Total Maximum Daily Load Development to Address a Benthic Impairment in the Little Calfpasture River, Rockbridge County, Virginia

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. BACKGROUND

The Little Calfpasture River (Watershed ID VAV-I32R) is located in Augusta and Rockbridge Counties, Virginia. The Little Calfpasture River drains a land area of 53,395 acres (83 mi^2). This area (the Little Calfpasture River watershed) is mostly covered by forest (86%), with 12% covered by pasture or hay. The Little Calfpasture River flows south and joins with the Calfpasture River near Goshen, Virginia to form the Maury River. The Maury River flows into the James River, which empties into the Chesapeake Bay.

Definition:

Watershed – All of the land area that drains to a particular point or water body.

1.2. THE PROBLEM

The Virginia Department of Environmental Quality (VADEQ) sets water quality standards or limits on the amount of pollution that is allowed in rivers and streams. A section of the Little Calfpasture River below the Goshen Dam fails to meet the general standard for aquatic life. This means that the river does not support a healthy and diverse community of bugs and fish. VADEQ conducted a study (called a stressor analysis) to figure out the reasons for this impairment. In general, the study found that the ultimate source of the impairment is the presence of Lake Merriweather and the Goshen Dam. The lake impacts the Little Calfpasture River in many ways, but the study found that the following three stressors were the most significant:

- Change in available food supply – This cause is to be expected when a river (such as the Little Calfpasture River) is dammed to form a lake. Food supplies in a lake are different than those in a stream, and directly below the dam, the available food supply resembles that of a lake more than a stream. This causes filter feeding organisms to dominate and outcompete those that would otherwise form a naturally diverse population. There is no way to correct this problem short of removing the dam, so VADEQ proposed to alter the water quality standard to allow for a zone of recovery below the dam. This proposal has been approved by the State Water Control Board and the USEPA.

- Low dissolved oxygen – During the late summer, low dissolved oxygen has been observed in the Little Calfpasture River below the dam. This condition occurred when very little surface water was coming over the dam spillway, and the majority of downstream flow was coming from an outlet pipe 10 ft deep in the lake. This deep discharge contains almost no oxygen and contributes to low dissolved oxygen downstream. To solve this problem, the Boy Scouts modified the outlet structure in 2009 to receive water from higher in the lake where there is more oxygen. Initial monitoring conducted by VADEQ in August 2009 suggests that this modification has solved the dissolved oxygen problem, but VADEQ will continue monitoring the Little Calfpasture River to ensure that dissolved oxygen standards are met.

- Sediment – High sediment loads from throughout the Little Calfpasture River watershed also contribute to the impairment below the dam. Sediment washed off of the land surface or eroded from the stream banks is transported into the lake during storm events. These high flow events also increase velocities through the lake, which can resuspend additional sediment that was previously deposited in the lake. Erosion of the lake shoreline can also contribute to sediment within the lake if lake levels are lowered prior to the storm event. All of these sources combine to increase suspended sediment concentrations in the lake following storm events. Some of the suspended sediment within the lake is re-deposited within the lake, but much (76% on average) is discharge from the lake through the spillway to the Little Calfpasture River below the dam. This discharge of sediment can persist for days to weeks following storm events. Since this discharge occurs as flows are receding from the event and velocities are decreasing, some of this sediment is deposited on the streambed below the dam. This excess sediment smothers certain bugs that live in the bottom of the stream and limits the diversity of aquatic life. To address this aspect of the impairment, VADEQ has developed a Total Maximum Daily Load (TMDL) for sediment in the Little Calfpasture River.

1.3. CURRENT SOURCES OF SEDIMENT

Sediment that is accumulated in rivers can come from direct point sources (such as a sewage treatment plant) or from non-point sources, such as general erosion of the land surface. In the Little Calfpasture River watershed, there are very few point sources, so the vast majority of sediment comes from the land surface. This includes a variety of different land uses including pasture, cropland, residential, impervious, and forest areas. Sediment sources would also include stream bank erosion and Lake Merriweather itself. The amount of sediment that comes from each of these sources depends on many factors, such as the soil type, slope, land use, and patterns of precipitation.

> **Definition:**
>
> Point Source – pollution that comes out of a pipe (like at a sewage treatment plant).
> Non-point Source – pollution that does not come out of a pipe but comes generally from the landscape (usually as runoff).

To account for these and many other important factors, VADEQ used two computer models (one called the Loading Simulation Program C++ model, or LSPC; and one called the Environmental Fluid Dynamics Computer Code, or EFDC) to track sediment from its source on the land, to the stream, and then downstream to the Maury River. To make sure that estimates from the model were accurate, the model was tested with real-world data. The model was used to predict sediment levels in the Little Calfpasture River from 2000 to 2006, and these predictions were compared to the results of suspended sediment samples collected from the Little Calfpasture River during that time period. Once the model passed this test, it could be used to make predictions about how sediment levels in the Little Calfpasture River might change if we better controlled the various sources of sediment and sediment management within Lake Merriweather.

> **Frequently Asked Question:**
>
> *Why use a computer model?*
> Sampling and testing tells you a lot about the present and the past, but nothing about the future. A computer model is a tool that can help you make predictions about the future. This is necessary to figure out how much effort is needed to clean up a stream.

Based on model results, approximately 3395 tonnes of sediment enter Lake Merriweather each year. The majority of this sediment comes from degraded riparian pasture, which is pasture land that is located along the river and its tributaries where cattle have access and where active bank erosion is occurring. While these areas account for only 2% of the land area in the watershed, they account for 52% of the sediment. Measureable amounts also come from upland pasture, cropland, forest, residential, and impervious areas (Figure 1-1). The sediment contribution to Lake Merriweather itself is primarily sourced from the Little Calfpasture River (94%). However, shoreline erosion also adds a measurable amount, as do the lakeside lands (5%). Below Lake Merriweather, almost all of the sediment in the Little Calfpasture River comes from the lake. This makes the lake a secondary source of sediment, passing through and resuspending sediment that had earlier entered the lake. The study found that the load of sediment discharged following a storm event was dependent upon the magnitude of the storm, but on average 76% of incoming sediment was transported downstream. The study also found that sediment discharge periods below the lake were more extended than above the lake, lasting up to 8 days following storm events. This extended duration of high solids events below the dam explains the observed pattern of solids in the Little Calfpasture River and a majority of the aquatic life impairment.

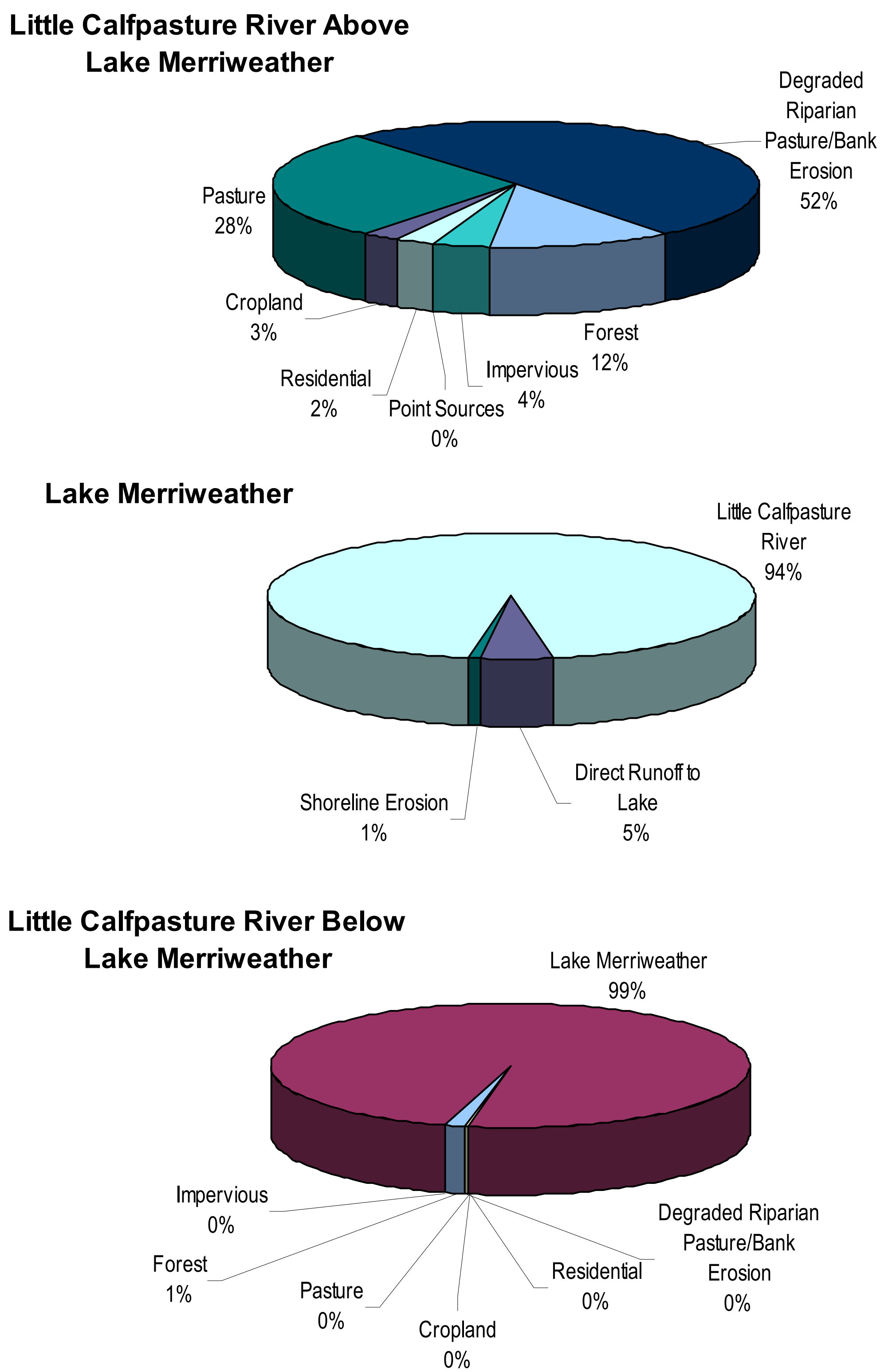

Figure 1-1. Sources of Sediment to the Little Calfpasture River.

1.4. FUTURE GOALS (THE TMDL)

After figuring out where the sediment in the Little Calfpasture River is currently coming from, the computer model was used to figure out how much sediment loads need to be reduced to clean up the Little Calfpasture River. The goal was to reduce sediment loads to 2001 levels, when downstream aquatic life met the state's standards. To do this, 40% reductions in sediment will be needed from cropland, pasture, residential, and urban lands; 66% reduction will be needed from degraded riparian pasture; and 34% reductions from improved lake sediment management will also be needed (Table 1-1). This report does not prescribe a single strategy for lake sediment management, but will allow various options to be investigated during implementation planning. This report does, however, emphasize the importance of a reduction strategy that includes both reductions in sediment sources throughout the watershed, and reductions coming from lake sediment management.

> Definition:
>
> <u>TMDL</u> – Total Maximum Daily Load. This is the amount of a pollutant that a stream can receive and still meet water quality standards. The term TMDL is also used more generally to describe the state's formal process for cleaning up polluted streams.

If the reductions specified in Table 1-1 are made, sediment loads will be reduced to below the 2001 levels (1198 tonnes/yr), and aquatic life should be restored. This reduced amount, known as the total maximum daily load (TMDL), is the maximum amount of sediment that can enter the Little Calfpasture River and still meet water quality standards. A small portion of this amount (30.4 tonnes /yr) is reserved for permitted discharges in the area (point sources), but most of the amount accounts for sediment from runoff and sources that do not come out of a pipe (nonpoint sources) (Table 1-2).

Table 1-1. Sediment Reductions Needed to Restore the Little Calfpasture River.

Source	Sediment Reductions Needed to Restore Water Quality
Forest	0%
Cropland	40%
Pasture	40%
Residential land	40%
Urban/Commercial/ Transportation	40%
Degraded Riparian Pasture	66%
Permitted Point Sources	0%
Lake Sediment Management	34%

Table 1-2. Total Maximum Daily Load of Sediment in the Little Calfpasture River that will Meet the Water Quality Standard.

Stream	Amount from Permitted Point Sources (WLA) (tonnes/yr)	Amount from Nonpoint Sources (LA) (tonnes/yr)	Margin of Safety (tonnes/yr)	Total Maximum Daily Load (tonnes/yr)
Little Calfpasture River (VAV-I32R)	30.4	1107.6	60	1198

1.5. WHAT HAPPENS NEXT

VADEQ will ask for public comment on this report and then submit it to the U.S. Environmental Protection Agency (USEPA) for approval. This report sets the clean-up goal for the Little Calfpasture River, leading to the next step a clean-up plan (or Implementation Plan) that lays out how that goal will be reached. The clean-up plan will set intermediate goals and describe actions that should be taken to clean up the Little Calfpasture River. Many of these actions are obvious and can be taken right now to reduce sediment and improve the health of the Little Calfpasture River. Some of these actions are listed below:

- Fence out cattle from streams and provide alternative water sources
- Leave a band of 35 – 100 ft along the stream in a natural condition so that it buffers or filters out sediment from farm or residential land (a riparian buffer)

- Practice conservation tillage practices
- Better manage sediment within Lake Merriweather
- Operate the dam in accordance with dam operation protocol and VADEQ consent order

These and other actions will be listed in the clean-up plan with associated costs and how much of each action it will take to meet the goals. The clean-up plan will also identify potential sources of money to help in the clean-up efforts. Most of this money will probably be available in the form of cost-share programs, which share the cost of improvements with the landowner. Please be aware that the state or federal government will not fix the problems in the Little Calfpasture River. It is primarily the responsibility of individual landowners and local governments to take the actions necessary to improve the river. The state agencies will help with developing the plan and finding money to support the plan, but actually making the improvements is up to those that live in the Little Calfpasture River watershed. By increasing education and awareness of the problem, and by working together to each do our part, we can make the changes necessary to improve the Little Calfpasture River.

Frequently Asked Question:

How will the TMDL be implemented? For point sources, TMDL reductions will be implemented through discharge permits. For nonpoint sources, TMDL reductions will be implemented through best management practices (BMPs). Landowners will be asked to voluntarily participate in state and federal programs that help defer the cost of BMP installation.

CHAPTER 2: INTRODUCTION

2.1. WATERSHED LOCATION AND DESCRIPTION

The Little Calfpasture River is located in Augusta and Rockbridge Counties, Virginia (Figure 2-1). The watershed is 53,395 acres is size, with 70% of the acreage located in southwestern Augusta County, and 30% located in northwestern Rockbridge County. The Little Calfpasture River flows south and converges with the Calfpasture River to form the Maury River near Goshen, Virginia. The Maury River is a tributary to the James River, which flows into the Chesapeake Bay.

Approximately 0.8 miles upstream from the confluence of the Little Calfpasture River with the Maury River is the Goshen Dam, which impounds the Little Calfpasture River and forms Lake Merriweather (Figure 2-1). Lake Merriweather is a 444-acre lake with a full pool at 1369 ft in elevation. The lake and dam are part of a 4,000-acre camp (Goshen Scout Camps) owed and operated by the Boy Scouts of America, National Capital Area Council. The Goshen Dam was constructed in 1966 to form Lake Merriweather and provide a recreational benefit to the Boy Scouts. While not constructed for flood control, the dam currently provides some flood control benefits. The operation of the dam has previously been identified as causing fish kills and biological impairment in the Little Calfpasture River and was the subject of a Virginia Department of Environmental Quality (VADEQ) enforcement action and special order (see Section 2.5).

The Little Calfpasture River watershed (designated VAV-I32R) is located in the Ridge and Valley Level III Ecoregion (Woods *et al*., 1999). The Ridge and Valley Level III Ecoregion is characterized by its generation from sedimentary rocks, including sandstone, shale, limestone, and dolomite. This ecoregion consists of alternating forested ridges and agricultural valleys that are elongated and folded and faulted. The land use in the watershed is primarily forest (86%), with 12% in pasture and hay (Figure 2-2). The majority of the pasture and hay lands are within the narrow stream valleys in close proximity to the stream.

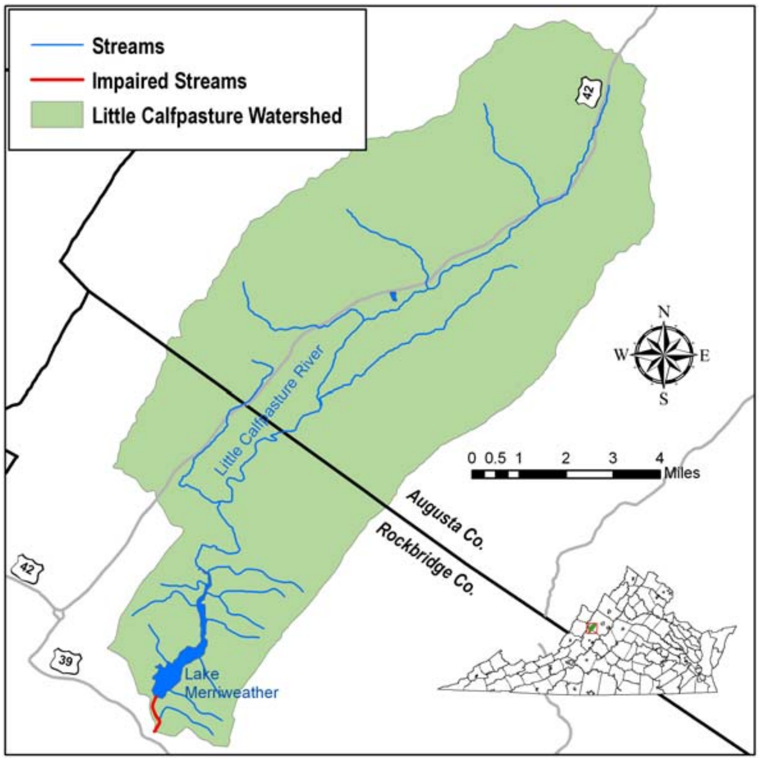

Figure 2-1. Location of Little Calfpasture River.

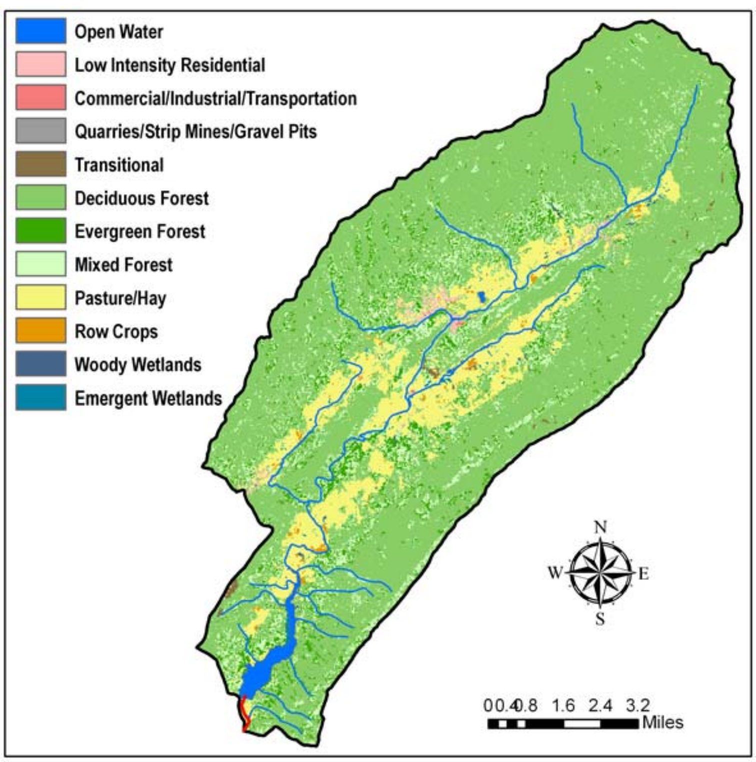

Figure 2-2. Land Use in the Little Calfpasture River Watershed.

2.2. DESIGNATED USES AND APPLICABLE WATER QUALITY STANDARDS

Virginia's Water Quality Standards (9 VAC 25-260-5) consist of designated uses established for water bodies in the Commonwealth, and water quality criteria set to protect those uses. Virginia's Water Quality Standards protect the public and environmental health of the Commonwealth and serve the purposes of the State Water Control Law (§62.1-44.2 *et seq.* of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 *et seq*.).

2.2.1. Designation of Uses (9 VAC 25-260-10)

> *"A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish"* (State Water Control Board, 2006).

The above listed uses are designated for all state waters, including the Little Calfpasture River. A portion of the Little Calfpasture River does not support the aquatic life designated use based on biological monitoring of the benthic macroinvertebrate community.

2.2.2. General Standard (9VAC 25-260-20)

The following general standard protects the aquatic life use:

> *"A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.*
>
> *Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled"* (State Water Control Board, 2006).

VADEQ's biological monitoring program is used to evaluate compliance with the above standard. This program monitors the assemblage of benthic (bottom-dwelling) macro (large enough to see) invertebrates (insects, mollusks, crustaceans, and annelid worms) in streams to determine the biological health of the stream. Benthic macroinvertebrates are sensitive to water quality conditions, important links in aquatic food chains, major contributors to energy and nutrient cycling in aquatic habitats, relatively immobile, and easy to collect. These characteristics make them excellent indicators of aquatic health. Changes in water quality are reflected in changes in the structure and diversity of the benthic macroinvertebrate community.

Currently, VADEQ assesses the health of the benthic macroinvertebrate community using the Virginia Stream Condition Index (VSCI). This index was first developed by Tetra Tech (2003) and later validated by VADEQ (2006). The VSCI is a multimetric index based on 8 biomonitoring metrics. The index provides a score from 0-100, and this score is compared to a statistically derived cutoff value based on the scores of regional reference sites.

2.3. 305(B)/303(D) WATER QUALITY ASSESSMENT

Under Section 305(b) of the Federal Clean Water Act, states are required to assess the quality of their water bodies in comparison to the applicable water quality standards. States are also required, under Section 303(d) of the Act, to prepare a list of water bodies that do not meet one or more water quality standards. This list is often called the "Impaired Waters List", or the "303(d) List", or the "TMDL List", or even the "Dirty Waters List". The Commonwealth of Virginia accomplishes both of these requirements through the publishing of an Integrated 305(b)/303(d) Water Quality Assessment Report ever two years. Each report assesses water quality by evaluating monitoring data from a six-year window. The assessment window for the most recent 2008 305(b)/303(d) Integrated Water Quality Assessment Report (VADEQ, 2008) was from January 1, 2001 through December 31, 2006.

The degree of support for the aquatic life designated use is assessed based on the Virginia Stream Condition Index (VSCI) calculated from biological monitoring data. According to VADEQ's current Water Quality Assessment Guidance (VADEQ, 2007), streams with a calculated VSCI score ≥60 are assessed as "fully supporting" the aquatic life designated use. Streams with VSCI scores <60 are assessed as "impaired" or "not supporting" the aquatic life designated use.

Prior to the 2008 Water Quality Assessment, VADEQ used the USEPA Rapid Bioassessment Protocol (RBP) II (Barbour *et al.*, 1999) for assessing the aquatic life use. This methodology compares a number of community structure and diversity metrics between a monitored site and a reference site. Reference sites are selected to represent a natural, unimpaired stream of approximately the same size and within the same ecoregion. Based on comparison to the reference site, the RBP produces a score for the monitored site and a classification of "non-impaired," "slightly impaired," "moderately impaired," or "severely impaired." In Virginia, any stream segment with an overall rating of "moderately impaired" or "severely impaired" was considered impaired and not meeting the aquatic life designated use.

Interesting Fact:

Over 10,000 miles of Virginia streams and rivers were listed as impaired in the 2008 Water Quality Assessment Report.

