waters on their impaired waters list. TMDLs must determine the allowable pollutant load that the water can assimilate, allocate that load among the various point and nonpoint sources, include a margin of safety, and address seasonality.

Thompson Creek in the Upper Clinch River watershed is listed on Tennessee's final 2008 303(d) list as not supporting designated use classifications due to low pH associated with abandoned mines. The TMDL utilizes Tennessee's general water quality criteria, net alkalinity (as $CaCO_3$) as a surrogate for pH, USGS continuous record station flow data, in-stream water quality monitoring data, a calibrated dynamic water quality model, load duration curves, and an appropriate Margin of Safety (MOS) to establish loadings of net alkalinity (as $CaCO_3$) which will result in the attainment of water quality standards for pH.

The proposed Upper Clinch River watershed pH TMDL may be downloaded from the Department of Environment and Conservation website:

http://www.state.tn.us/environment/wpc/tmdl/proposed.shtml

Technical questions regarding this TMDL should be directed to the following members of the Division of Water Pollution Control staff:

Vicki S. Steed, P.E., Watershed Management Section
Telephone: 615-532-0707

Sherry H. Wang, Ph.D., Watershed Management Section
Telephone: 615-532-0656

Persons wishing to comment on the proposed TMDLs are invited to submit their comments in writing no later than April 13, 2009 to:

Division of Water Pollution Control
Watershed Management Section
7th Floor, L & C Annex
401 Church Street
Nashville, TN 37243-1534

All comments received prior to that date will be considered when revising the TMDL for final submittal to the U.S. Environmental Protection Agency.

The TMDL and supporting information are on file at the Division of Water Pollution Control, 6th Floor, L & C Annex, 401 Church Street, Nashville, Tennessee. They may be inspected during normal office hours. Copies of the information on file are available on request.