2.3.1. Little Calfpasture River Impairment Listing

The Little Calfpasture River was first assessed as impaired and listed on the 303(d) list in 1996. The impaired segment is a 0.83 mile reach from the Goshen Dam to the confluence with the Calfpasture River (shown in red on Figure 2-1). This reach fails to meet the general standard for aquatic life based on biomonitoring of the benthic macroinvertebrate community. This aquatic life impairment has continued, and this section of the Little Calfpasture River (Assessment Unit ID: VAV-I32R_LCF01A00) has remained on the 303(d) list from 1996 through the most current 2008 305(b)/303(d) Integrated Report (VADEQ, 2008).

2.4. TMDL DEVELOPMENT

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for water bodies that fail to meet designated water quality standards and are placed on the state's Impaired

Waters List. A TMDL reflects the total pollutant loading that a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

Due to the aquatic life impairment listed for the Little Calfpasture River, this segment was scheduled for TMDL development by 2010 and assigned a TMDL Group ID of 00371. This report establishes a sediment TMDL to address the aquatic life impairment in this segment.

2.5. VADEQ ENFORCEMENT ACTIONS

On December 17, 1992, VADEQ staff investigated a fish kill on the Little Calfpasture River downstream of Lake Merriweather. The cause of the fish kill was identified as excessive sedimentation resulting from the draining of Lake Merriweather to make repairs to the dam gates. The lake was drained by opening the bottom sluice gate that is located at the bottom of the dam structure at a depth of 26 ft. This allowed sediment accumulated in the lake to flow downstream. Heavy downstream sedimentation was observed for the remaining length of the Little Calfpasture River and into the Maury River. This sedimentation caused a fish kill of at least 223 fish.

In response to the fish kill, VADEQ issued a Notice of Violation to the Boy Scouts of America on January 15, 1993. VADEQ also took enforcement action against the Boy Scouts of America and issued a Special Order on April 30, 1993 (State Water Control Board, 1993). The Order included a civil charge and required the Boy Scouts of America to implement an alternate method for draining the lake without opening the subsurface discharge or construct a settling basin for removing sediment when using the subsurface discharge. The special order also contained requirements for ameliorating the impacts if subsurface draining of the lake was necessary prior to the implementation of an alternate draining method.

On September 30, 1996, VADEQ issued an additional Notice of Violation, stating that the Little Calfpasture River remains severely impaired by sediment release from the dam. Each fall the level in the lake was lowered to protect against flooding during the winter and spring months. At the lowered lake level, lake sediments are exposed around the perimeter of the lake. Erosion of these sediments by rain events introduces the sediment back to the lake water column and eventually downstream, causing continued impairment of the benthic aquatic life downstream.

To address the continuing degradation of the stream, VADEQ amended the original Special Order on April 6, 1998 (State Water Control Board, 1998). The amendment required that Lake Merriweather be maintained at full pool and not drawn down except when flooding or other emergency circumstances require the lake to be lowered. The amendment also required the Boy Scouts of America to submit to VADEQ a spillway gate operation protocol and quarterly reports summarizing activities. The Boy Scouts of America were also to continue seeking funds for rehabilitating the dam.

Based on dam operation records obtained from the Boy Scouts of America, it is assumed that the dam was primarily operated in accordance with the Order from May 1998 through October 2004. During this time period the lake was kept at full pool with the exception of lowering during large storm events. Table 2-1 shows the record of lake lowering events greater than 2 feet. Prior to October 2004, the lake was lowered for brief periods of time in response to major storm events, such as Hurricanes Dennis, Isabel, Francis, Ivan, and Jeanne. Beginning in October 2004, however, the lake was again routinely lowered during the winter. During the winter of 2004-2005, the lake was lowered 8 ½ feet for a duration of 160 days. During the winter of 2005-2006, the lake was again lowered 8 feet for 91 days.

In June 2006, VADEQ monitoring and enforcement staff met with the Boy Scouts to reiterate the requirements of the Order. The Boy Scouts stated their intent to comply with the Order, but expressed concern that the current spillway gate operation protocol did not adequately allow for proactively responding to storm events. Since that meeting, the lake has been maintained at a higher level, but the practice of routinely lowering the lake over the winter has continued. Beginning in September 2006 the lake was lowered 4 to 5.5 feet for more than 184 days over the fall and winter.

In February 2007, VADEQ monitoring, enforcement, and TMDL staff met again with the Boy Scouts to discuss the environmental concerns associated with long-term lowering of the lake level. The Boy Scouts again expressed their intention to comply with the Order, and committed to completing maintenance activities as soon as possible and raising the lake level to full pool. The gates were returned to the full pool position on March 8, 2007. To VADEQ's knowledge, the gates have not been lowered for extended periods of time since March 2007.

Table 2-1. Record of Lake Lowering Events Greater Than Two Feet[1].

Dates of Lake Lowering		Reason	Number of Days Lowered	Minimum Gate Position (ft)	Feet Below Full Pool (ft)
From	To				
1/22/1998	5/15/1998	Seasonal Debris	113	22	4
9/17/1999	10/15/1999	Hurricane Dennis	28	22	4
9/16/03	9/19/03	Hurricane Isabel	3	23	3
11/19/03	11/21/03	Storm Event	2	23.5	2.5
9/6/04	10/13/04	Hurricanes Francis, Ivan, and Jeanne	37	17	9
10/19/04	3/28/05	Seasonal Debris	160	17.5	8.5
9/10/05	10/28/05	Unknown	48	16	10
12/3/05	3/4/06	Seasonal Debris	91	18	8
9/5/06	3/8/07	Seasonal Debris	184	20.5	5.5

[1] Records of dam operation were obtained from the Boy Scouts of America. Records were incomplete, so listing of lake lowering events may also be incomplete. Records obtained from 12/1997 – 12/2001 contained only lake level data and did not record gate operations. No records were available from 12/2001 – 2/2003. Records since 2/2003 have primarily only included a summary of gate operations and not lake levels. Large gaps in records during this time period were also present.

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. WATER RESOURCES

The Little Calfpasture River watershed is located in Augusta and Rockbridge Counties, Virginia (Figure 2-1). The Little Calfpasture River flows south from its headwaters in Augusta County into Rockbridge County within a narrow valley between Great North Mountain to the west and Little North Mountain to the east (Figure 3-1). The Little Calfpasture River is 22.3 miles in length and receives flow from perennial tributaries, intermittent tributaries, and springs. Named perennial tributaries within the Little Calfpasture River watershed include Montgomery Run, Kennedy Draft, Wallace Draft, Smith Creek, and Cove Run. Significant springs include Augusta Springs, which serves as a water source for Augusta County, and Wallace Mill Spring, which serves the Castaline Trout Farm. The most notable water resource in the Little Calfpasture River watershed is Lake Merriweather. Lake Merriweather is a 444-acre manmade impoundment formed by the Goshen Dam, which is located approximately 0.8 miles upstream from the watershed outlet. To assist in modeling the hydrology of the Little Calfpasture River the watershed was divided into 23 sub-watersheds (Figure 3-1).

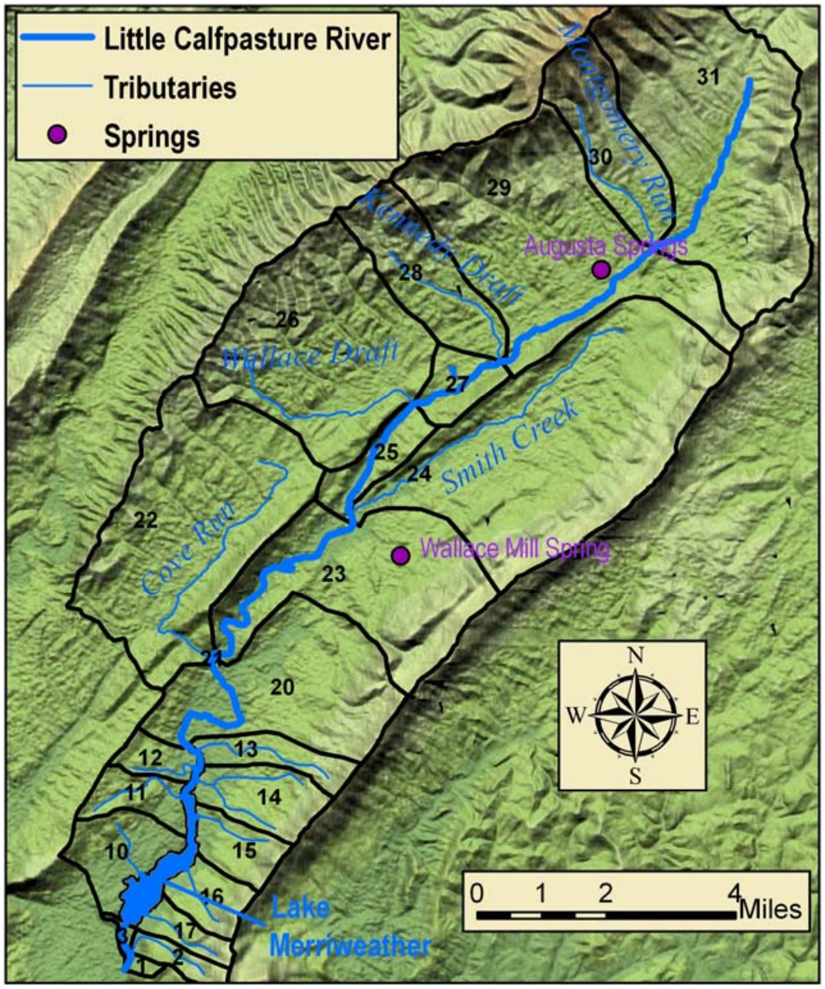

Figure 3-1. Little Calfpasture River Sub-watersheds and Tributaries.

3.2. ECOREGION

The Little Calfpasture River watershed is located in the Ridge and Valley Level III Ecoregion (Woods *et al*., 1999). The Ridge and Valley Level III Ecoregion is characterized by its generation from sedimentary rocks, including sandstone, shale, limestone, and dolomite. This ecoregion consists of alternating forested ridges and agricultural valleys that are elongated and folded and faulted. Level IV Ecoregions within the watershed include the Northern Sandstone Ridges along Little North Mountain to the east and on Knob Mountain in the south central portion of the watershed, Northern Dissected Ridges and Knobs along Great North Mountain to the west, Northern

Limestone/Dolomite Valleys at the western base of Little North Mountain, and Northern Shale Valleys at the eastern base of Great North Mountain.

The Northern Sandstone Ridges are characterized by high, steep, forested ridges with narrow crests. The ridges are primarily vegetated with Appalachian Oak forests. Elevations on the ridge forming the eastern boundary of the watershed range from approximately 2500 to 3000 feet. Streams flowing off of this ridge are high gradient and have low buffering capacity due to the underlying sandstone.

The Northern Dissected Ridges and Knobs Level IV Ecoregion is composed of more broken and dissected ridges. Elevations in this ecoregion along the western boundary of the watershed are similar to those along the eastern boundary, yet slightly more variable due to the dissecting. The underlying geology is composed of interbedded sedimentary rock including siltstones, leading to greater buffering capacity than on Northern Sandstone Ridges. Like the standstone ridges to the east, the Northern Dissected Ridges are primarily vegetated with Appalachian Oak forests.

The Northern Limestone/Dolomite Valley Level IV Ecoregion, forms the southeast portion of the Little Calfpasture River valley. This ecoregion is characterized by broad, level to undulating, fertile valleys that are extensively farmed, and contain scattered woodlands on steeper slopes. Sinkholes, underground streams, and other karst features have developed on the underlying limestone and dolomite. Streams tend to flow year-round and have gentle slopes.

The northwestern portion of the Little Calfpasture River valley is composed of the Northern Shale Valley Level IV Ecoregion. This ecoregion is characterized by rolling valleys and low hills and is underlain mostly by shale, siltstone, and fine-grained sandstone. Soils are generally less fertile than limestone-derived soils in the Northern Limestone/Dolomite Valley Ecoregion.

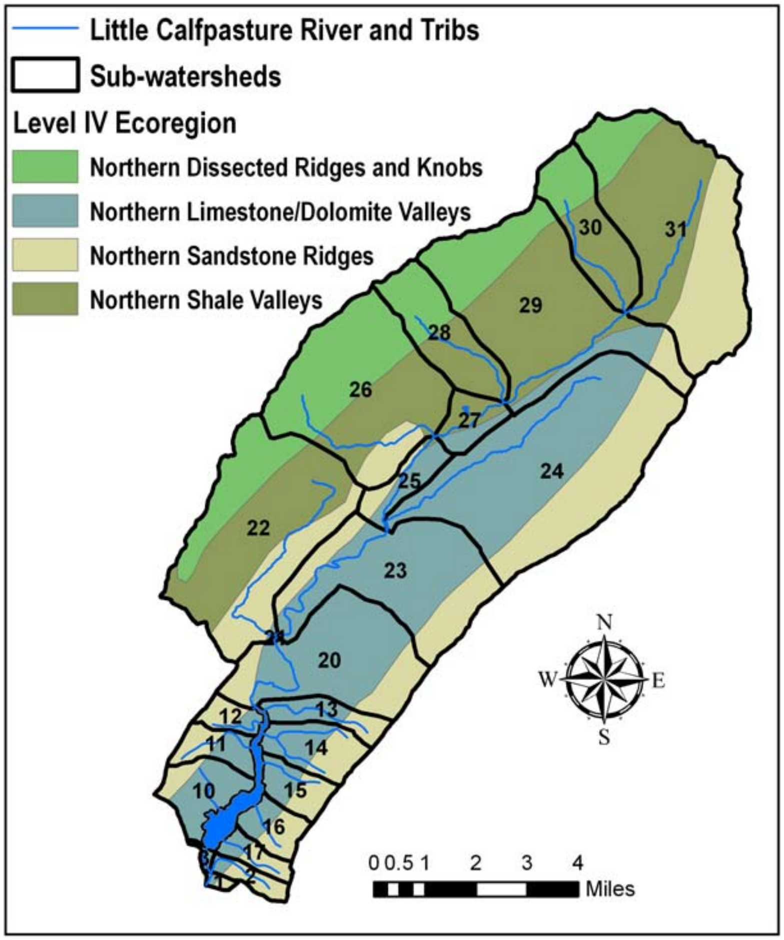

Figure 3-2. Level IV Ecoregions in the Little Calfpasture River Watershed.

3.3. SOILS AND GEOLOGY

Soils data for the Little Calfpasture River watershed were obtained from the U.S. General Soil Map (STATSGO) database (NRCS, 2006) and are shown in Figure 3-3. The predominant soils in the Little Calfpasture River watershed are the Berks-Weikert-Laidig series (VA001). These soils are found throughout most of the northern Little Calfpasture River valley. These soils are shallow to very deep and are well drained. They are loamy and weathered from shale, siltstone, and fine-grained sandstone. Permeability in these soils is moderate to moderately rapid. These soils are in hydrologic soil group C.

The southern portion of the valley consists of the similar Shottower-Laidig-Weikert series soils (VA016). The Shottower series are moderately permeable soils on high stream terraces. They formed in old alluvium derived from sandstone, quartzite, limestone, shale, and siltstone. The Shottower series is in hydrologic soil group B.

The Wallen-Dekalb-Drypond series soils (VA005) are found along Little North Mountain to the east, Great North Mountain to the west, and Knob Mountain in the south central portion of the watershed. These soils are moderately deep, somewhat excessively drained soils weathered from fine-grained sandstone, siltstone, and shale. These soils are typically on mountain tops and have moderately rapid permeability. These soils are in hydrologic soil group B.

Along the base of Great North Mountain, there is a band of Frederick-Carbo-Timberville soils (VA003) that are coincident with the Northern Limestone/Dolomite Valley Level IV Ecoregion. These soils consist of very deep, well drained soils derived mainly from dolomitic limestone with interbeds of sandstone, siltstone, and shale. Depth of these soils to bedrock is more than 72 inches, and permeability is moderate. These soils are in hydrologic soil group B.

A small portion of the watershed consists of Moomaw-Jefferson-Alonzville soils (VA004). These soils consist of deep and very deep, well drained soils formed in acid sandstone, quartzite, shales, and siltstones. These soils are common on stream terraces. Permeability is moderate to moderately rapid in Jefferson and Alonzville series, but are slow to moderately slow in Moomaw series due to a fragipan at 15 to 30 inches in depth. Rock outcrops are common in this soil type, and permeability is moderate. These soils are in hydrologic soil group B/C.

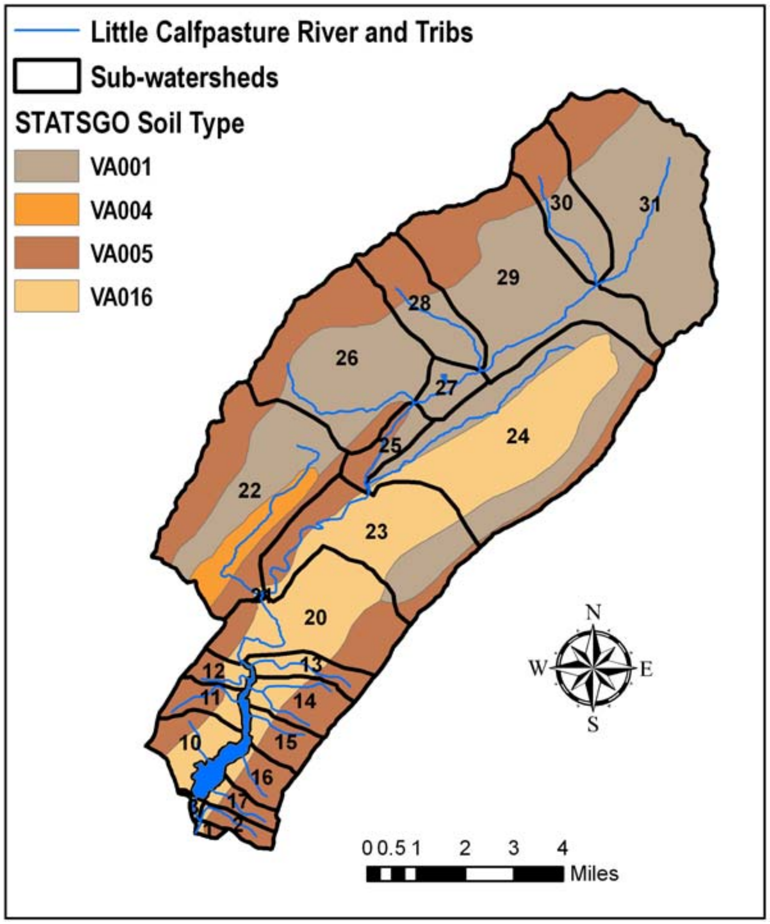

Figure 3-3. Soil Types in the Little Calfpasture River Watershed.

3.4. CLIMATE

Climate data from the Craigsville 2S weather station and the Lexington weather station were used to characterize climate in the Little Calfpasture River watershed (SERCC, 2008). The average annual precipitation at this location from 1963-2005 is 42.39 inches, with average monthly precipitation varying from 2.64 inches in February to 4.58 inches in July. Average annual snowfall is 20.1 inches, occurring in October through April, with 60% occurring in January and February. The average annual maximum and minimum temperatures are 67.8 and 43.0°F, respectively. The average monthly maximum temperature of 86.9°F occurs in July, and the average monthly minimum temperature of 24.3°F occurs in January.

3.5. LAND COVER

Land cover data for the Little Calfpasture River watershed was obtained from the 2005 Virginia Department of Forestry's (VADOF) Virginia Land Use Dataset (VADOF, 2005). This database was developed from satellite imagery captured from 2002 to 2005, and is currently the most up-to-date land cover data available for the Little Calfpasture River watershed. Figure 3-4 shows the land cover in the Little Calfpasture River watershed. This watershed is primarily forested (85.5%), with most of the remainder in pasture, hay, or cropland (12.2%). Those agricultural lands in the watershed are mostly located along the stream corridors, where slopes are shallow and more fertile soils are present. Only slightly above 1% of the watershed consists of urban/transportation and residential land cover. These areas are primarily along US Route 42 and in the town of Craigsville.

Table 3-1 shows the acreage and percentage of each land cover type in the Little Calfpasture River watershed. These 14 land cover categories were further summarized into 6 aggregated land cover categories (plus open water) to simplify modeling efforts. Section 6.2.2 describes how land cover data were further modified to provide an accurate land use data set for modeling the watershed.

Table 3-1. Land Cover in the Little Calfpasture River Watershed.

Land Cover	Acres	%	Aggregated Land Cover	Acres	%
Water	452	0.8%	Water	452	0.8%
Pavement	504	0.9%	Urban/Transportation	504	0.9%
Rooftop	0	0.0%			
Residential/Industrial	284	0.5%	Residential	284	0.5%
Natural Barren	0	0.0%	Transitional	0	0.0%
Mine/Quarry	0	0.0%			
Bare Soil	0	0.0%			
Forest Harvest	0	0.0%			
Hardwood Forest	33617	63.0%	Forest	45633	85.5%
Pine Forest	6273	11.8%			
Mixed Forest	5744	10.8%			
Grassland	0	0.0%	Crop/Pasture/Hay	6509	12.2%
Crop/Pasture/Hay	6509	12.2%			
Salt Marsh	0	0.0%	Wetland	0	0.0%
Total	**53382**	**100.0%**	**Total**	**53382**	**100.0%**

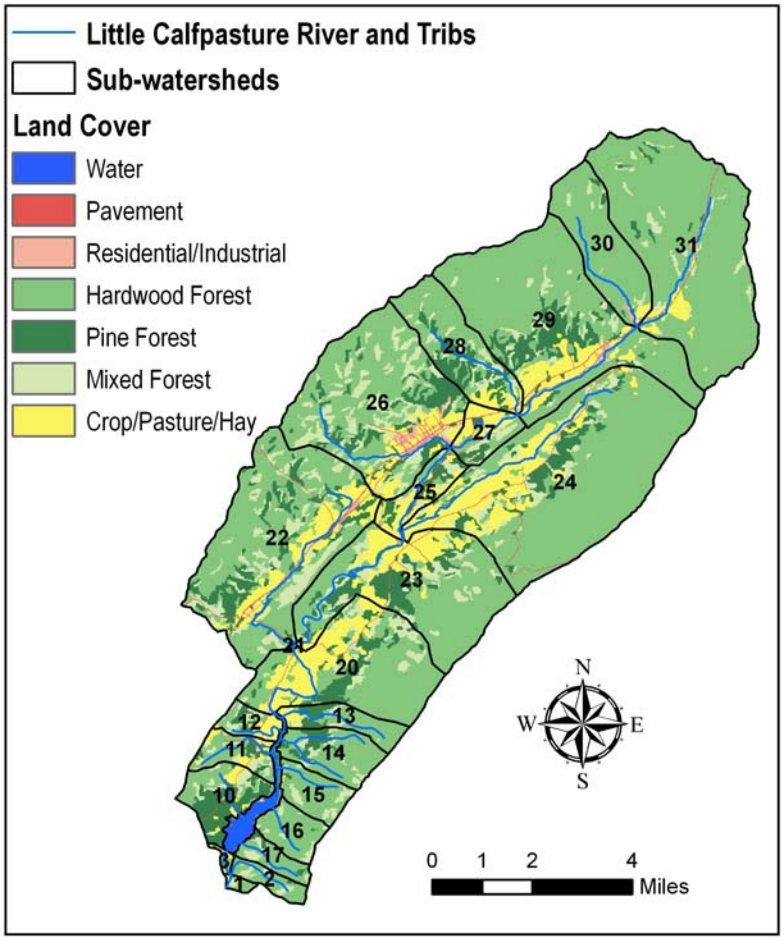

Figure 3-4. Land Cover in the Little Calfpasture River Watershed.

CHAPTER 4: STRESSOR IDENTIFICATION ANALYSIS

4.1. OVERVIEW

Benthic impairments are based on biological assessments of the benthic community. These biological assessments are effective at determining whether a water body is impaired or not, but they do not provide information on the stressor or source causing the impairment. To determine the cause of the impairment, a stressor identification analysis is conducted. VADEQ conducted this analysis according to EPA's Stressor Identification Guidance Document (USEPA, 2000). The first step in the stressor identification analysis is to list potential candidate stressors. VADEQ identified these from the listing information, monitoring data, scientific literature, and historic information. The next step is to analyze all of the available evidence to support or eliminate potential candidate stressors. VADEQ used physical, chemical, and biological data collected upstream and within the impaired reach to evaluate potential stressors. Based on the weight of evidence supporting each potential candidate, stressors were then separated into the following categories: non-stressor(s), possible stressor(s), and most probable stressor(s).

Once the most probable stressor(s) was identified, a causal analysis was conducted to directly link sources to the stressors and those stressors to the impairment. A conceptual model was developed to describe the causal pathways from source to stressor to impairment. The pathways in the conceptual model were then evaluated to determine if the existing data supported those mechanisms for producing the impairment.

4.2. BIOLOGICAL AND CHEMICAL DATA

VADEQ has seven monitoring stations located on the Little Calfpasture River (Figure 4-1). These stations have been monitored for various lengths of time and for various purposes. Table 4-1 shows the number of samples and the period of time over which individual stations were monitored. The primary benthic monitoring stations are just upstream of Lake Merriweather (2-LCF004.80), just downstream of the Goshen Dam (2-

LCF000.76), and just prior to the confluence with the Maury River (2-LCF000.02). The primary water quality monitoring station has historically been station 2-LCF007.00, which is several miles upstream of Lake Merriweather. In more recent years, bimonthly water quality samples at station 2-LCF000.02 have been collected concurrently with samples collected from 2-LCF007.00. This sampling was intended to bracket the impaired reach and provide water quality information for this stressor identification analysis.

Table 4-1. Summary of Monitoring Stations on the Little Calfpasture River.

Station	Station Type	Benthic Sampling		Water Quality Sampling	
		Monitoring period	Samples Collected	Monitoring period	Samples Collected
2-LCF000.02	Benthic and Water Quality	1999-2006	10	2002-2006	32
2-LCF000.76	Benthic	1994-2006	15		
2-LCF004.80	Benthic and Water Quality	1994-2006	15	2002	11
2-LCF007.00	Water Quality			1991-2006	150
2-LCF011.72	Water Quality			2002	11
2-LCF010.83	Benthic	1996	1		
2-LCF013.93	Water Quality			2001-2003	12

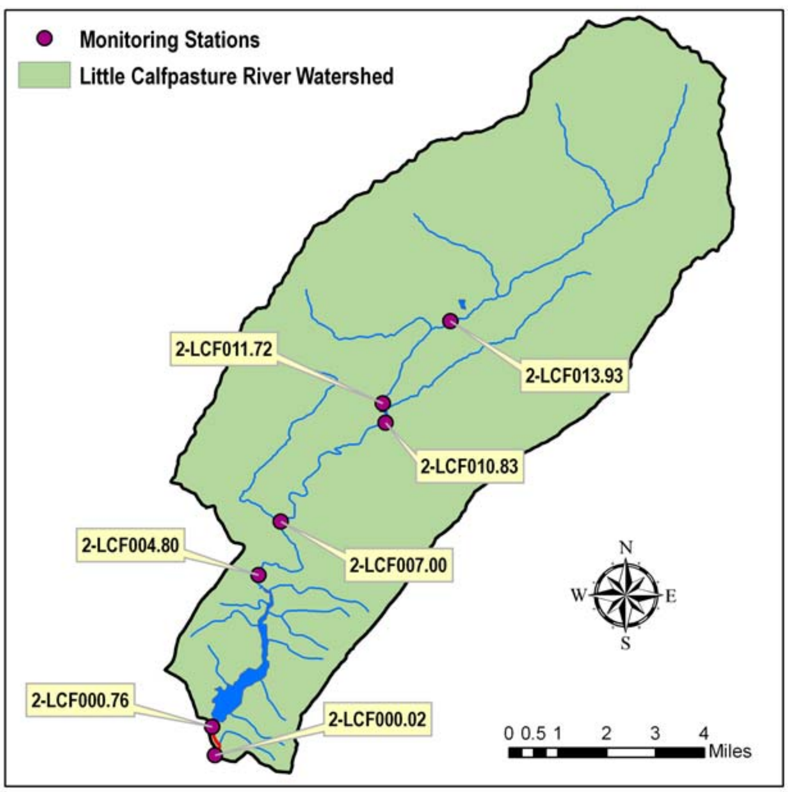

Figure 4-1. Monitoring Stations on the Little Calfpasture River.

4.2.1. Benthic Assessments

Benthic assessments have been conducted approximately 6 miles upstream of Lake Merriweather (2-LCF010.83), directly upstream of Lake Merriweather (2-LCF004.80), directly downstream of Lake Merriweather (2-LCF000.76), and further downstream near the mouth of the Little Calfpasture River (2-LCF000.02). The average Stream Condition Index (SCI) scores and average RBPII scores for each of these stations are shown in Figure 4-2. At both stations upstream of Lake Merriweather, average SCI scores are in the non-impaired range (above 60) and RBPII scores are in the slightly impaired region (54 to 79), which is assessed as meeting the aquatic life use. At both stations below Lake Merriweather, SCI scores are in the impaired range (below 60) and RBPII scores are in the moderately or severely impaired region, which is assessed as not meeting the aquatic life use. Benthic scores are lowest directly below the Goshen Dam, with SCI scores averaging 24 and RBPII scores in the severely impaired region (12). Benthic scores improve to moderately impaired as distance from the dam increases.

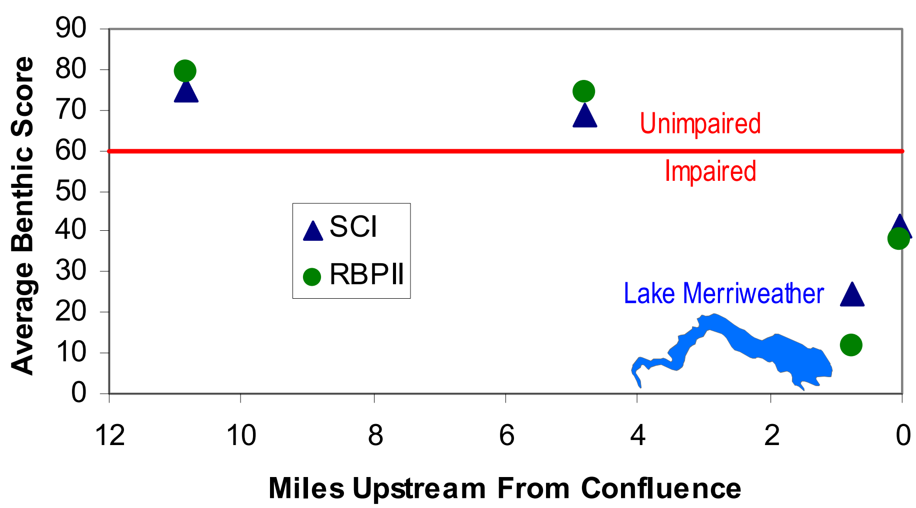

Figure 4-2. Average Benthic Assessment Scores for Little Calfpasture River Stations.

Figure 4-3 shows how benthic scores have varied over the past 12 years. Only one benthic sample was collected from station 2-LCF010.83 (in 1996), but 9 to 15 samples were collected from the other three stations. Benthic scores above Lake Merriweather (at

2-LCF004.80) have been consistently good, with all scores falling above the impairment threshold. At station 2-LCF000.76, directly below Goshen Dam, benthic scores have been consistently well below the impairment threshold, varying between 16 and 28. Further downstream, at station 2-LCF000.02, benthic scores have been much more variable, ranging from 19 to an unimpaired 61.

The historic time series of benthic monitoring shows that directly below Lake Merriweather (at Station 2-LCF000.76), conditions are consistently very poor and not likely to improve regardless of operational practices at the dam. At the mouth of the Little Calfpasture River, however, historic benthic monitoring shows that attainment of the aquatic life standard is possible. The SCI score in Fall 2001 was in the unimpaired range. This was during a time period when the dam was being operated in accordance with the DEQ Consent Order and significant lake lowerings had not been conducted for a period of 24 months prior to the benthic sample. This aquatic life score and others close to the unimpaired range in Spring 2002 and Fall 2005 show that attainment of the aquatic life standard is possible at the mouth of the Little Calfpasture River.

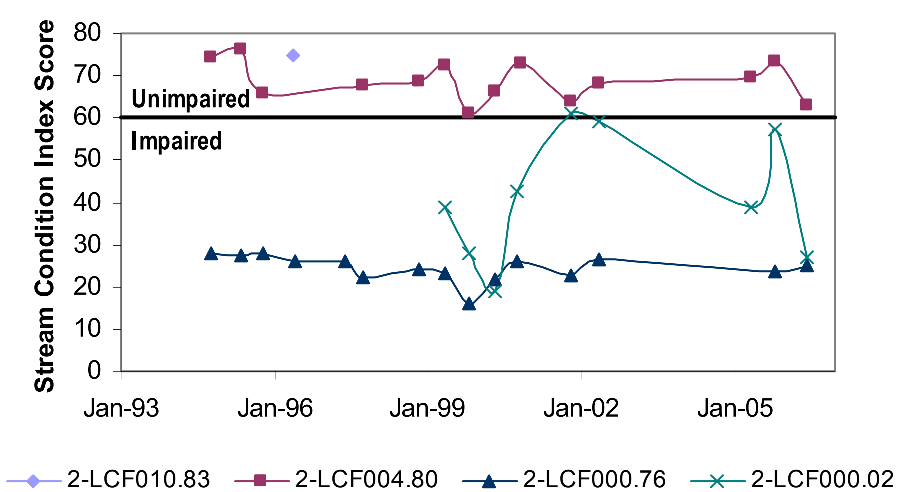

Figure 4-3. Stream Condition Index Scores Over Time in the Little Calfpasture River.

The Stream Condition Index is a multimetric index derived from a series of individual metrics of benthic community health. The individual metric scores were examined to elucidate any patterns or causes for overall low SCI scores at the downstream stations. Figure 4-4 shows the average scores for individual SCI metrics. The decreased SCI scores at downstream stations were not due to a single or few poor individual metric scores. All metric scores were lower below Lake Merriweather than at the upstream station (2-LCF004.80).

The total number of taxa decreased from an average of 16.4 at the upstream station (2-LCF004.80) to 6.5 just below the dam (2-LCF000.76) and 11.0 further downstream (2-LCF000.02). The number of Ephemeroptera, Plecoptera, and Trichoptera taxa also decreased from an average of 8.4 at the upstream station to 1.3 just below the dam and 4.2 further downstream. With the exception of Hydropsychidae, only one other Trichoptera taxa, no Plecoptera taxa, and three Ephemeroptera taxa have been found at station 2-LCF000.76. Ephemeroptera accounted for 24.9% of the population at the upstream station and only 0.26% below the dam. The percentage of Ephemeroptera was much better further downstream with 20.1%. The percentage of Plecoptera and Trichoptera (minus Hydropsychidae) was 16.0% upstream, 0.75% just below the dam, and 3.7% further downstream. While Ephemeroptera, Plecoptera, and Trichoptera accounted for a smaller percentage of the population at downstream impaired sites, Chironomidae, which are typically less sensitive and burrow in sediments, accounted for a much higher percentage. Chironomidae represented only 6.4% of the population upstream of Lake Merriweather, 23.7% below the dam, and 31.3% further downstream. As the community structure downstream of the dam changed, the population was more dominated by fewer species. The percentage of the population represented by the two most abundant species was 51.1% at the upstream station, and increased to 82.5% below the dam and 75.4% further downstream. Lastly, functional feeding groups also changed at the downstream impaired stations. The percent scrapers fell from 35.6% at the upstream station to 0.39% below the dam and 19.8% further downstream.

Figure 4-5 compares the difference in individual metrics between the upstream station and each of the impaired downstream stations. As previously discussed, all metric scores were decreased at the downstream stations, with scores typically worst just below the dam. The individual metrics that decreased the most from upstream to just below the dam were the EPT score and the % scraper score. The individual metrics that decreased the most from upstream to the most downstream station were the EPT score and the % Plecoptera and Trichoptera (minus Hydropsychidae) score.

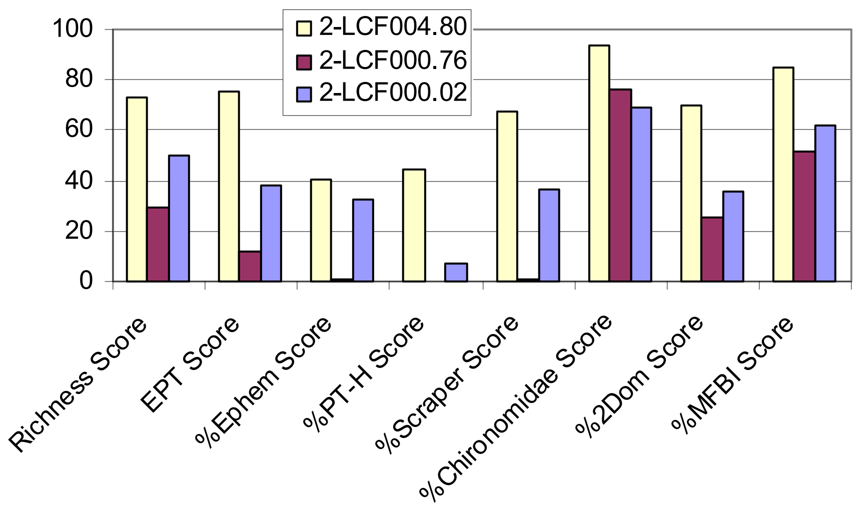

Figure 4-4. Average Scores for Individual Benthic Metrics in the Little Calfpasture River.

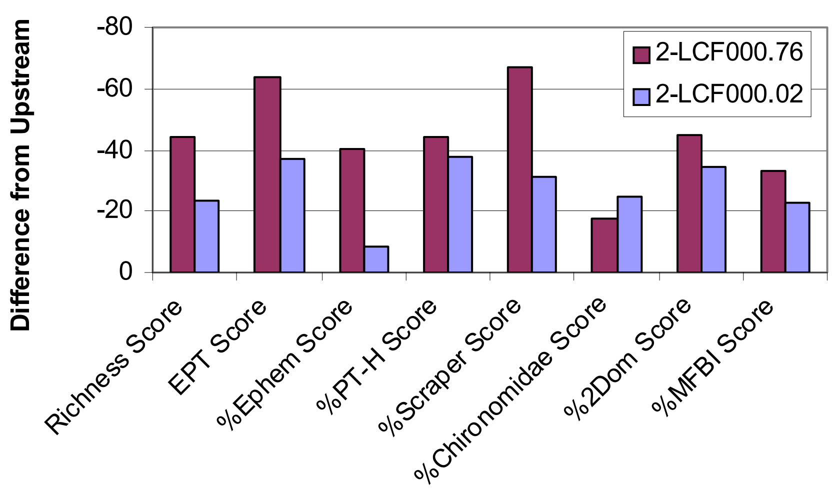

Figure 4-5. Difference in Individual Benthic Metric Scores Between Little Calfpasture River Stations Upstream and Downstream of Lake Merriweather.

Individual metrics showed that diversity (e.g., richness), taxonomic community structure (e.g., %2 dominant), and community function (e.g., % scrapers) were all altered at downstream impaired stations. To further investigate the changes in community structure and function, the benthic assemblages at each station were plotted according to taxonomic group (Figure 4-6) and functional feeding group (Figure 4-7). At the upstream station (2-LCF004.80), the community structure was relatively diverse and evenly distributed. Diptera, Hydropsychidae, Ephemeroptera, Trichoptera (minus Hydropsychidae), and Coleoptera each accounted for approximately 10 to 25% of the population. Downstream of the dam (at station 2-LCF000.76) the more sensitive taxonomic groups of Ephemeroptera, Plecoptera, Trichoptera (minus Hydropsychidae), and Coleoptera were all virtually eliminated. These organisms were replaced by an increasing percentage of Diptera (primarily Chironomidae) and the appearance of flatworms. Further downstream (at station 2-LCF000.02) Ephemeroptera and a few Trichoptera (minus Hydropsychidae) reappeared. Corbicula clams, which were not present in appreciable numbers at other sites, also appeared at the most downstream station.

Changes in functional feeding groups among the stations (Figure 4-7) mainly consisted of a loss of scrapers at the downstream impaired stations. These scrapers were replaced by an increase in filterers and collectors. This change in functional feeding groups reflects a change in the type of organic carbon or food available at each station. The lake acts as a sink for leaf litter and large woody debris, but produces more soluble and suspended organic matter (such as planktonic algae). Downstream from the lake this abundance of suspended organic matter creates a wider niche for filter feeders. While the lake produces an abundance of free floating algae, the depth of the lake limits the production of attached algal species. For this reason, there is little transport of attached algal species to recolonize rock substrates downstream. Downstream periphyton could also be smothered by sediment released from the dam. This lack of downstream periphyton transport and sediment loading could reduce the population of scrapers below the dam.

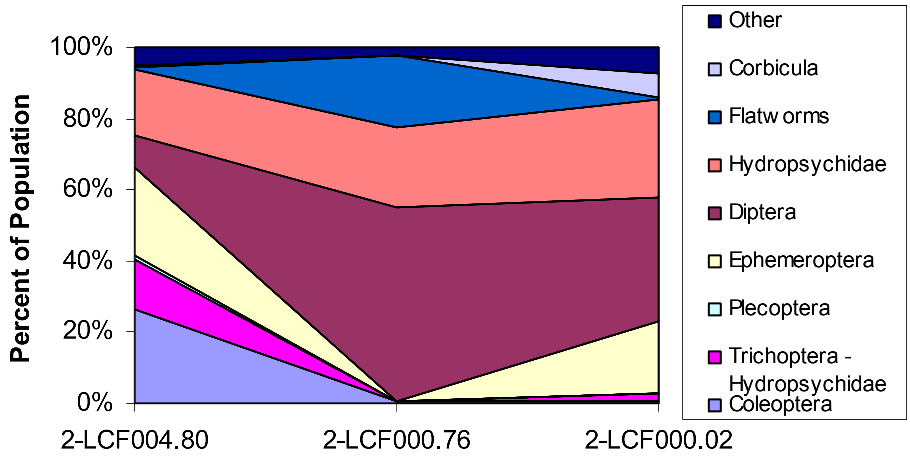

Figure 4-6. Taxonomic Community Structure in the Little Calfpasture River.

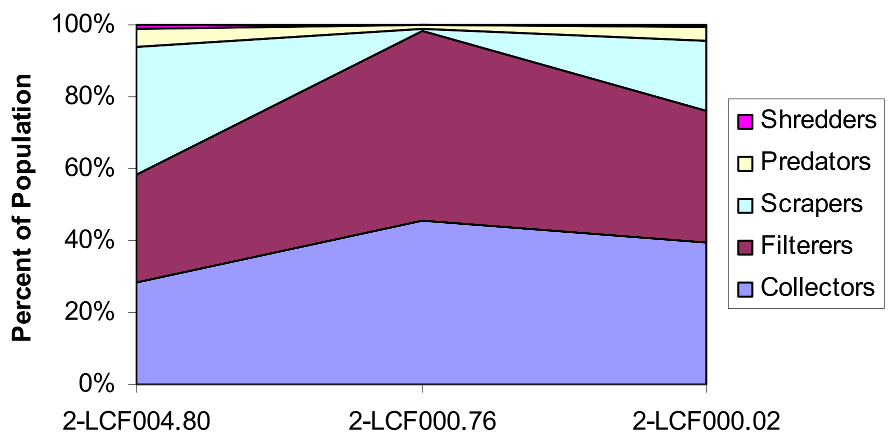

Figure 4-7. Functional Feeding Groups in the Little Calfpasture River.

4.2.2. Habitat Assessments

As part of the Rapid Bioassessment Protocol, a visual habitat assessment is performed at the time of each sample collection. This assessment entails scoring each of a series of habitat components from 0 to 20. These habitat components include channel alteration, bank stability, bank vegetation, embeddedness, flow, riffles, riparian vegetation, sediment, substrate, and velocity. The individual scores for each of these measures are then added for a total habitat score. Figure 4-8 compares the total habitat scores at each station over the time period of benthic assessments. Total habitat scores averaged 128.6 at station 2-LCF004.80, 115.7 at station 2-LCF000.76, and 148.1 at station 2-LCF000.02. Based on a statistical t-test assuming unequal variances, the total habitat scores at station 2-LCF000.76 were significantly lower than at the upstream station, and total habitat scores at station 2-LCF000.02 were significantly higher than at the upstream station. Since habitat at the impaired downstream station (2-LCF000.02) is rated higher than habitat at the unimpaired upstream station, overall habitat conditions should not be considered the cause of the impairment.

Individual habitat metrics are shown in Figure 4-9. Several habitat metrics (channel alteration, embeddedness, flow, sediment, substrate, and velocity) at station 2-LCF000.76 were significantly lower (t-test with unequal variances, alpha 0.05) than metrics at the upstream station (2-LCF004.80). No individual habitat metrics at station 2-LCF000.02 were significantly lower than at the upstream station. Only metrics for embeddedness, flow, and riffles were lower at 2-LCF000.02 than at 2-LCF004.80, and this difference was not statistically significant.

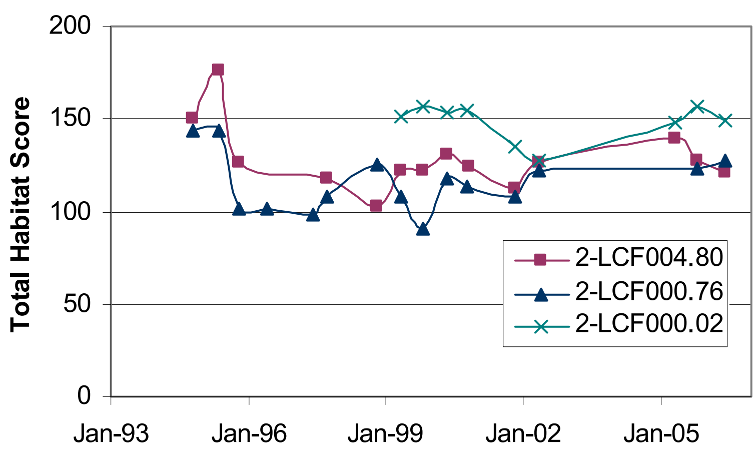

Figure 4-8. Total Habitat Scores for Little Calfpasture Benthic Stations.

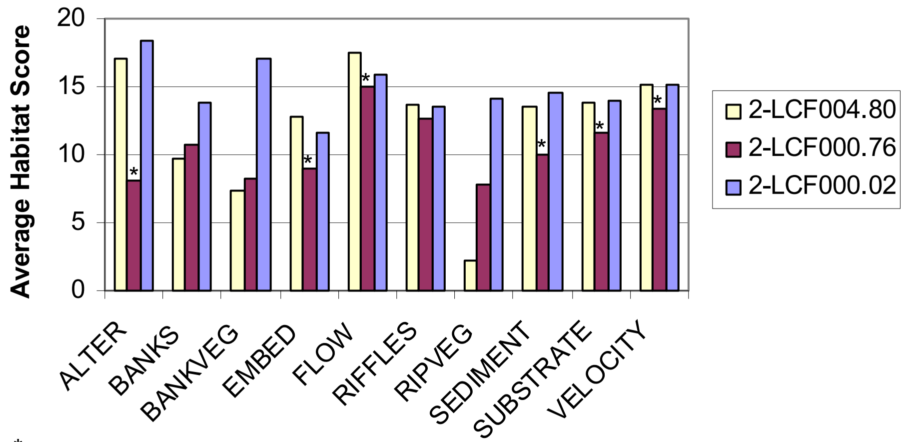

Figure 4-9. Individual Habitat Metric Scores for Little Calfpasture Benthic Stations.

4.2.3. Water Quality Data

Beginning in 2001, a suite of water quality parameters were measured both upstream of Lake Merriweather (at station 2-LCF007.00) and downstream of the lake at the impaired benthic station (2-LCF000.02). Water quality parameters were measured at approximately a bimonthly frequency. The following water quality parameters were measured: temperature, pH, dissolved oxygen, conductivity, total suspended solids, volatile solids, turbidity, ammonia, nitrite, nitrate, total orthophosphate, total organic carbon, total dissolved carbon, and chlorophyll-A.

4.2.3.1. Temperature

Measured temperatures in the Little Calfpasture River are shown in Figure 4-10. None of the measured temperatures exceeded the water quality standard of 31°C for mountainous zone waters. Temperatures below the lake were consistently higher than those upstream of the lake, particularly in the summer. Summer temperatures below the lake were as much as 5.2°C warmer than temperatures above the lake on the same day. The average temperature at 2-LCF000.02 was 16.5°C, while the average temperature at 2-LCF007.00 was 14.3°C. A paired t-test of samples collected on the same day at both sites (alpha 0.05) showed that the increase in temperature below the lake was statistically significant ($p<0.0001$).

This increase in temperature below the lake is typical for impoundments. The large surface area of the lake provides an opportunity for solar radiation to heat the water as it moves slowly through the lake due to the relatively long residence time. Thermal stratification of the lake during the summer also accentuates the downstream heating, since most of the lake overflow is from the warmer epilimnion.

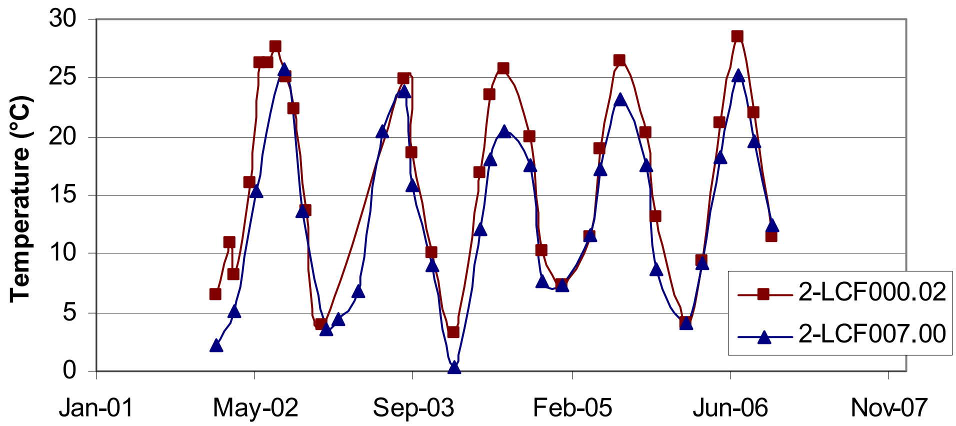

Figure 4-10. Temperature in the Little Calfpasture River.

4.2.3.2. pH

Measured pH in the Little Calfpasture River is shown in Figure 4-11. None of the measured pH values exceeded the water quality standard range of 6 to 9 for mountainous zone waters. pH values below the lake were slightly lower than those upstream of the lake. The average pH at 2-LCF000.02 was 7.75, while the average pH at 2-LCF007.00 was 7.97. A paired t-test of samples collected on the same day at both sites (alpha 0.05) showed that the decrease in pH below the lake was statistically significant ($p<0.01$). While this decrease in pH may be statistically significant, it may have little biological significance with respect to the benthic impairment. The change in pH is relatively small and measured pH ranges are well within the tolerance limits of benthic macroinvertebrates.

The cause of the small but statistically significant decrease in pH could be due to changes in water chemistry within the lake, or it could simply be an artifact of sampling times. On each sampling date, samples were collected from station 2-LCF000.02 before station 2-LCF007.00. Because of the daily pattern of surface water pH, which rises throughout the daylight hours, earlier collected samples would systematically be lower in pH. This diurnal pattern in pH is due to photosynthesizing algae consuming CO_2 during the day. Because CO_2 is slightly acidic, its removal from the water column increases pH during the daylight hours. At nighttime when photosynthesis ceases, respiration exceeds photosynthesis, and CO_2 is produced by aquatic life, lowering the pH. Samples from station 2-LCF000.02 were on average collected about an hour and a half prior to samples from station 2-LCF007.00. This difference could explain the lower pH values at station 2-LCF000.02.

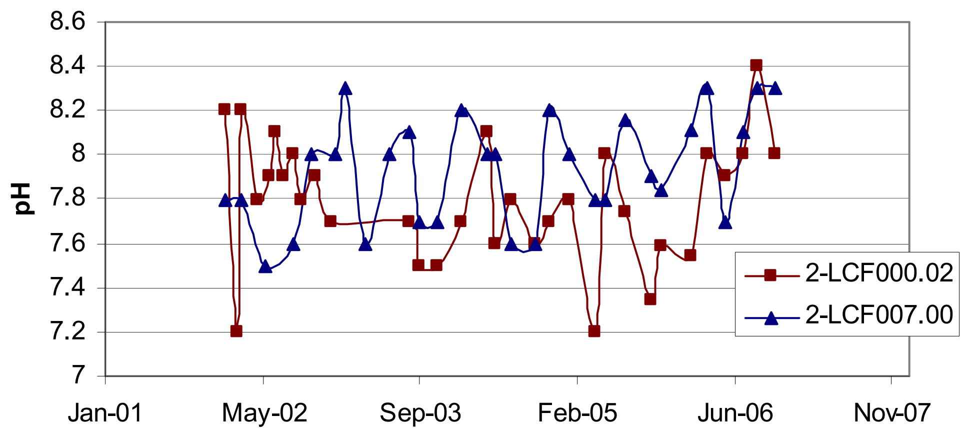

Figure 4-11. pH in the Little Calfpasture River.

4.2.3.3. Dissolved Oxygen

Periodically measured dissolved oxygen levels in the Little Calfpasture River are shown in Figure 4-12. None of these periodically measured dissolved oxygen levels violated the water quality standard of 5.0 mg/L daily average or 4.0 mg/L minimum for mountainous zone waters, but these periodic measurements were all measured during daylight hours when dissolved oxygen is typically highest. Periodically measured dissolved oxygen levels downstream of the lake were consistently lower than those upstream of the lake. Dissolved oxygen levels averaged 0.99 mg/L lower at station 2-LCF000.02 than at station 2-LCF007.00, but dissolved oxygen was as much as 3.23 mg/L lower on individual days. As a percentage of upstream dissolved oxygen levels, station 2-LCF000.02 average 9.15% lower and was as much as 34% lower on individual days. A paired t-test of samples collected on the same day at both sites (alpha 0.05) showed that the decrease in dissolved oxygen below the lake was statistically significant ($p<0.001$).

As was the case for pH, it is possible that a portion of the decrease in dissolved oxygen between the two stations could be due to the timing of sample collection at the two stations. Samples were collected an average of 1.39 hours earlier at station 2-LCF000.02 than at station 2-LCF007.00. The diurnal pattern of dissolved oxygen increasing through the morning and midday hours would result in slightly lower dissolved oxygen levels at earlier sample collection times. This artifact of sampling times, however, cannot account for the entire difference in dissolved oxygen levels between the two stations. Based on diurnal dissolved oxygen monitoring, the average rate of increase in dissolved oxygen through the morning and midday hours is 0.27 mg/L/hr. With an average of only 1.39 hours between measurements at the two stations, the dissolved oxygen would only be predicted to increase an average of 0.38 mg/L. This difference is only 38% of the observed difference in dissolved oxygen between the two stations, so sample times cannot account for the observed decrease in dissolved oxygen from above the lake to below the lake. This decrease is likely due to the lake and the outlet structure. The quiescent conditions in a lake typically mean less reaeration compared to a flowing stream. Also, if the outlet structure of the dam allows water from the oxygen-poor hypolimnion of the lake to be discharged, this will greatly decrease downstream dissolved oxygen levels.

In addition to periodically measured dissolved oxygen levels, VADEQ measured diurnal (round the clock) dissolved oxygen patterns at 5-10 minute intervals throughout the course of several days in August of 2005, 2006, and 2007 at station LCF000.02 (just above the confluence with the Maury). These diurnal dissolved oxygen patterns are important because dissolved oxygen levels are typically lower at night when algae are unable to photosynthesize and produce oxygen. The late summer was selected for diurnal monitoring because the high temperatures, high algal production, and low water flow produce the most critical conditions for dissolved oxygen levels. In 2005, dissolved oxygen was measured for a 4-day period from 8/1/05 to 8/5/05. Dissolved oxygen during this time period averaged 6.31 mg/L and ranged from 5.50 to 7.89 mg/L (Figure 4-13). Daily dissolved oxygen peaks were observed at approximately 3:00 pm, and daily lows were observed at approximately midnight. This pattern is typical of natural rivers and reflects oxygen input from photosynthesis during daylight hours and respiration at night. During this 4-day period in 2005, dissolved oxygen levels did not violate daily average or minimum instantaneous water quality standards.

Diurnal dissolved oxygen was again measured at station LCF000.02 in the summer of 2006 for a 3-day period from 8/28/06 to 8/30/06. This monitoring period began at the end of a relatively dry period. Based on rainfall data recorded in Goshen, Virginia, there had only been 0.64 inches of rain in the past 37 days. While flow in the Little Calfpasture River is not gaged, it is likely that flow during this time period was low. In the nearby Calfpasture River, which is gaged, flows during this period were in the lower 5th percentile of historic flows. During most of this diurnal monitoring period, dissolved oxygen levels were very low (Figure 4-14). For approximately two days, dissolved oxygen levels did not reach above 5 mg/L. During this time period, both daily average and minimum instantaneous water quality standards for dissolved oxygen were violated. A total of 407 individual measurements violated the instantaneous water quality standard of 4 mg/L, and dissolved oxygen levels were as low as 3.12 mg/L. Daily averages also violated the water quality standard, averaging 4.2, 3.9, and 4.3 mg/L during the three days, respectively. These low dissolved oxygen levels for several days could result in a loss of benthic macroinvertebrates with low tolerance for dissolved oxygen excursions. If these conditions are experienced periodically, this could explain persistent impairment of the benthic community.

Because of the very dry conditions during this monitoring period, it is likely that levels in Lake Merriweather were low and little flow may have been coming over the spillway. If the large majority of water from the lake was coming from the hypolimnion through the control structure, this could explain the low dissolved oxygen levels downstream. The dam is designed to pass the majority of water over the spillway, but screens in the control structure allow subsurface water to pass through the dam. These screens include a low level outlet at a depth of 21 feet and a mid level outlet at a depth of 10.5 feet. According to the dam operator, only the mid level screen was open during this time period.

The diurnal monitoring period was intended to last for 4 days, but was cut short due to the approaching remnants of Tropical Storm Ernesto and the threat of flash flooding. The in situ monitoring device was removed just after 2 days of monitoring to avoid loss or damage to equipment. Just prior to removal of the monitoring device, a curious pattern in dissolved oxygen was observed. At approximately 2:45 pm on 8/30/06, the dissolved oxygen rapidly rose from 3.31 mg/L to nearly 7 mg/L within 10 minutes. This increase in dissolved oxygen over such a short interval is too large to be due to natural causes, particularly since the approaching storm had not yet reached the area (rainfall was not recorded at the Goshen precipitation gage until 8/31/06). It is likely that this dramatic change in water quality was due to a large release of water from Lake Merriweather. Because of the threat of potential flooding from the approaching tropical storm remnants, the lake was probably lowered in anticipation of the storm to provide flood control. This release would be water from the more oxygenated epilimnion through the dam gates. If water was being discharged from the hypolimnion through the control structure prior to lowering the flood gates, this lowering would result in a large and quick increase in dissolved oxygen downstream. Records of dam operations from the Boy Scouts do not confirm this explanation of events. No gate lowering activities were recorded on 8/30/06, however, dam operation records are sparse and no information at all was recorded from 3/15/06 to 9/5/06. In addition, downstream flows in the Maury River at Rockbridge Baths strongly suggest a dam lowering on 8/30/06 (Figure 4-15). The quick vertical increase in flow without a defined peak suggests a dam lowering event rather than a natural rise in flow from a storm event. Around the time that dissolved oxygen levels increased in the Little Calfpasture River, the Maury River flow gage recorded a 306 cfs increase in flow over a 2 hour period. During this same 2 hour period, the Calfpasture River gage showed only a 0.8 cfs increase in flow, meaning that virtually all of the increased flow was from the Little Calfpasture River.

To confirm low summer oxygen levels at station LCF000.02, VADEQ again conducted diurnal dissolved oxygen monitoring for a 5-day period in late August, 2007. Monitoring equipment was deployed at station 2-LCF000.02 from 8/22/07 through 8/27/07, however, the dissolved oxygen probe fouled on 8/24/07 and reliable data were only obtained for 3 days. During this 3-day period, dissolved oxygen levels did not violate the instantaneous water quality standard of 4 mg/L (Figure 4-16). The daily average criterion, however, was violated on each of the three days. Dissolved oxygen averaged 4.8, 4.8, and 4.6 mg/L on the 3 days, respectively.

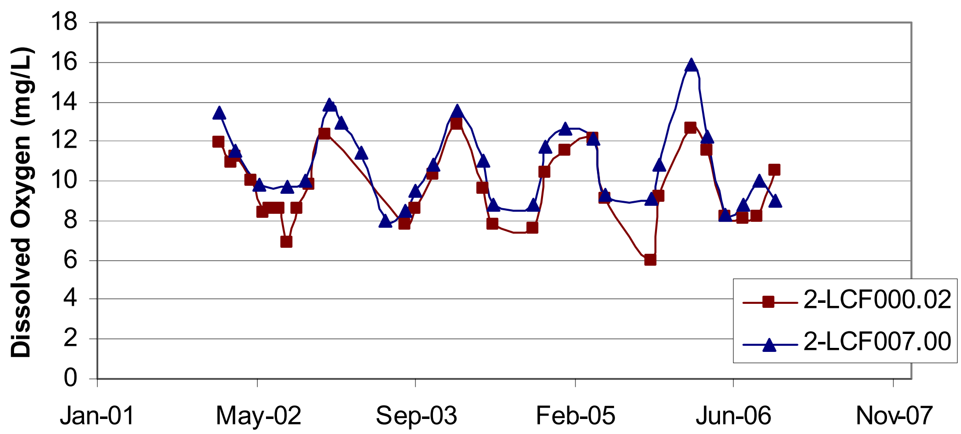

Figure 4-12. Dissolved Oxygen in the Little Calfpasture River.

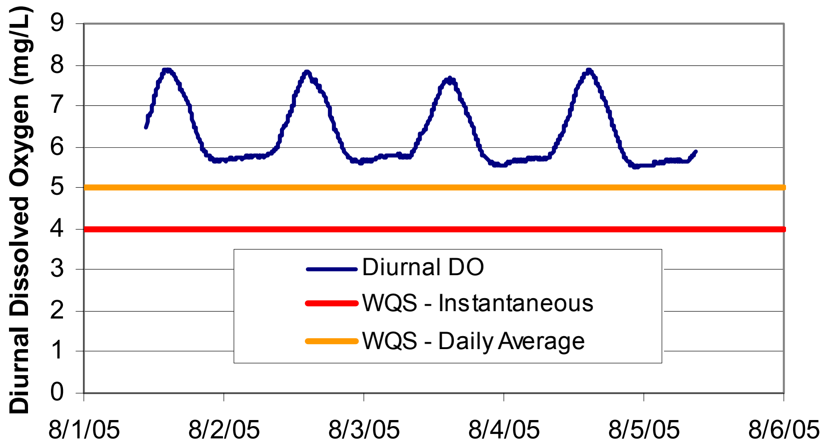

Figure 4-13. Diurnal Dissolved Oxygen Pattern in the Little Calfpasture River in August 2005.

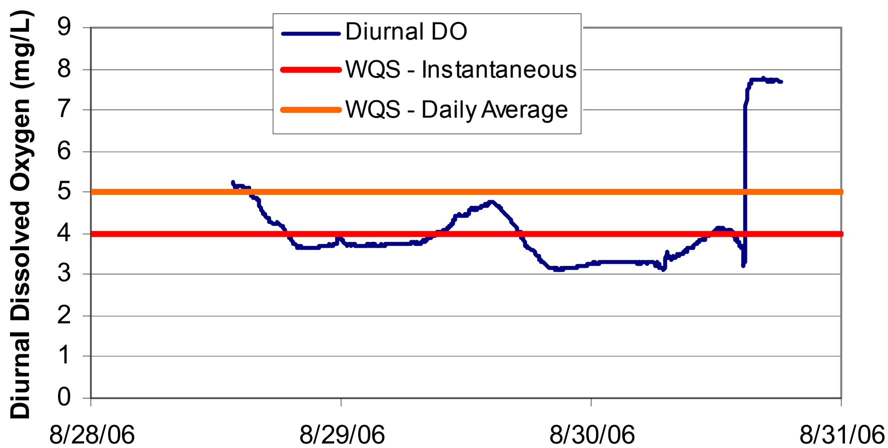

Figure 4-14. Diurnal Dissolved Oxygen Pattern in the Little Calfpasture River in August 2006.

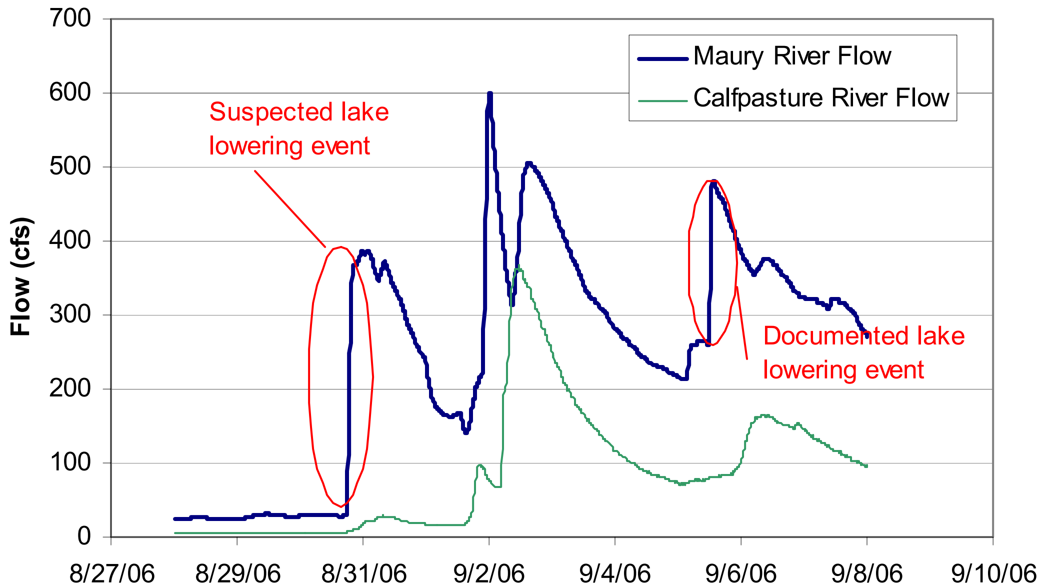

Figure 4-15. Flow in Maury River at Rockbridge Baths During Diurnal DO Study.

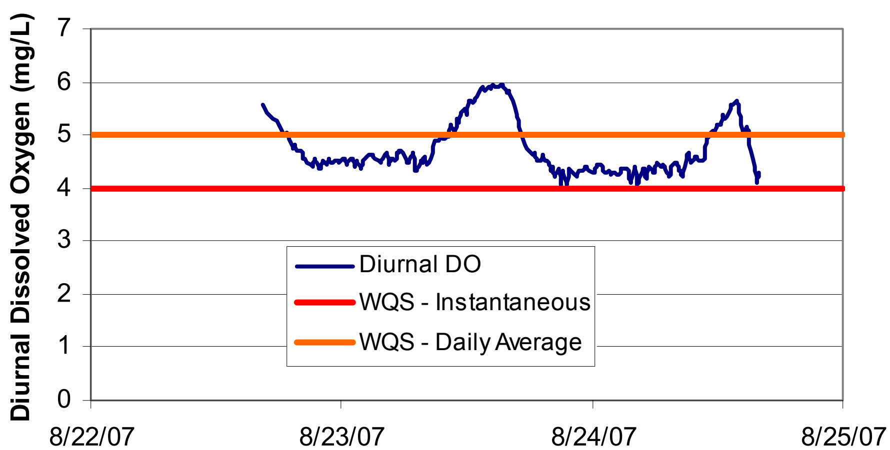

Figure 4-16. Diurnal Dissolved Oxygen Pattern in the Little Calfpasture River in August 2007.

To investigate the causes of low dissolved oxygen levels below Lake Merriweather, VADEQ conducted lake monitoring and lake discharge monitoring in the fall of 2007. VADEQ monitored the depth profile of oxygen in Lake Merriweather on 8/22/07 and 9/4/07. At these times, late in the summer, thermal stratification of the lake should be well developed. Both of these times also represented very low flow conditions. On

8/22/07, no water was flowing over the top of the dam, and on 9/4/07 only a minimal flow of water was coming over 3 of the gates.

On both dates, Lake Merriweather exhibited thermal stratification. Stratification is when warmer water at the surface does not mix with cooler water deeper in the lake. Within the top 10 feet of the lake, temperatures were relatively consistent, varying by less than 1.5°C (Figure 4-17). This indicates that the upper 10 feet of water is relatively well mixed. Below 10 feet, temperatures decreased more sharply, indicating transition from the upper, well-mixed epilimnion to the poorly-mixed hypolimnion. This region of transition is called the thermocline. Compared to other lakes, the thermocline in Lake Merriweather is relatively shallow (at 10 ft) and not as well defined. The total change in temperature from top to bottom in the lake is only 8.9°C. This suggests that the depth of the thermocline in Lake Merriweather may be relatively flexible and variable.

While the temperature profile showed a rather gradual transition below the thermocline, the dissolved oxygen profile showed a very distinct boundary between the upper well-oxygenated epilimnion and the lower poorly-oxygenated hypolimnion (Figure 4-18). Dissolved oxygen in the upper 10 feet of the lake averaged 7.4 mg/L, while dissolved oxygen below 11 feet averaged only 0.3 mg/L. This dissolved oxygen profile shows a very distinct transition between 10 and 11 feet of depth where water goes from healthy levels of dissolved oxygen to virtually no oxygen.

While the lake profile measurements were being made, measurements of the location of the cold water discharge pipes were also made. These pipes (as indicated on Figure 4-18) are located at approximately 10.5 and 21 feet in depth. This places the upper cold water discharge directly in the transition area between high and low dissolved oxygen. As the thermocline fluctuates (even slightly), the upper cold water discharge could be pulling well-oxygenated or poorly-oxygenated water from the lake, depending on the exact position of the thermocline. This could explain the periods of low dissolved oxygen downstream during dry conditions when little water is coming over the top of the spillway.

The lower cold water discharge was located firmly within the hypolimnion of the lake, and would be expected to discharge very low oxygen water from the lake throughout the period of stratification. In fact, depth measurements show that sediment has filled in the deeper portions of the lake, such that the lower cold water discharge is now sitting on the bottom of the lake. This is confirmed by the very high concentration of suspended solids (206 mg/L) in the discharge from the lower cold water release.

On 9/4/07 VADEQ also measured water quality parameters in the discharge from the two cold water releases (both separately and combined). These data are shown in Table 4-2. At the time of sampling on 9/4/07, it appears that the upper cold water discharge was drawing water from just above the thermocline, because dissolved oxygen levels in this discharge were representative of the lake's epilimnion. Due to the position of this intake, however, slight fluctuations in the thermocline could cause the upper cold water discharge to release very low dissolved oxygen water. When this occurs, the dissolved oxygen level in the upper cold water discharge would be expected to produce results similar to that observed in the lower cold water discharge. Measurements from the lower cold water release show that water exiting this discharge has a dissolved oxygen level of about 4.4 mg/L. This is higher than would be expected from the dissolved oxygen levels measured in the lake's hypolimnion (0.3 mg/L), but is likely due to limited re-aeration of the water as it flows through the discharge structure.

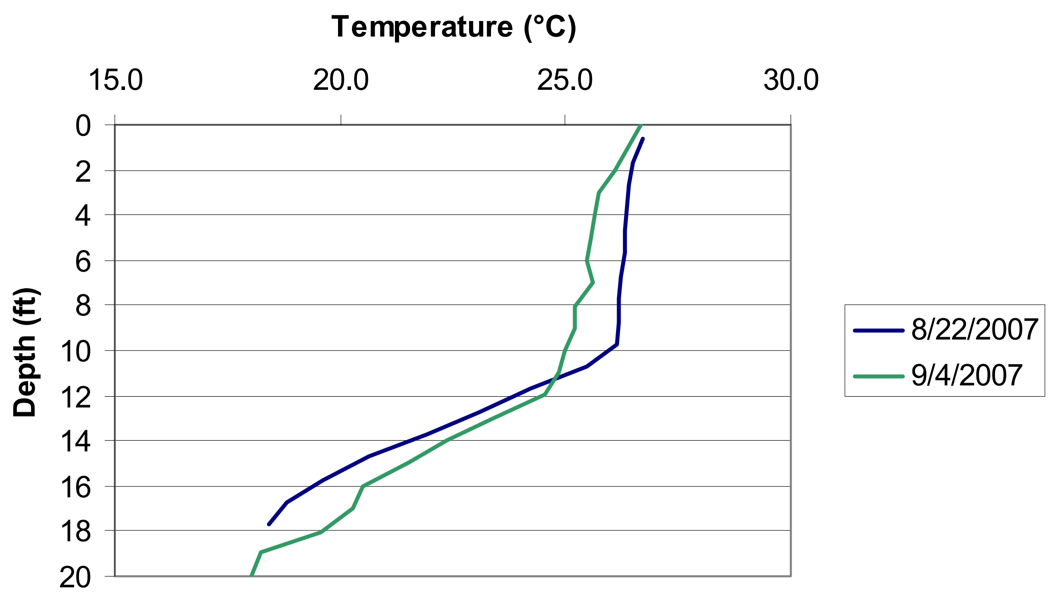

Figure 4-17. Temperature Profile With Depth in Lake Merriweather.

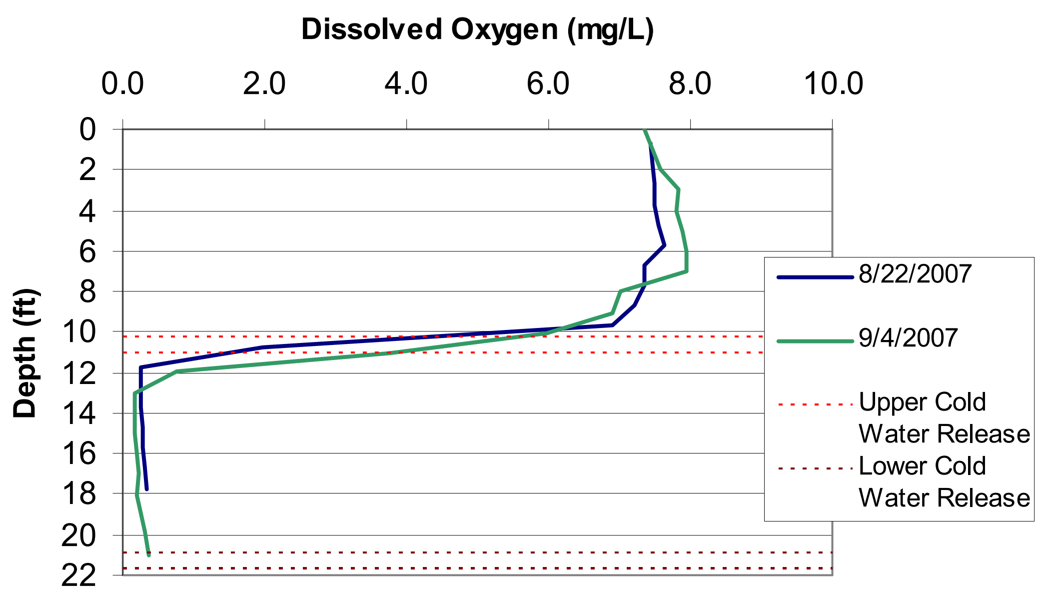

Figure 4-18. Dissolved Oxygen Profile With Depth in Lake Merriweather.

Table 4-2. Water Chemistry of Cold Water Discharges.

	Temp (°C)	DO (mg/L)	pH	TSS (mg/L)	Turbidity (NTU)
Upper Cold Water Discharge	25.4	7.8	8.1	7	9.2
Lower Cold Water Discharge	19.4	4.4	7.0	206	284
Both Cold Water Discharges	24.3	7.4	7.4	39	54

4.2.3.4. Conductivity

Conductivity in the Little Calfpasture River is shown in Figure 4-19. Conductivity averaged 133 umohs/cm at station 2-LCF000.02 and 157 umhos/cm at station 2-LCF007.00. A paired t-test of samples collected on the same day at both sites (alpha 0.05) showed that the difference in conductivity between the two sites was statistically significant ($p<0.01$). While there is a statistically significant difference in conductivity levels above and below the lake, this difference is not likely to be significant biologically. All measured conductivity levels are well within the range of typical surface waters in the Valley and Ridge ecoregion.

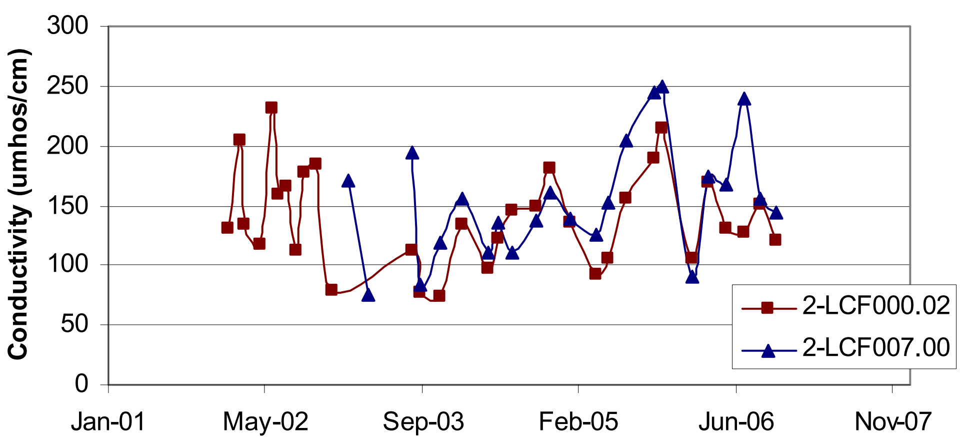

Figure 4-19. Conductivity in the Little Calfpasture River.

4.2.3.5. Solids

Total suspended solids (TSS) and turbidity were measured in the Little Calfpasture River upstream and downstream of Lake Merriweather (Figure 4-20 and Figure 4-21). The highest TSS and turbidity values measured were at station 2-LCF007.00 on 9/28/04. This date corresponds to the passage of the remnants of Hurricane Jeanne through the area. With the exception of this flooding event, the next 5 highest TSS and turbidity measurements were at the downstream station (2-LCF000.02). Overall, TSS and turbidity averaged higher below the dam than above Lake Merriweather. TSS averaged 10.3 mg/L at station 2-LCF000.02 and 8.5 mg/L at station 2-LCF007.00. Turbidity averaged 12.6 NTU at station 2-LCF000.02 and 6.0 NTU at station 2-LCF007.00. In addition to averaging higher, turbidity was higher below the lake than above the lake on 17 of the 21 monitoring dates. Because of the one extremely high solids measurement at the upstream station during Hurricane Jeanne, a paired t-test of samples collected on the same day at both sites (alpha 0.05) did not distinguish a statistically significant difference in TSS or turbidity above and below the lake. If the sampling date during Hurricane Jeanne is discarded as not representative, however, the increase in TSS and turbidity below the lake is determined to be statistically significant ($p<0.01$).

It is uncommon for lakes to act as sources of suspended sediment. Impoundments typically trap incoming sediments by allowing particles to settle to the bottom under quiescent conditions. Consistently higher solids and turbidity measurements downstream suggests one or more of the following conditions:

- Flows from the dam are sufficient to create increased erosion downstream
- Water from the bottom of the lake, which contains entrained sediments, is released through the dam
- Algal productivity within the lake increases the organic solids loading from the lake
- Dam operation and maintenance results in significant erosion of the lake shoreline

- Flow velocities, wind action, and lake level fluctuations are sufficient to resuspend settled solids in the lake that has aged and partially filled with sediment.

In 1998, the Virginia Department of Game and Inland Fisheries conducted a 3-month turbidity study in the Little Calfpasture River to try to elucidate the cause of increased sedimentation downstream of Lake Merriweather (VADGIF, 2001). In this study, turbidity was measured on 11 occasions from March to May, 1998. Turbidity was measured above and below Lake Merriweather, as well as in the Maury River and the Calfpasture River. Figure 4-22 shows the measured turbidity above and below Lake Merriweather during this study. Turbidity levels were consistently higher below the lake than above it. Turbidity above the lake averaged 5.5 NTU, while turbidity below the lake averaged 14.9 NTU. A paired t-test of these data (alpha 0.05) showed that the increase in turbidity below the lake was statistically significant ($p<0.01$).

The other obvious trend in the data is the correlation with dam operations. During the majority of the turbidity study, Lake Merriweather was maintained below full pool at 22 ft. On March 15, 1998, the Lake was raised to the 26 ft full pool mark. All of the nine turbidity measurements taken while the lake was below full pool showed much higher turbidity downstream. Turbidity averaged 4 NTU upstream and 16 NTU downstream. This is a 4-fold increase in turbidity below the lake. After the lake was raised to full pool on March 15, 1998, turbidity measurements were lower below the lake. This demonstrates the significant impact of lake lowering on sediment transport downstream. It also supports the last two scenarios identified above: that lake lowering increases shoreline erosion, and lake lowering increases mixing within the lake to resuspend settled particles.

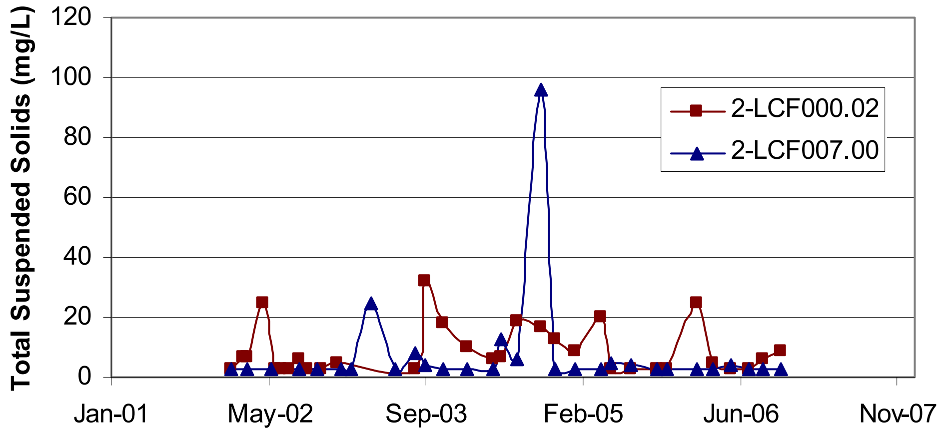

Figure 4-20. Total Suspended Solids in the Little Calfpasture River.

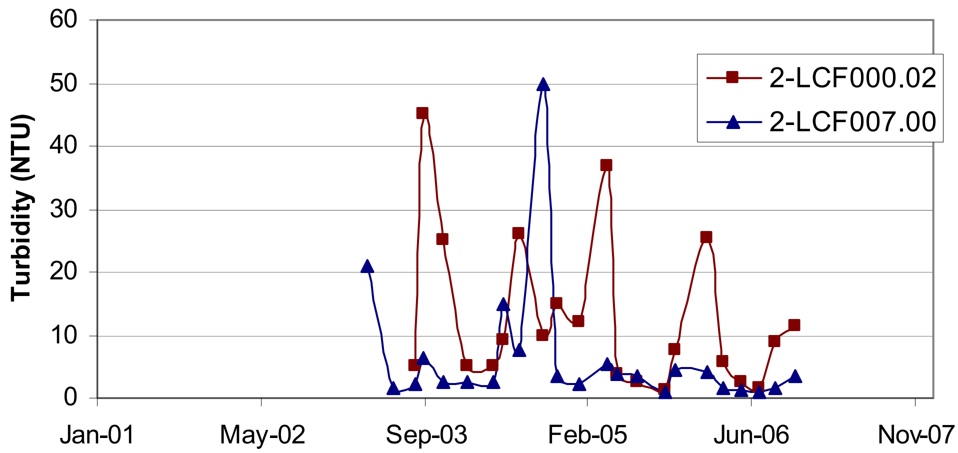

Figure 4-21. Turbidity in the Little Calfpasture River.

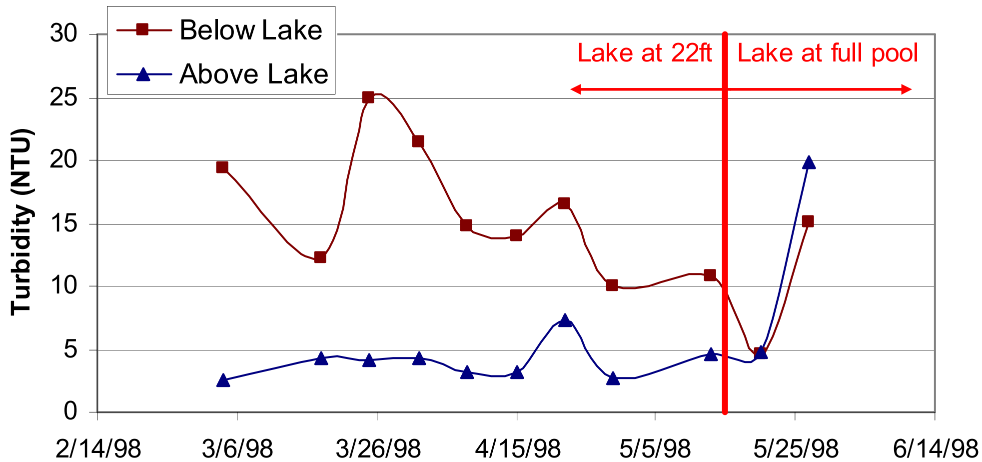

Figure 4-22. Results of VADGIF Turbidity Study on the Little Calfpasture River in 1998.

4.2.3.6. Organic Matter

Measures of total volatile solids, total organic carbon (TOC), dissolved organic carbon (DOC), and chlorophyll-A were made upstream and downstream of Lake Merriweather. Very few of the volatile suspended solids measurements were above the detection limit of 3 mg/L (Figure 4-23). As with total suspended solids, the highest volatile suspended solids measurement was associated with Hurricane Jeanne in September, 2004.

Fewer measurements of TOC, DOC, and chlorophyll-A were made than for other parameters. Despite the limited data set, significant differences were observed between stations above and below the lake. TOC and DOC were consistently higher below the lake. TOC averaged 2.72 mg/L below the lake at station 2-LCF000.02 and 2.07 mg/L above the lake at station 2-LCF007.00. DOC averaged 2.72 mg/L below the lake and 2.1 mg/L above the lake. Chlorophyll-A averaged 4.68 ug/L below the lake and 1.1 ug/L above the lake. A paired t-test of samples collected on the same day at both sites (alpha 0.05) showed that the differences in TOC and DOC between the two sites were statistically significant ($p<0.01$ for TOC $p<0.05$ for DOC). Differences in chlorophyll-A between the two sites were not statistically significant.

Increases in organic carbon downstream of an impoundment are typical. Lakes provide good conditions for primary productivity. Through photosynthesis, free floating algae fix carbon from CO_2 in the water into organic matter. This organic matter is transported downstream from the lake in the form of living algae or zooplankton or in the form of breakdown products from dead algae or zooplankton. Based on the concentrations of total and dissolved organic carbon, it appears that most of the organic carbon is dissolved. This organic matter provides a rich food source for downstream macroinvertebrates.

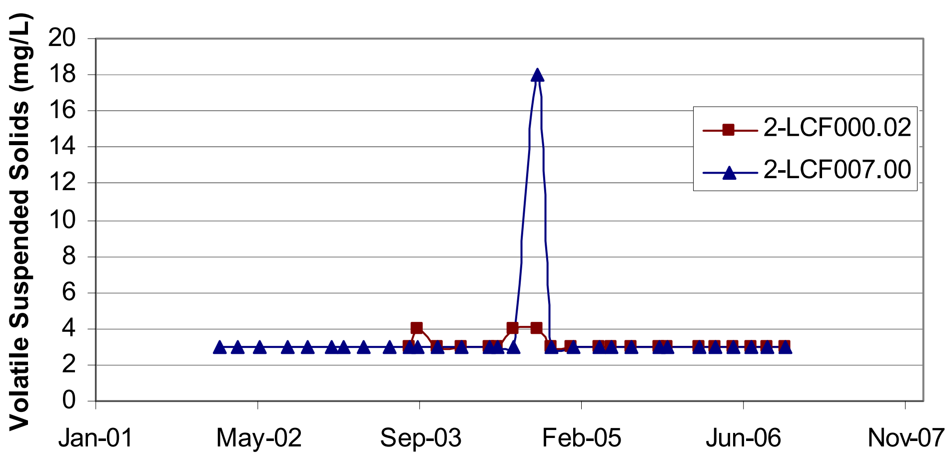

Figure 4-23. Volatile Suspended Solids in the Little Calfpasture River.

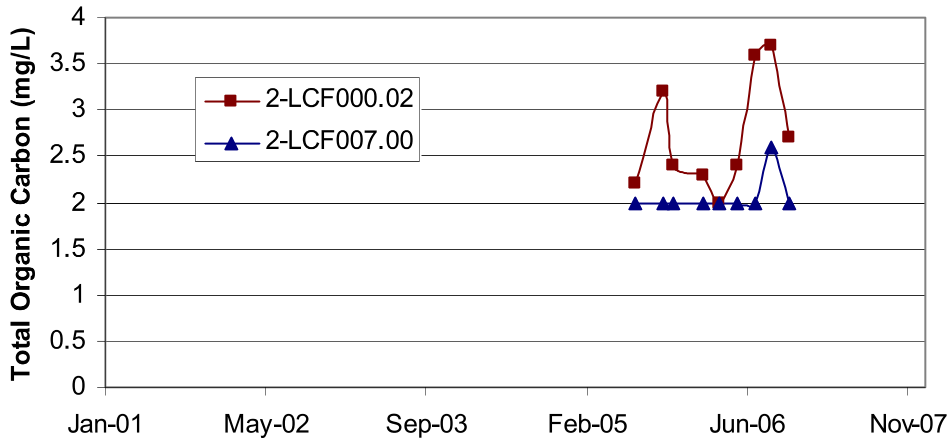

Figure 4-24. Total Organic Carbon in the Little Calfpasture River.

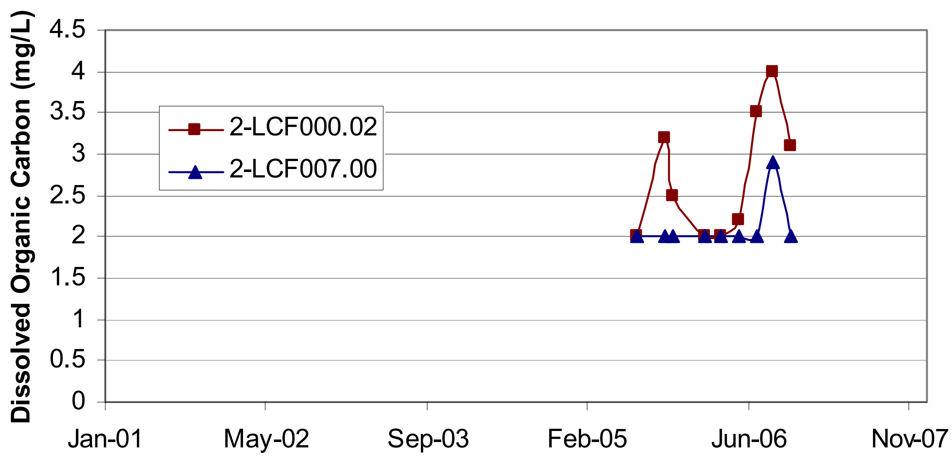

Figure 4-25. Dissolved Organic Carbon in the Little Calfpasture River.

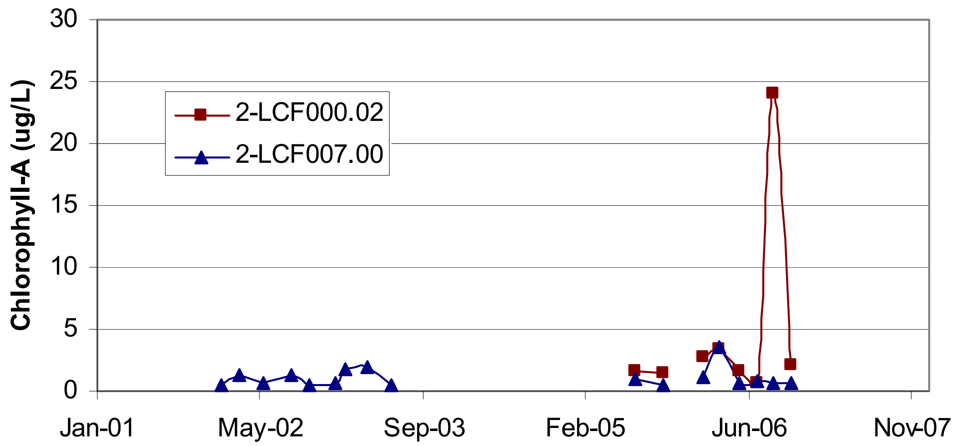

Figure 4-26. Chlorophyll-A in the Little Calfpasture River.

4.2.3.7. Nutrients

The following nutrient components were measured upstream and downstream of Lake Merriweather: ammonia, nitrite, nitrate, and total orthophosphate. There were several ammonia peaks downstream of the dam, while all upstream ammonia values were at the detection limit of 0.04 mg/L-N (Figure 4-27). Ammonia levels downstream of the dam were as high as 0.21 mg/L, but none of the values exceeded water quality standards for ammonia based on the pH and temperature at the time of each sample. Overall ammonia levels averaged 0.067 mg/L-N below the dam at station 2-LCF000.02 and <0.04 mg/L-N above the lake at station 2-LCF007.00. A paired t-test of samples collected on the same day at both sites (alpha 0.05) showed that the increase in ammonia below the lake was statistically significant ($p<0.05$).

In a typical lake, higher ammonia levels in the fall could be due to natural turnover of the lake. Nutrients that settle from the epilimnion into the oxygen-poor hypolimnion during the summer stratification accumulate in the least oxidized form (ammonia). When the thermal stratification of the lake breaks down in the fall, ammonia accumulated in the hypolimnion can mix throughout the entire lake and raise overall ammonia levels. Due to gate operations, however, Lake Merriweather probably does not exhibit natural fall turnover. Thermal stratification is probably prematurely destroyed when lake levels are lowered and mixing increases. In fact, all but one (7 out of 8) of the ammonia measurements above detection were measured at times when the lake was below full pool or had recently (within 6 days) been below full pool. When the lake is in the lowered position, mixing likely increases and ammonia accumulated at the bottom of the lake is introduced into the water column and transported downstream.

With the exception of two samples collected in October and November of 2005, all nitrite levels below the lake were at the detection level of 0.01 mg/L-N (Figure 4-28). All nitrite levels above the lake were at the detection level. The higher nitrite levels in October and November again were associated with lake lowering events.

Nitrate levels above and below the lake are shown in Figure 4-29. With the exception of the fall of 2005, nitrate levels below the lake were consistently lower than above the lake. The average nitrate level below the lake at station 2-LCF000.02 was 0.15 mg/L-N, and the average nitrate level above the lake at station 2-LCF007.00 was 0.20 mg/L-N. A paired t-test of samples collected on the same day at both sites (alpha 0.05) showed that the decrease in nitrate levels below the lake was statistically significant ($p<0.05$). This decrease in nitrate and nitrogen in general below the lake is typical. The lake acts as a sink for nutrients, as nutrients are lost to the bottom sediments.

By summing the ammonia, nitrite, and nitrate species, total inorganic nitrogen was calculated for each sample. Total inorganic nitrogen levels were comparable between the upstream and downstream stations (Figure 4-30), with levels slightly higher above the lake. The average inorganic nitrogen level below the lake was 0.23 mg/L-N, and the average level above the lake was 0.25 mg/L-N. A paired t-test of samples collected on the same day at both sites (alpha 0.05) showed that there was no significant difference in total inorganic nitrogen levels above and below the lake.

Like total inorganic nitrogen, total orthophosphate levels were not significantly different between the upstream and downstream locations. All total orthophosphate levels below the lake were at the detection limit of 0.02 mg/L-P, and all but one orthophosphate level above the lake were at the detection limit (Figure 4-31).

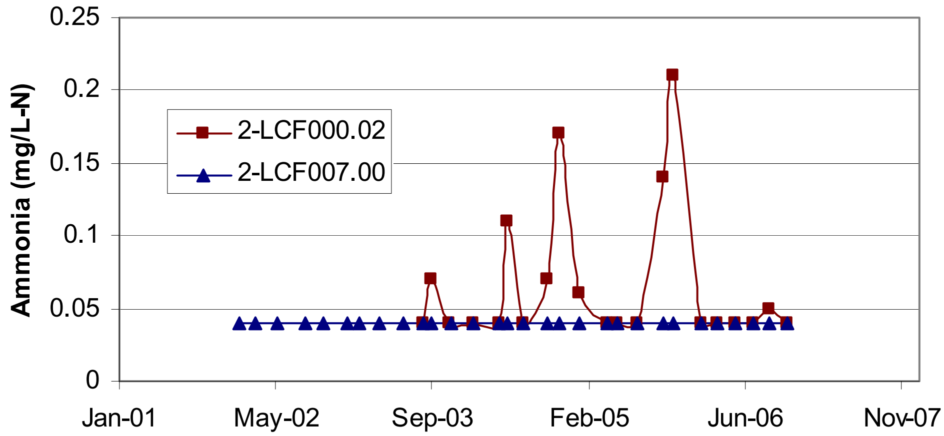

Figure 4-27. Ammonia in the Little Calfpasture River.

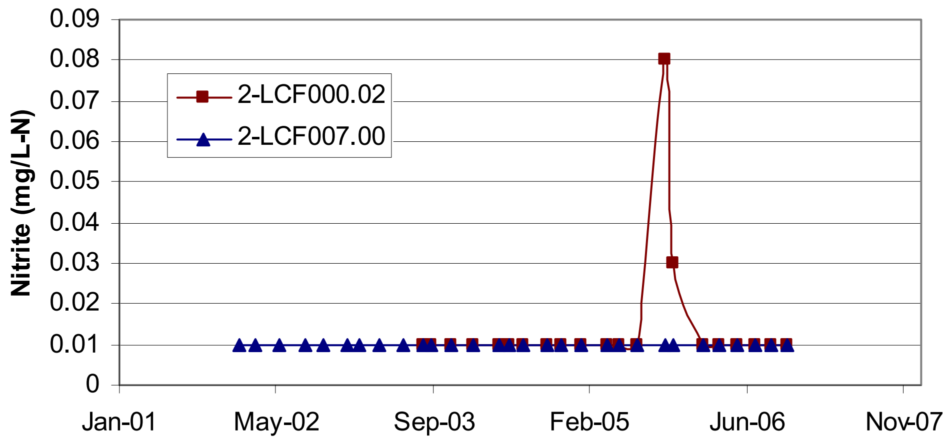

Figure 4-28. Nitrite in the Little Calfpasture River.

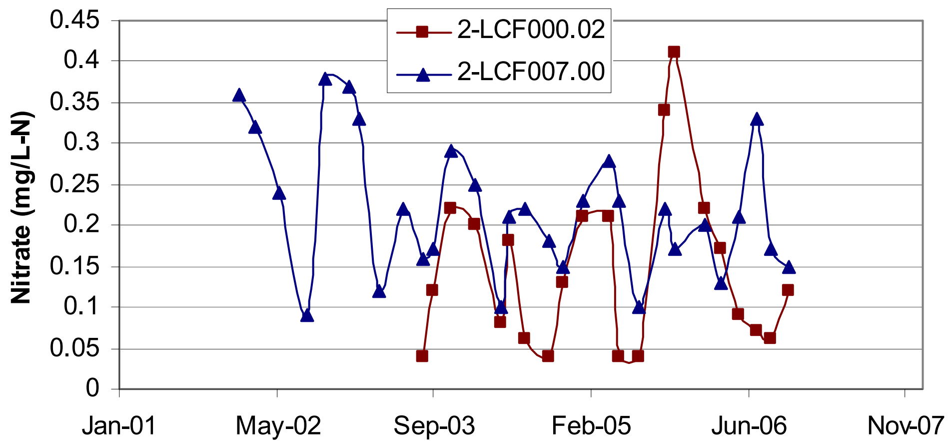

Figure 4-29. Nitrate in the Little Calfpasture River.

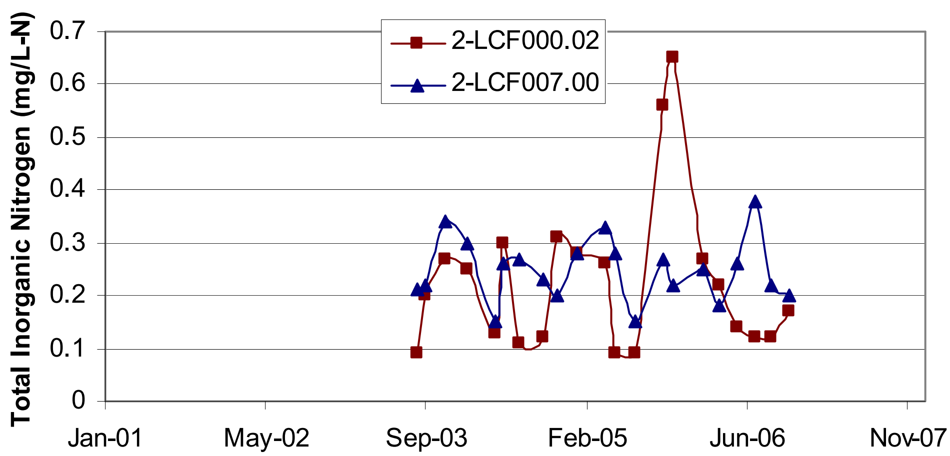

Figure 4-30. Total Inorganic Nitrogen in the Little Calfpasture River.

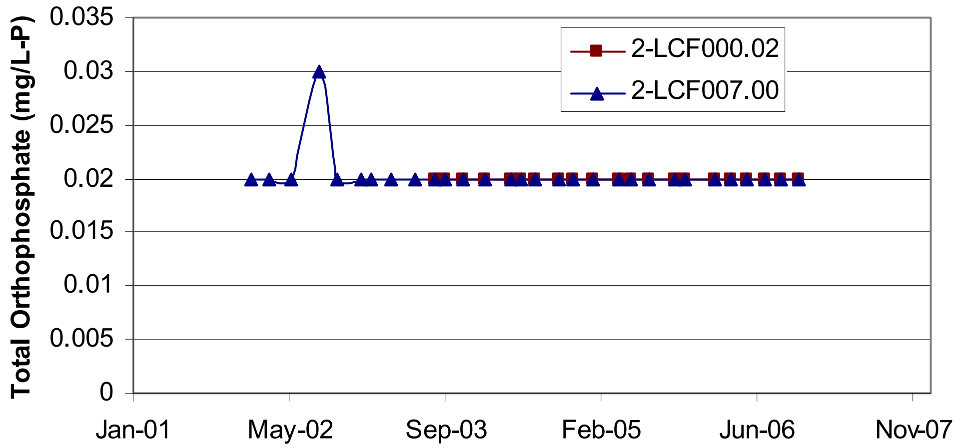

Figure 4-31. Total Orthophosphate in the Little Calfpasture River.

4.3. NON-STRESSORS

4.3.1. pH

While pH values were significantly lower below Lake Merriweather, all pH values were well within the tolerance ranges for benthic macroinvertebrates. pH is not believed to be a stressor on the benthic community that is responsible for the impairment.

4.3.2. Conductivity

As with pH values, conductivity was significantly lower below Lake Merriweather, but all conductivity values were well within the tolerance ranges for benthic macroinvertebrates. Conductivity is not believed to be a stressor on the benthic community that is responsible for the impairment.

4.3.3. Nutrients

Nutrient levels in the non-impaired reach above Lake Merriweather and in the impaired reach below the lake were not significantly different. Total inorganic nitrogen levels were actually slightly lower below the lake than above it, and phosphorus levels were all below the detection level. For these reasons nutrients are not considered to be a stressor on the benthic community that is responsible for the impairment.

4.3.4. Toxics

Ammonia levels in the impaired reach were significantly higher than in the upstream non-impaired reach. These ammonia levels, however, were well below water quality standards. The highest measured ammonia level was only 5.2% of the allowable water quality standard level on that day based on temperature and pH. Other toxics were not measured in the impaired reach, but based on the land use in the watershed and absence of industrial sources, toxics are not believed to be a stressor on the benthic community that is responsible for the impairment.

4.4. POSSIBLE STRESSORS

4.4.1. Temperature

Temperatures were significantly higher in the impaired reach downstream of the lake than in the upstream unimpaired reach. Temperatures did not exceed the water quality standard of 31°C in the downstream reach, however, the increased temperature could have indirect effects on the benthic community. The increased temperature will reduce the oxygen saturation potential and will increase biological activity. Both of these effects will lower dissolved oxygen levels downstream. Because low dissolved oxygen is one of the most probable stressors (see Section 4.5.3), the indirect effects of increased temperature were considered a possible stressor.

4.4.2. General Habitat Conditions

Total habitat scores just below the dam (at station 2-LCF000.76) were significantly lower than at the upstream unimpaired station, however, scores further downstream within the impaired reach were higher than at the upstream unimpaired station. This indicates that habitat conditions may play a role in the impairment directly downstream of the dam, but that general habitat conditions are not responsible for impaired benthic conditions throughout the length of the impaired reach. For this reason, general habitat conditions were listed as a possible stressor. The individual habitat parameter of embeddedness is considered in Section 4.5.2.

4.5. MOST PROBABLE STRESSORS

4.5.1. Change in Available Food Supply

Multiple lines of evidence suggest that a change in available food supply downstream of Lake Merriweather is one of several most probable stressors to the benthic community. Analysis of benthic data revealed that there was a large shift in functional feeding groups from the unimpaired reach to the impaired reach below Lake Merriweather. There was a large loss of scrapers and an increase in filter feeders within the impaired reach (see Section 4.2.1). Directly below the dam, the % Scrapers score (as part of the SCI metric) was decreased by 67% from the upstream unimpaired station, and further downstream the % Scraper score was reduced by 31%. This change in functional feeding groups from scrapers to filterers is indicative of a change in the available food source for benthic macroinvertebrates.

Within healthy flowing streams, the primary food sources are leaf litter and periphyton. The leaf litter is slowly grazed on by shredders and decomposed into smaller and smaller particles that become available to filter feeders. The periphyton and organic biofilms on the leaf litter and stream bottom are grazed upon by scrapers. The presence of Lake Merriweather acts as a sink for leaf litter and woody debris, thereby reducing the amount of these available food sources downstream. This narrows the niches for shredders and scrapers downstream and thereby reduces their populations. The lake also promotes the growth of planktonic (or free-floating) algae. These algae and the breakdown products from dead and decaying algae produce a downstream supply of food in the suspended or soluble forms. This becomes a rich food supply for downstream filter feeders, and the filter feeding niche widens. The presence of the lake also reduces the downstream transport of attached algal species. Within the lake, planktonic algal species dominate, and depth and light conditions limit the growth of attached algal species. This reduces downstream colonization of attached algae, which comprise most of the periphyton used as a food source for scrapers. This likely further limits the width of the ecological niche for scrapers.

A change in the available food supply is also supported by the water quality monitoring data. Chlorophyll-A measured in the water column was higher downstream of Lake Merriweather than upstream (although this difference was not statistically significant). The amount of total organic carbon and dissolved organic carbon were also higher downstream of the lake, and difference in both of these parameters were statistically significant. These increases in chlorophyll-A and organic carbon in the water column are consistent with the shift of the benthic community towards filter feeders and away from scrapers and shredders.

4.5.2. Sediment

Multiple lines of evidence also suggest that sediment is a most probable stressor of the benthic community within the impaired reach. The first line of evidence is historical documentation that includes Notices of Violation, Consent Orders, and numerous investigations and complaints. All of this documentation points to the periodic release of large amounts of sediment from the lake. VADEQ enforcement files include pictures (Figure 4-32) and descriptions of intense sediment loads coming through the dam and continuing downstream into the Maury River. Enforcement files have documented the periodic release of sediment during lake drawdown, and more sustained sediment releases during time periods when the lake was below full pool and exposed shorelines were eroded by storm events. The Consent Orders were intended to address these problems by requiring the Boy Scouts to develop protocols for dam operation that keep the lake at full pool (except under anticipated flood conditions) and eliminate the use of subsurface discharges for drawing down the lake. However, compliance with these Consent Orders has not been consistent, and there is still the periodic need to lower lake levels during flood events and for maintenance.

Figure 4-32. View of Sediment Discharging from the Little Calfpasture River into the Maury River.

In addition to historic documentation, habitat assessments indicate that sediment is a probable stressor downstream of the lake. Habitat scores for embeddedness were significantly lower just below the dam than at the upstream station. Further downstream, embeddedness scores were still lower, but the difference was not statistically significant. Observations recorded by VADEQ biologists at the time of biological assessments also support sediment as a most probable stressor. Biologists recorded that “moderately turbid water” was being discharged from the lake (Bolgiano, 1996). In 1996, the regional biologist concluded that “the chronic discharge of sediment (punctuated by episodes of even heavier loadings of fines during resuspension by storms) is maintaining a reach of stream that is inhospitable to normal benthic assemblages” (Bolgiano, 1996). In 1999 the regional biologist again concurred that “sediment embeddedness is the most likely cause of impairment in the Little Calfpasture and Maury Rivers” (VanWart, 1999). At this time, it was also observed that there was delineation in the Maury River between clean substrate above the confluence with the Little Calfpasture River and embedded substrate below the Little Calfpasture River.

Water quality sampling above and below the lake also confirms that sediment is a probable stressor. TSS and turbidity levels were consistently higher downstream of the lake in the impaired reach than in the upstream unimpaired reach. Excluding the conditions during Hurricane Jeanne, these increases in TSS and turbidity downstream of the dam were statistically significant. A VADGIF turbidity study of the Little Calfpasture River in 1998 also confirmed that turbidity levels below the lake were significantly higher than above the lake. This study also showed the direct correlation of increased turbidity with lake lowering (Figure 4-22).

More recent turbidity levels monitored above and below the lake were analyzed in relation to storm events and dam operations to investigate causes for the increased downstream turbidity. Figure 4-33 shows the difference in turbidity measurements taken the same day above and below the dam. This difference represents the turbidity at station 2-LCF000.02 minus the turbidity at station 2-LCF007.00, so positive values indicate higher turbidity downstream of the dam. This figure plots the difference in turbidity against the number of days since the last storm event. Different symbols also distinguish between whether gates were near (within 2 feet of) full pool during the week preceding the turbidity measurement or whether gates were in a lower position (more than 2 feet below full pool) during that time period.

This figure presents three distinct regions. The first is when storm events occurred on the day of turbidity sampling. Under these conditions, turbidity above and below the lake was highly variable. Turbidity below the lake was higher on three occasions and turbidity above the lake was higher on three occasions. This variability might be expected due to the timing of sampling in relation to the timing, location, and intensity of rainfall. Because turbidity naturally increases in streams during storm events, it is not surprising that the three highest measured turbidities above the lake were measured during storm events. It should also be noted that the only three times when turbidity was higher above the lake was on days when storm events occurred.

The second distinct region apparent in Figure 4-33 is when rainfall occurred from one to five days prior to the turbidity measurement. In all of these situations (11 sampling events), turbidity was higher below the lake. The degree of increased turbidity below the lake, however, was directly tied to the operation of the dam. When the dam gates were more than 2 ft below full pool, turbidity below the lake was much higher. Under these conditions, turbidity below the lake averaged 20 NTUs higher than turbidity above the lake. When the dam was at full pool, however, turbidity was only slightly greater below the lake, averaging only 3.1 NTUs higher. This indicates that in the days following a storm event (1-5 days) turbidity below the lake is consistently higher than above the lake. When the dam is operated at full pool, this increase is small, but when the dam gates are set in a lower position, the increase in turbidity below the lake is large.

The last distinct region in Figure 4-33 is during dry conditions when rainfall has not occurred in at least the preceding 9 days. Under these conditions, turbidity is only slightly higher below the lake than above it. The difference in turbidity levels also did not appear to be greatly influenced by the position of the dam gates. Even when dam gates were lowered, turbidity levels below the lake were only slightly higher than above the lake.

Taken in total, this analysis highlights several implications regarding the functioning of the Goshen Dam. First, when it is not raining, turbidity is consistently higher below the lake. This finding is probably typical for shallow lakes. Sediment is retained in the lake during storm events and released more slowly over the following days as the lake clears. Phytoplankton production within the lake also adds to the increased turbidity downstream, regardless of storm events. Secondly, the lowering of dam gates greatly increases the downstream turbidity following storm events. When dam gates are lowered, barren shoreline and previously settled sediment are exposed. Storm events erode this material, washing it into the lake. The more shallow depths and increased velocities due to the lowered lake levels also increase turbulence and mixing within the lake. This keeps sediment suspended in the water column and increases sediment in the overflow. For 1 to 5 days (and possibly up to 8 days) following a storm event, turbidity below the lake is greatly increased when dam gates are lowered. Increases of as much as

38.8 NTUs over lake influent levels were measured in the days following storm events. At more than 8 days following storm events, conditions appeared to clear and turbidity in lake outflow was only slightly higher than inflow.

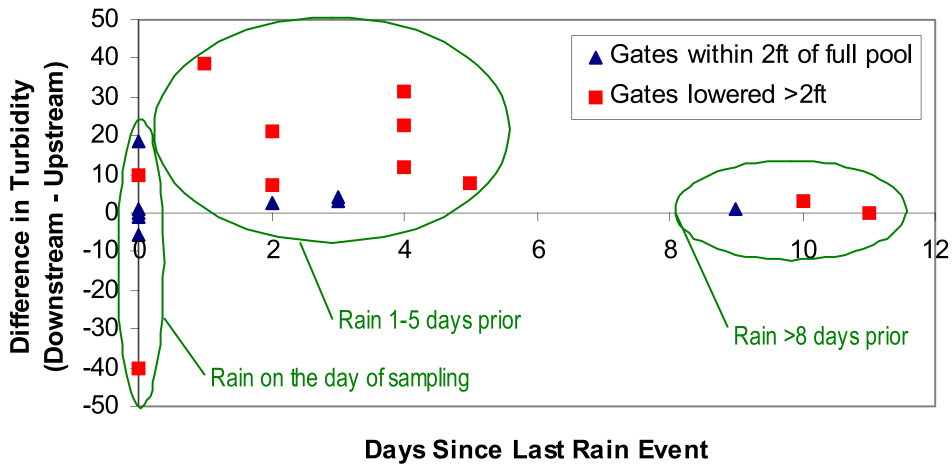

Figure 4-33. Analysis of Turbidity Levels Upstream and Downstream of Lake Merriweather in Relation to Storm Events and Dam Operations.

These observations in conjunction with modeling results produce the following picture of sediment impairment in the Little Calfpasture River below the Goshen Dam. Sediment washed off of the land surface or eroded from the stream banks is transported into the lake during storm events. These high flow events also increase velocities through the lake, which can resuspend additional sediment that was previously deposited in the lake. Erosion of the lake shoreline can also contribute to sediment within the lake if lake levels are lowered prior to the storm event. All of these sources combine to increase suspended sediment concentrations in the lake following storm events. Some of the suspended sediment within the lake is re-deposited within the lake, but much (76% on average) is discharge from the lake through the spillway to the Little Calfpasture River below the dam. This discharge of sediment can persist for days to weeks following storm events. Since this discharge occurs as flows are receding from the event and velocities are decreasing, some of this sediment is deposited on the streambed below the dam. This excess sediment smothers certain bugs that live in the bottom of the stream and limits the diversity of aquatic life.

4.5.3. Dissolved Oxygen

Low dissolved oxygen within the impaired reach was also determined to be one of the most probable stressors impacting the benthic community in the Little Calfpasture River downstream from Lake Merriweather. Periodic water quality monitoring above and below Lake Merriweather confirmed that dissolved oxygen was significantly lower below the lake. Dissolved oxygen averaged 9% lower below the dam, but was as much as 34% lower on individual days during periodic monitoring.

In addition to periodic dissolved oxygen monitoring, VADEQ conducted continuous diurnal dissolved oxygen monitoring in August 2005, 2006, and 2007. This monitoring confirmed that low dissolved oxygen is one of the most probable stressors contributing to the benthic impairment in the Little Calfpasture River. In two of the three years where diurnal dissolved oxygen studies were conducted, violations of the dissolved oxygen standard were observed. During August 2006, dissolved oxygen levels violated both the instantaneous and daily average water quality standards. A total of 407 individual measurements violated the instantaneous water quality standard of 4 mg/L, and daily averages violated the water quality standard on all three days of monitoring. In August 2007, the instantaneous water quality standard was not violated, but the daily average criterion was again violated on each of the three days.

These low oxygen events are likely caused by a combination of the following conditions:

- Dry, low-flow conditions, where a minimal volume of water is flowing over the spillway of the dam.
- Thermal stratification of Lake Merriweather causing a discharge of low dissolved oxygen water.

In the summer, the lake thermally stratifies and dissolved oxygen is depleted in the hypolimnion, or bottom portion of the lake. The location of the bottom cold water discharge (which is rarely opened) is completely within this low oxygen hypolimnion. The upper cold water discharge is located right at the transition from the well-oxygenated epilimnion to the poorly-oxygenated hypolimnion. With very slight fluctuations in the lake's thermocline (less than 1ft), the upper cold water release can also discharge very low oxygen water from the hypolimnion. During the late summer when conditions are dry and flows are low, there may not be sufficient flow over the top of the dam to dilute the low dissolved oxygen water from the cold water discharge. This causes low dissolved oxygen conditions downstream of the lake. During the night, when oxygen-consuming respiration continues, but oxygen-producing photosynthesis ceases, dissolved oxygen conditions are at their critical values.

This explanation for low dissolved oxygen conditions in the Little Calfpasture River is supported by lake monitoring and flow information during low dissolved oxygen periods. Lake monitoring confirms that the lower cold water discharge is fully within the hypolimnion, and the upper cold water discharge is right at the edge of the hypolimnion, likely to receive moderately oxygenated to poorly oxygenated flows. Low oxygen discharge from the lake combined with little flow over the spillway can produce the observed low dissolved oxygen downstream. When poor oxygen levels were observed in the 2006 diurnal study, water was flowing over the top of the dam (according to the dam tender, via personal communication), but this flow was likely minimal. Flow gage records in the Calfpasture River indicate that flow levels during the 2006 diurnal study were less than the 5^{th} percentile historically. During the 2007 diurnal study, when oxygen levels were again below water quality standards, no water was flowing over the top of the dam (visual observation by VADEQ staff). Comparatively, during the 2005 diurnal dissolved oxygen study, when dissolved oxygen levels were adequate, flows over the top of the dam were more substantial. Flow conditions during that time period were above the median (52 percentile) flow condition in the gaged Calfpasture River. This likely explains why critical dissolved oxygen levels were not as low during the 2005 diurnal study.

This explanation for low dissolved oxygen conditions in the Little Calfpasture River is also supported by anecdotal information provided by the dam tender. According to the dam tender, there was no flow of water over the top of the dam for about 2 weeks prior to VADEQ's visit on 8/22/07. As this period progressed the water below the dam became foul smelling and brownish-orange in color. The foul odor (similar to rotten eggs) is hydrogen sulfide gas and the brownish-orange color is iron hydroxide precipitate. The presence of both of these compounds are indicative of anoxic conditions and indicate that the upper cold water release was discharging low oxygen water from the hypolimnion of the lake. In the anoxic hypolimnion of the lake, sulfur compounds are reduced to hydrogen sulfide and iron compounds are reduced to ferrous iron. These compounds can remain dissolved under the anoxic conditions in the hypolimnion. Once hypolimnetic water is discharged through the outlet structure, some of the dissolved hydrogen sulfide is volatilized to produce the rotten egg smell, and the dissolved ferrous iron is oxidized to ferric hydroxide, which precipitates and forms the brownish-orange floc. The dam tender's description of the conditions during the August 2007 diurnal monitoring period is completely consistent with a low oxygen discharge of hypolimnetic water from the upper cold water release.

The dam tender also described remedying the foul smell by opening the lower cold water release in addition to the upper cold water release. This action likely caused a hydraulic forcing of the thermocline to a lower depth in the immediate vicinity of the intake, in turn, causing the upper cold water release to be positioned in the epilimnion and discharging oxygenated water. The mixture of the now more-oxygenated upper cold water release and the consistently poorly-oxygenated lower cold water release created an overall increase in the dissolved oxygen of the discharge.

In addition to the low dissolved oxygen contributions from the lake hypolimnion, dissolved oxygen conditions below the lake are also likely suppressed by increased temperature and sediment oxygen demand. The presence of the lake increases retention time and surface area, which aid in solar heating of the water body. For this reason, downstream temperatures are slightly higher than above the lake. This can influence dissolved oxygen concentrations by increasing respiration rates and decreasing oxygen saturation potential. The sediment impairment may also contribute to dissolved oxygen suppression by exerting a sediment oxygen demand. The degradation of organic matter in the sediment can result in greater oxygen demand below the lake than above it.

While these two additional factors (increased temperature and increased sediment oxygen demand) exacerbate low dissolved oxygen conditions, they are not likely the cause of observed dissolved oxygen violations. These factors likely account for the general suppression of dissolved oxygen observed in periodic measurements above and below the lake (9-34% decreases), but not violations of the dissolved oxygen water quality standard. The severe depressions in dissolved oxygen observed in August 2006 and August 2007, however, are linked to hypolimnetic discharges and are greater than would be expected from sediment oxygen demand and temperature alone. While downstream increases in temperature were statistically significant, they were not incredibly large, averaging +2.2°C, and no measured temperatures were above the water quality standard of 31°C. Sediment oxygen demand is also expected to be higher below the lake due to increased sediment deposition, but not high enough to cause dissolved oxygen violations. The organic matter in sediments collected from the lake is not high (2% TOC), so the sediments would not exert an inordinate demand on oxygen. The weight of evidence collected on dissolved oxygen conditions in the Little Calfpasture River suggest that low dissolved oxygen is one of the probable stressors, and this condition results from the discharge of hypolimnetic water from Lake Merriweather. The correction of this problem should eliminate violations of the dissolved oxygen standard, however, dissolved oxygen conditions are likely to remain slightly depressed below the lake due to temperature increases and sediment oxygen demand.

4.6. CONCEPTUAL MODEL AND CAUSAL ANALYSIS

Based on the observed data and analysis of potential stressors, a conceptual model was developed to describe the causal relationships between the source of the impairment, the most probable stressors, and the observed loss of benthic macroinvertebrates. Figure 4-34 shows this conceptual model. The source of the impairment identified in the conceptual model is the impoundment, or the dam that forms Lake Merriweather. This conclusion is based on the spatial location of the impaired reach. Benthic monitoring just upstream of Lake Merriweather (station 2-LCF004.80) shows consistently healthy and non-impaired benthic conditions. Benthic monitoring just below the dam (station 2-LCF000.76) consistently shows severely impaired benthic conditions. The lake itself is the only reasonable source between the unimpaired and severely impaired benthic locations. Further downstream below the dam at station 2-LCF000.02, the benthic community remains consistently impaired, but the impairment is less severe than just below the dam. This also supports the conclusion of the impoundment being the source of the impairment, because the severity of the impairment decreases with downstream distance from the source. Lastly, historic documentation of investigations, complaints, and enforcement actions regarding the operation of the dam support this determination.

The conceptual model defines several different pathways by which the impoundment causes the observed benthic impairment. These pathways are color-coded to demonstrate those which are a result of the design and operation of the dam and those which are simply the result of the impoundment's existence. For instance, the pathway on the far left describes one of the natural consequences when a flowing river is impounded and a lake is formed. The impoundment changes the ecology of the system. Where leaf litter and periphyton dominate the energy flow and food supply in free-flowing rivers, energy and food supplies are dominated by the photosynthesis of planktonic algae in lakes. This leads to a significant change in the available food supply downstream of the impoundment, which alters the ecological feeding niches and results in a loss of certain invertebrates. The observed evidence supporting the existence of this causal pathway was previously discussed in Section 4.5.1. The effects of this causal pathway are felt most dramatically directly downstream of the impoundment and slowly dissipate farther downstream as energy dynamics return to more natural conditions for free-flowing rivers. This causal pathway is a natural consequence of impounding the Little Calfpasture River and cannot be remedied by any design or operational changes in the dam. Even if other causal pathways are mitigated, this pathway will remain, and it is likely that some level of impairment will continue for some distance downstream of Lake Merriweather.

The causal pathway on the far right is also a natural consequence of impounding the Little Calfpasture River and can be only minimally influenced by the design and operation of the dam. The existence of the impoundment means that water through the lake flows at a much slower velocity and the surface area is greatly increased. The slower velocity and the lake depth cause less natural reaeration of the water and a corresponding decrease in dissolved oxygen as the Little Calfpasture River flows through the lake. This was demonstrated by the statistically significant decrease in dissolved oxygen below the lake (see Section 4.2.3.3). In addition to the direct decrease in dissolved oxygen, the lake also causes an increase in temperature and indirect effects on dissolved oxygen. The increased surface area and slower velocity in the lake mean that radiant energy from the sun can more efficiently heat the water. This creates increased water temperatures in the surface of the lake and downstream. Thermal stratification of the lake in the summer time further exacerbates the heating of surface water. As discussed in Sections 4.2.3.1 and 4.4.1, this effect is documented by the statistically significant increase in water temperature below the lake. This increase in water temperature reduces the oxygen saturation potential and increases biological activity, which both indirectly further lower dissolved oxygen downstream.

The other ramification of the decreased velocity through the lake is that when storm events produce high TSS loads to the lake, the duration of these high TSS episodes downstream of the lake is extended. Large storm events can cause turbid conditions throughout the lake, which can persist for more than a week after the storm event. Under these conditions, the Little Calfpasture River above the lake clears much more quickly than below the lake. Downstream benthic life are exposed to higher TSS concentrations for extended periods of time, and extending the duration past the flow peak creates a greater opportunity for sediment to settle and fill interstitial spaces. This pathway is confirmed by downstream monitoring of turbidity following storm events (see Section 4.5.2) and modeling results (see Section 7.1.2).

The two causal pathways in the center of Figure 4-34 are more related to the design and operation of the dam. First, the lowering of the lake level for flood control (or as a routine practice during the winter) creates exposed shoreline around the lake with no vegetative cover. This exposed area is also covered by sediments that have settled out of the lake when water levels were higher. The sediments in these exposed areas can easily be eroded and wash into the lake causing a higher sediment or particulate load downstream. Lower lake levels also increase the velocity and mixing within the lake, which encourages the resuspension of settled particles. In addition, the increased growth of planktonic algae within the lake (as discussed above) adds to the increased amount of fine particles transported downstream. The increased sediment and fine particulate load can change feeding niches downstream by providing favored conditions for filter feeders and burrowers. The increased sediment load also fills interstitial spaces among the benthic substrate, which lowers dissolved oxygen in the pore spaces and also results in a loss of suitable habitat for invertebrates requiring a clean substrate. The evidence supporting this pathway was discussed in Section 4.5.2.

The final causal pathway is through the release of water from the deoxygenated hypolimnion. There is evidence that this has happened on a large scale at certain times during the lowering of the lake level (see Section 2.5), but there is also evidence that this occurs more frequently through the control structure during dry periods when lake levels are low and reduced flow is passing over the spillway. This was likely the cause of the decreased dissolved oxygen conditions during the 2006 and 2007 diurnal dissolved oxygen studies (see Sections 4.2.3.3 and 4.5.3). The release of water from subsurface discharge points that are at or below the thermocline of the lake can create greatly reduced dissolved oxygen conditions downstream. It can also cause the resuspension of particles near the bottom of the lake and further increase downstream transport of sediment and fine particulates.

In Figure 4-34, the width of the connecting arrows was designed to symbolize the strength of the individual causal pathways. For instance, the widest connecting arrows flow through the pathway of increased sediment and particulates. It is likely that this causal pathway has the most influence on the loss of invertebrates and the benthic impairment. The second strongest influence on the benthic community is likely through the pathway of low dissolved oxygen. Lastly, changes in the available food supply and feeding niches is likely the least important of the causal pathways, but still exerts an impact on the benthic community.

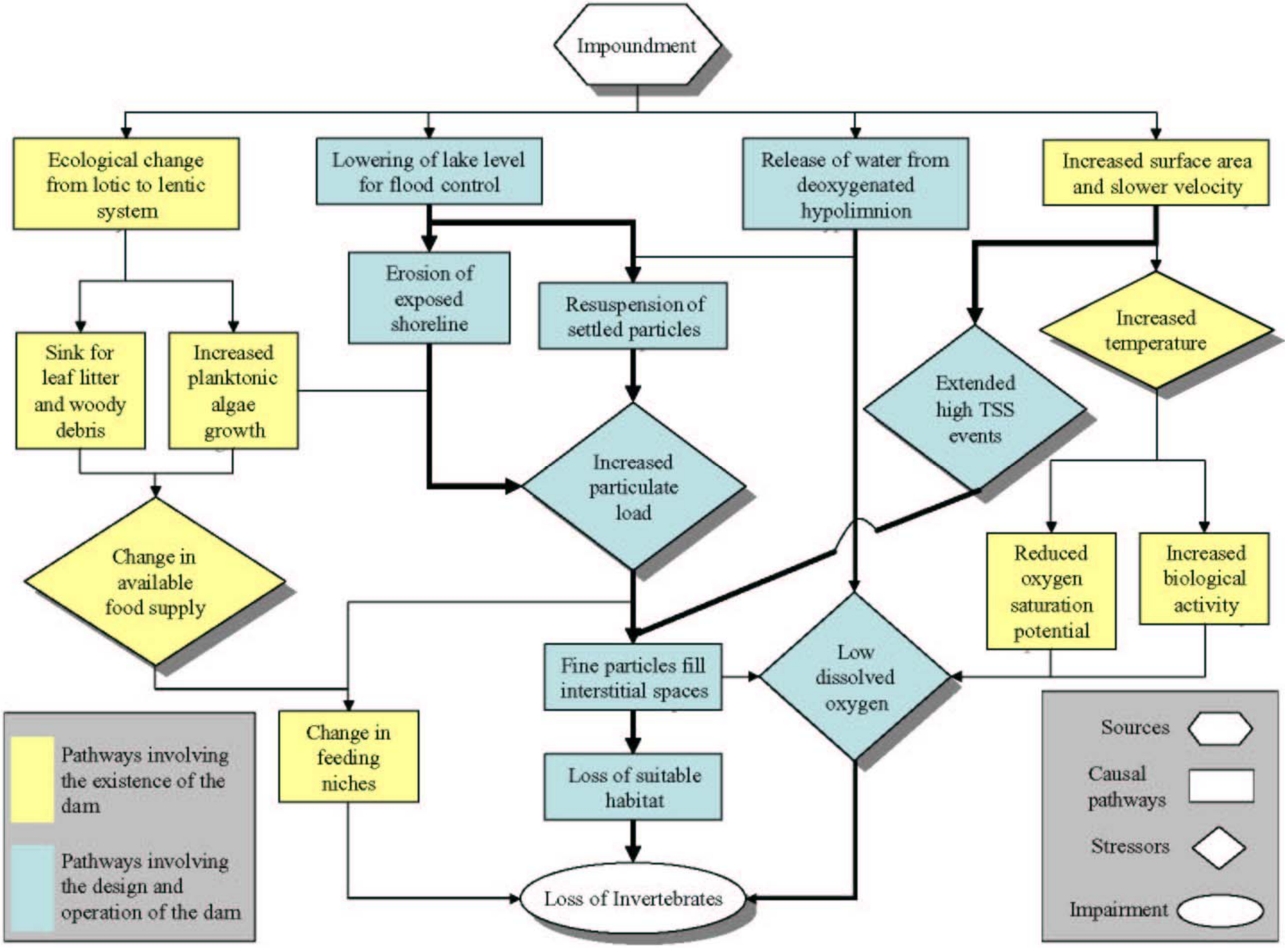

Figure 4-34. Conceptual Model for the Cause of Impairment in the Little Calfpasture River.

4.7. PROPOSED PLAN TO ADDRESS THE WATER QUALITY IMPAIRMENT

4.7.1. Overview

The stressor identification analysis used existing benthic, habitat, water chemistry, and historical data to document and support the existence of multiple stressors in the Little Calfpasture River. The most probable stressors in this system are a change in available food supply, excess sediment, and low dissolved oxygen. Each of these three stressors impacts the benthic community, with excess sediment and low dissolved oxygen exerting the greatest impact. To fully restore the benthic health within the impaired reach, each of these three stressors will have to be addressed. Since the ultimate source of these three stressors is the Goshen Dam, removal of the dam would be one option for eliminating the impairment. This option can continue to be considered, however, it was not selected as the current TMDL scenario, because there is no reasonable assurance that it would be implemented. No existing regulations, including a TMDL, could enforce such an option. Besides removing the dam, other options are available for restoring aquatic life health below the dam. This section provides a framework for addressing these stressors through a variety of approaches including:

- development of a TMDL to reduce pollutant loadings to the lake
- enforceable controls to ensure that the dam is operated in a way that mitigates environmental degradation while maintaining human health and safety
- structural modifications to the dam outlet structure to increase dissolved oxygen
- designated use change that provides attainable aquatic life standards below the dam

4.7.2. Changes in Available Food Supply

The change in available food supply downstream of Lake Merriweather is a natural consequence of impounding a river system. For this reason, this stressor will remain as long as the Goshen Dam is present. This is evidenced by the consistently poor aquatic life scores at the monitoring station directly below the dam (2-LCF000.76) (Figure 4-3). VSCI scores at this site have averaged 24.5 and ranged only from 16.0 to 27.9 over the past 12 years. Scores have been consistently poor regardless of the operational practices at the dam or pollutant loadings. Even when the dam had not been lowered in 24 months, sediment loadings were low, and aquatic life further downstream (2-LCF000.02) met water quality standards (as on 10/29/01), aquatic life conditions just below the dam were still severely impaired (VSCI of 22.8). These data along with the conceptual model of causal relationships demonstrate that the aquatic life use cannot be fully met in the Little Calfpasture River for some distance downstream of the Goshen Dam.

The Goshen Dam was built to form Lake Merriweather and provide recreational uses. While the dam was not built for flood control, it currently provides some flood control uses. Based on these beneficial uses and the potential financial and social costs, removal of the dam is not a feasible option at this time for achieving full attainment of the aquatic life use.

Because dam removal is not an option and the aquatic life use cannot be fully met while the dam remains, a change in the aquatic life designated use was required. Such changes to designated uses are allowed under federal regulations. Under 40 CFR 131.10(g), states may remove a designated use which is not an existing use or establish sub-categories of a use if the state can demonstrate that attaining the designated use is not feasible because, "dams, diversions, or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use."

As a part of triennial standards review, VADEQ proposed a special standard for aquatic life use that would apply to the Little Calfpasture River below the Goshen Dam. The following special standard was proposed on 3/31/2008 and approved by the State Water Control Board on 10/17/2008. NOTE: As of 12/29/2009, the EPA approved this special standard as part of the 2009 Triennial Review.

> *"Little Calfpasture River from the Goshen Dam to 0.76 miles above its confluence with the Calfpasture River has a stream condition index (A Stream Condition Index for Virginia Non-Coastal Streams, September 2003, Tetra Tech, Inc.) of at least 20.5 to protect the subcategory of aquatic life that exists here as a result of the hydrologic modification. From 0.76 miles to 0.02 miles above its confluence with the Calfpasture River, aquatic life conditions are expected to gradually recover and meet the general aquatic life uses at 0.02 miles above its confluence with the Calfpasture River." (SWCB, 2008)*

This special standard allows for a zone of recovery from dam impacts that cannot be mitigated, but ensures that the general standard is maintained at station 2-LCF000.02. Results from benthic sampling in 2001 demonstrated that meeting the general standard at this location is possible (Figure 4-3), but additional measures must be taken to ensure that the standard is consistently met. These additional measures include development and implementation of a sediment TMDL, compliance by the Boy Scouts of America with the existing Consent Order, and structural modifications of the dam outlet structure. If these measures are taken, the general standard should be consistently met at station 2-LCF000.02 and impacts from the Goshen Dam will be limited to a less than 0.76 mile section of the Little Calfpasture River and will not impact the Maury River.

Within the dam impact area, at station 2-LCF000.76, the special standard was set to match the maximum attainable aquatic life use. At this station, benthic scores have always remained severely impaired, even when conditions at the mouth have improved (Figure 4-3). Table 4-3 provides summary statistics for benthic VSCI scores at station 2-LCF000.76, and Figure 4-35 shows the cumulative frequency distribution for scores at this station. These scores indicate the consistent nature of impacts from the dam at this location and the necessity of a special standard that recognizes the natural consequences of the dam's presence. To develop the special standard for this location, VADEQ used the same methodology used in the development of the original VSCI cutoff (Tetra Tech, 2003). The 10^{th} percentile of historic VSCI scores at station 2-LCF000.76 was calculated as 20.5 and was used as the criterion within the dam impact area.

Table 4-3. Statistics for Benthic VSCI Scores at Station 2-LCF000.76.

Statistic	Value
Sample Date Range	10/1994 - 6/2006
N	15
Average	24.47
Median	25.21
Min	15.95
Max	27.87
Std. Dev.	3.09
CV	12.6%

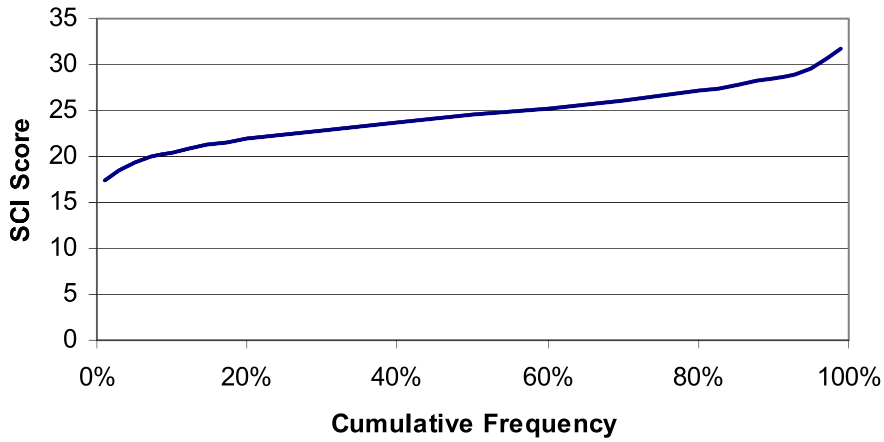

Figure 4-35. Cumulative Frequency Distribution for Benthic SCI Scores at Station 2-LCF000.76.

4.7.3. Sediment

Two actions are necessary to address the sediment impairment in the Little Calfpasture River. First, VADEQ has developed a sediment TMDL to reduce sediment loadings to the Little Calfpasture River. Secondly, VADEQ will continue to enforce the 1998 Special Order with the Boy Scouts of America that requires the lake to be kept at full pool except under emergency flooding conditions.

Monitoring results and modeling results have documented that seasonal lowering of the lake level greatly increases suspended sediment concentrations and loads downstream of the lake. This is due to a combination of decreased residence time in the lake to settle suspended particles, increased resuspension of previously settled particles, and erosion of exposed shoreline and lake bottom. To limit suspended sediment discharges from the lake, the 1998 Special Order requires the Boy Scouts of America to maintain the lake level at full pool year-round except under emergency flooding conditions. From 1998 to October 2004, it is assumed that the Boy Scouts complied with the Order, and in response, downstream aquatic life (at station 2-LCF000.02) was able to improve to a non-impaired condition for a brief period of time. Between 2004 and 2007, however, the Boy Scouts did not fully comply with the Order, and aquatic life conditions downstream remained degraded. In meetings with VADEQ in 2007, the Boy Scouts of America expressed their intent to fully comply with the Order. Since March 2007, the Boy Scouts have complied with the Order, and VADEQ will continue to ensure that compliance continues. Full compliance with the Order will be necessary to restore aquatic life in the Little Calfpasture River.

In addition to compliance with the 1998 Consent Order, a sediment TMDL for the Little Calfpasture River is needed. Even during full compliance with the order, downstream aquatic life has been impaired by excess sediment. To further reduce sediment loadings to the downstream portion of the Little Calfpasture River, the TMDL will set reductions on sediment sources throughout the watershed and call for sediment reductions to be achieved through improved lake sediment management. This report documents the development of the sediment TMDL for the Little Calfpasture River watershed.

4.7.4. Dissolved Oxygen

The stressor analysis determined that the dissolved oxygen impairment in the Little Calfpasture River downstream of the Goshen Dam was due to occasional discharge of low dissolved oxygen water from the lake hypolimnion through the cold water release. VADEQ met with the Boy Scouts of America on several occasions to discuss this problem and provide options to remedy the situation. In July 2009, the Boy Scouts instituted a structural change to the dam outlet structure that will remedy the problem. An elbow and riser was installed on the cold water release intake pipe, such that the release comes from 3 feet higher in the water column. This 3-foot increase in the height will place the intake fully within the epilimnion of the lake and will avoid low dissolved oxygen discharges from the hypolimnion. VADEQ monitored diurnal dissolved oxygen in August 2009 and found no violations of the dissolved oxygen water quality standard. Figure 4-36 shows dissolved oxygen in the Little Calfpasture River from August 3, 2009 through August 7, 2009. Over the 4-day period, dissolved oxygen averaged 7.18 mg/L and reached a minimum of only 6.32 mg/L, well above the water quality standards. These preliminary results suggest that modifications to the dam outlet structure were successful in remedying dissolved oxygen violations. VADEQ will continue to monitor dissolved oxygen downstream of the dam to ensure that this trend is maintained and water quality standards are not violated.

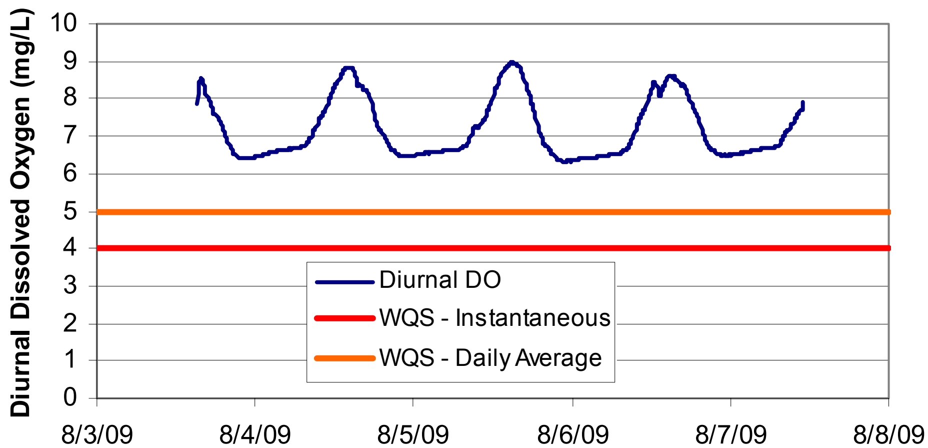

Figure 4-36. Diurnal Dissolved Oxygen Levels in the Little Calfpasture River During August 2009.

CHAPTER 5: SOURCE ASSESSMENT OF SEDIMENT

Sediment sources in the Little Calfpasture River watershed include both direct point sources, such as discharges from sewage treatment plants, and non-point sources, such as runoff from the land surface. Information on point sources and permitted non-point source discharges was obtained from VADEQ and the Virginia Department of Conservation and Recreation (VADCR). Sediment from the remaining non-point sources was modeled using the LSPC watershed model (see Chapter 6). This model simulates soil detachment and washoff from various land uses during rain events. In the Little Calfpasture River watershed, this non-point source of sediment dominates. This section describes and quantifies the sediment loads from various point and non-point sources within the watershed.

5.1. PERMITTED POINT SOURCES

Within the Little Calfpasture River watershed, there are a total of eight permitted point source discharges (Figure 5-1). There are four dischargers that currently hold individual Virginia Pollutant Discharge Elimination System (VPDES) permits, three Single Family Home (SFH) Domestic Sewage general permits, and one Industrial Stormwater general permit.

The Augusta Springs Water Treatment Plant (VA0090395) is permitted to discharge up to 72,000 gal/d of dechlorinated reject water at a monthly average TSS concentration of less than 30 mg/L and at a maximum concentration of 60 mg/L. Flows from this facility are intermittent and are only produced during backwash of filters or when produced water fails to meet acceptable turbidity levels for drinking water. Typical flows from this facility are considerably less than the permitted flow and have averaged less than 10,000 gal/d since 2003. The annual wasteload allocation for this facility was calculated as the permit design flow times the 30 mg/L average monthly TSS limit, and the daily allocation was calculated as the design flow times the 60 mg/L maximum TSS limit.

Similarly, the Craigsville Water Treatment Plant (VA0092487) is permitted to discharge up to 12,000 gal/d of dechlorinated reject water at a monthly average TSS concentration of less than

30 mg/L and at a maximum concentration of 60 mg/L. Flows from this facility will be intermittent and only produced during backwash of filters or when produced water fails to meet acceptable turbidity levels for drinking water. While this facility is permitted, it has not yet been constructed. The annual wasteload allocation for this facility was calculated as the permit design flow times the 30 mg/L average monthly TSS limit, and the daily allocation was calculated as the design flow times the 60 mg/L maximum TSS limit.

The Casta Line Trout Farm (VA0091227) is a privately-owned fish rearing facility that uses natural spring water in a flow-through design. Reductions in organic solids from this facility were called for in a TMDL developed to meet aquatic life standards in the receiving stream, Wallace Mill Stream. This TMDL allocated the trout farm a wasteload of 2,814 lbs/yr of organic solids, which was a reduction of 43% (VADEQ, 2002). In order to meet these reductions, VADEQ issued a VPDES permit for the facility that required specific best management practices including: use of high energy feed, redesigned end-of-raceway settling basin, frequent cleaning of sediment traps and settling basin, and proper land application of removed solids. The facility is currently working towards installing all of these best management practices in accordance with the permit and a schedule of compliance. No further reductions are required from this facility to meet water quality standards in the Little Calfpasture River. The annual wasteload allocation for this facility in the Little Calfpasture River was equivalent to the Wallace Mill organic solids wasteload allocation converted to total suspended solids using a 60% organic solids content. The daily wasteload allocation was calculated by dividing this annual allocation by 365.

The Craigsville STP is currently a no discharge facility that spray irrigates partially treated wastewater at designated land application sites. The facility will be upgrading the treatment works to more completely treat and discharge the wastewater. Once the upgrade is complete, the VPDES permit will allow a maximum design flow of 0.435 MGD, an average monthly TSS concentration of 30 mg/L, and a weekly average TSS concentration of 45 mg/L. The annual wasteload allocation for this facility was calculated as the maximum design flow times the monthly average TSS limit, and the daily allocation was calculated as the design flow times the weekly average TSS limit. Based on other permit requirements (for BOD and nutrients), anticipated TSS concentrations will be much lower than the allowed 30 mg/L.

In addition to the individual VPDES permits in the Little Calfpasture River watershed, there are three Single Family Home (SFH) Domestic Sewage general permits and one Industrial Stormwater general permit. SFH general permits are issued for alternative waste treatment systems for homes that are not approved for traditional septic systems. These general permits allow the discharge of up to 1,000 gal/d of treated sewage with an instantaneous maximum TSS concentration of 30 mg/L. The annual and daily wasteload allocations for these facilities were calculated as the maximum allowable flow times the maximum TSS concentration.

The Industrial Stormwater general permit in the Little Calfpasture River watershed is issued to Blue Ridge Lumber Company in Bells Valley. This permit allows the discharge of stormwater from the facility through two outfalls. The facility is required to operate a stormwater pollution prevention plan and limit TSS in stormwater runoff to less than 100 mg/L. The annual wasteload allocation for this facility was calculated as the modeled average annual runoff volume from 12.8 acres of impervious land times the permitted TSS concentration of 100 mg/L. The daily wasteload allocation was calculated as the 95th percentile modeled runoff volume times the permitted TSS concentration of 100 mg/L.

Table 5-1 lists the permitted point sources in the Little Calfpasture River watershed along with TSS wasteload allocations (WLA) for those permitted discharges. Figure 5-1 shows the location of point source discharges in the watershed. Those SFH permits that discharge to perennial streams are shown in red, and those that discharge to dry ditches or intermittent streams are shown in yellow.

Table 5-1. Permitted Point Sources in the Little Calfpasture River Watershed.

Facility	Permit #	Permitted Flow (MGD)	Permitted TSS Conc. (mg/L)[a]	Wasteload Allocation	
				Annual WLA (tonnes/yr)	Daily WLA (tonnes/d)
Augusta Springs WTP	VA0090395	0.072	30/60	2.99	0.0164
Casta Line Trout Farm	VA0091227			2.13[b]	0.00584
Craigsville STP	VA0091821	0.435	30/45	18.1	0.0741
Craigsville WTP	VA0092487	0.012	30/60	0.497	0.00273
Blue Ridge Lumber Co.	VAR050879		100	4.66[c]	0.0861[c]
3 Single Family Home General Permits	Various	0.003	30	0.125	0.000341
			Total	28.4	0.185

[a] When two numbers are given, the first is the average monthly limit and the second is the maximum or average weekly limit.
[b] Wasteload allocation from the Wallace Mill Stream TMDL. This wasteload allocation was 2,814 lbs/yr organic solids. The allocation was converted to total suspended solids using a 60% organic solids content. Conversion to T/yr equals 2.13 T/yr. No additional reductions (beyond those required in the Wallace Mill Stream TMDL) are required from this facility to meet water quality standards in the Little Calfpasture River.
[c] Wasteload allocation was determined from modeling 12.8 acres of impervious area.

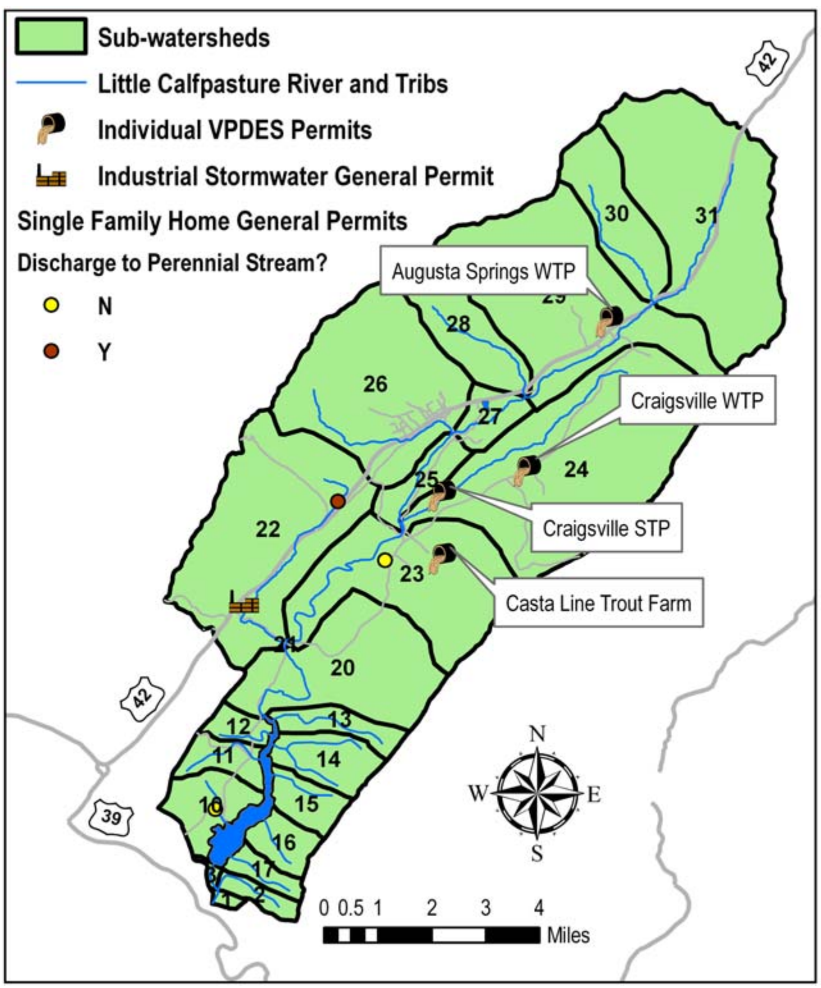

Figure 5-1. Point Source Dischargers in the Little Calfpasture River Watershed.

5.2. NON-POINT SOURCES

Non-point sources of sediment in the watershed include runoff from residential areas, cropland, pasture, forest, and impervious areas. Erosion of the stream bank is another source of sediment in the watershed. Because stream bank erosion is difficult to estimate and model, the Chesapeake Bay Program has instituted an additional land use category to represent areas of active bank erosion. This land use category was termed degraded riparian pasture, and represents areas with no riparian vegetation and where cattle have access to the stream. These areas are locations of high bank erosion rates, because cattle hooves trample and dislodge bank sediments and because the bank soil is not stabilized by riparian vegetation. These areas were identified from aerial imagery, and designated as a 100 meter band along either side of a visually eroding stream bank with limited vegetation and cattle access.

Sediment loads from the non-point sources were modeled using the LSPC watershed model (see Chapter 6). Based on the calibrated model, edge-of-stream sediment loads were calculated for the various sources in all sub-watersheds. The contributions from various sources within the watershed are shown in Figure 5-2. Below Lake Merriweather, nearly all of the sediment (99%) comes from flow over the Goshen Dam. This is not surprising considering that the land area below the dam represents only 1% of the Little Calfpasture River watershed, while 99% of the watershed drains to Lake Merriweather.

Above Lake Merriweather, sediment contributions are primarily from degraded riparian pasture, pasture/hay, and forest land uses. Degraded riparian pasture accounts for the largest source of sediment above Lake Merriweather. While degraded riparian pasture accounts for only 2% of the watershed area, it accounts for approximately half of the sediment load. This is due to the very high unit area sediment load from this land use and its close proximity to the stream. The unit area sediment loads from degraded riparian pasture are nearly 4 times higher than any other land use in the watershed (Figure 5-3). In contrast, forest represents 86% of the watershed area, but only 12% of the sediment load, due to very low unit area sediment contributions (0.01 T/yr/acre). Pasture was the second highest contributor to sediment loads, representing 27% of the load. Impervious areas accounted for 4% of the sediment load, while cropland accounted for

3% and residential areas accounted for 2%. All point sources combined accounted for less than 0.01% of the sediment load.

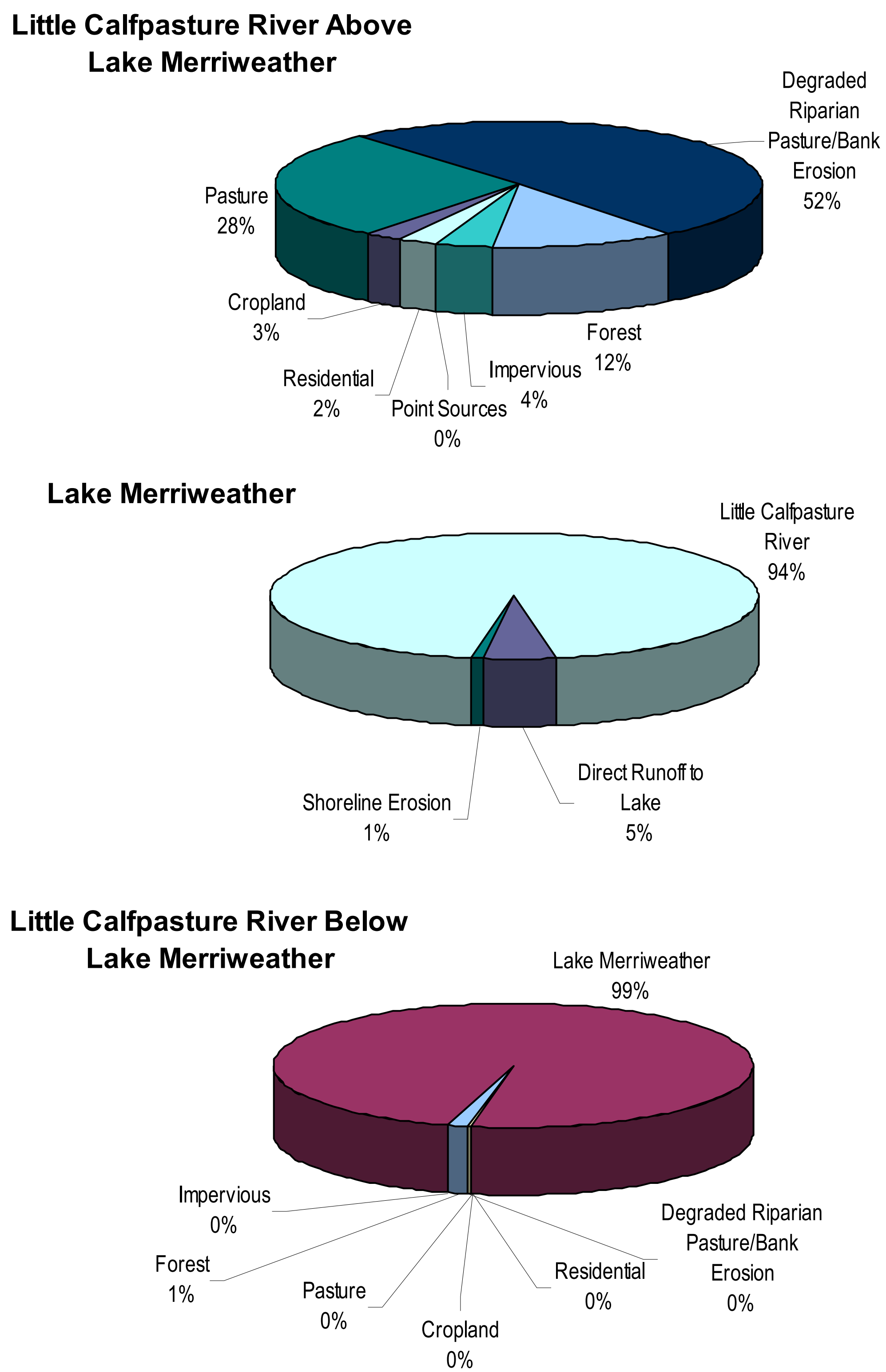

Figure 5-2. Sediment Loads from Various Sources in the Little Calfpasture River Watershed Above Lake Merriweather, to the Lake, and Below Lake Merriweather.

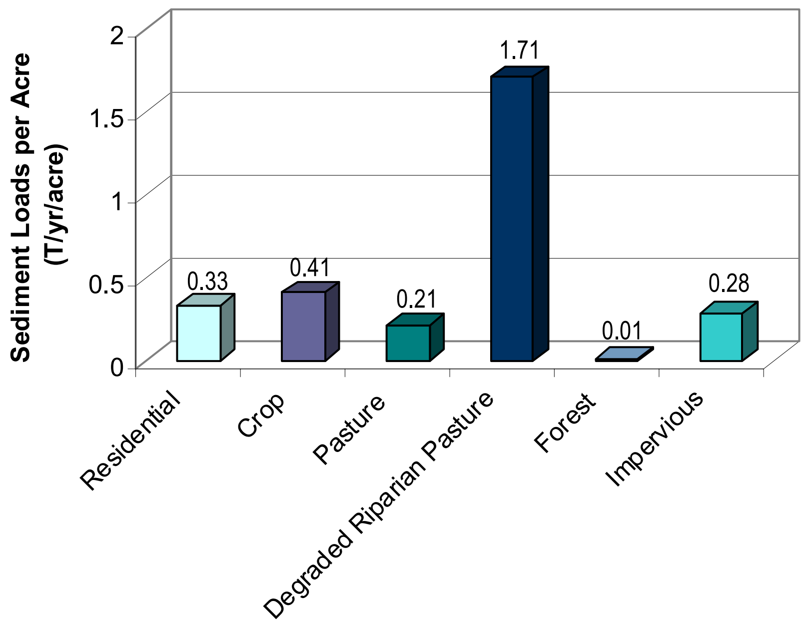

Figure 5-3. Sediment Loads per Acre from Sources Above Lake Merriweather.

Sediment loadings were also calculated for each sub-watershed. The largest sediment loading was from sub-watershed 24, which covers the Estaline Valley and is drained by Smith Creek. Sediment loads from this watershed averaged 1184 T/yr, which is more than 10 times the load of most sub-watersheds and nearly twice as high as the next highest sub-watershed. This is not surprising since sub-watershed 24 contains the most acres of pasture and degraded riparian pasture of any sub-watershed. The second highest sediment load is from sub-watershed 22, which contains the most impervious area of any sub-watershed and the second most degraded riparian pasture and pasture acres. Sub-watersheds 20 and 23 were the next highest contributors of sediment loads. These top 4 sub-watersheds in sediment contribution are also some of the largest sub-watersheds, so loads are expected to be higher than in smaller sub-watersheds. Figure 5-5 shows sub-watershed sediment contributions on a unit area basis (i.e., sediment load per acre). On this basis, an area on the north end of Lake Merriweather, an area just north of Craigsville, and Estaline Valley have the highest unit area sediment loads.

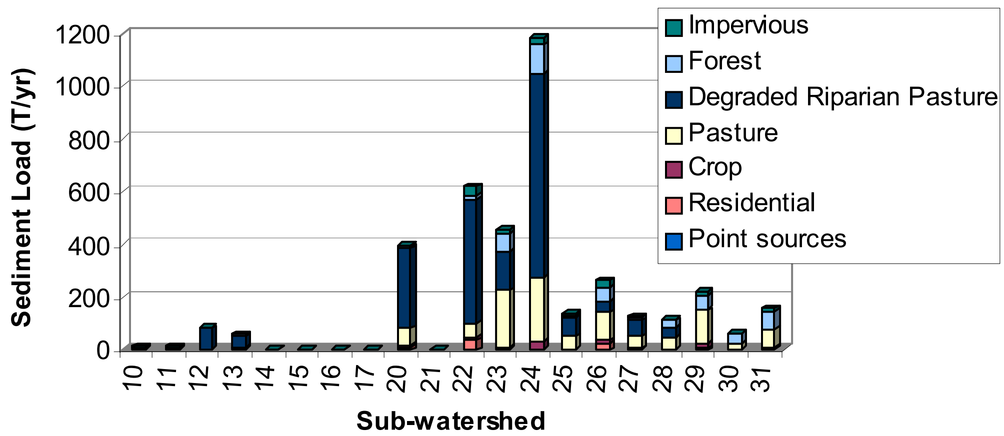

Figure 5-4. Sediment Loads in Little Calfpasture River Sub-watersheds Above Lake Merriweather.

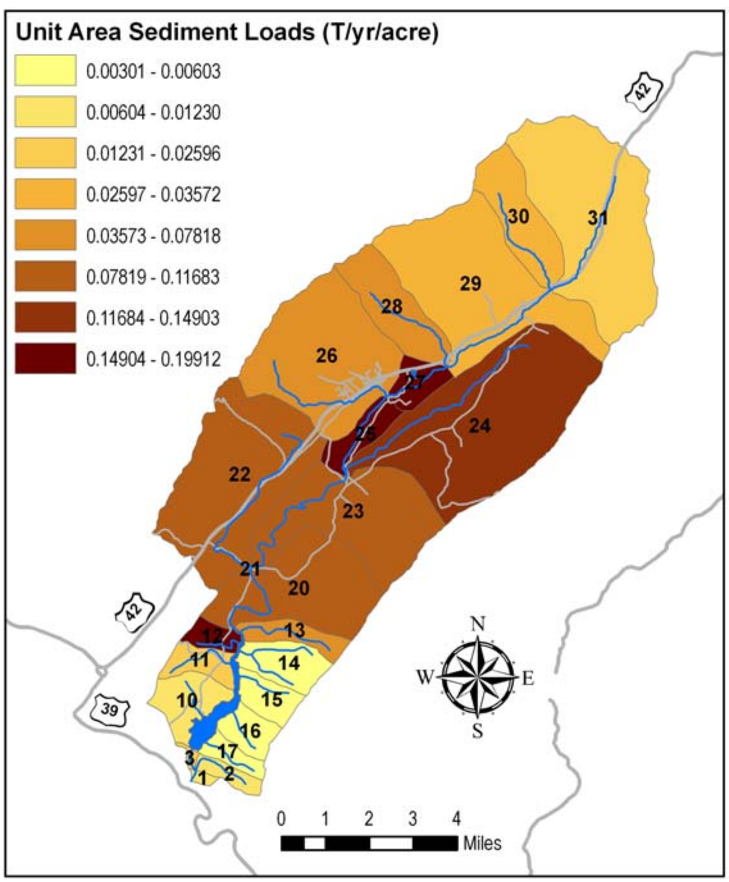

Figure 5-5. Unit Area Sediment Loads Among Little Calfpasture River Sub-watersheds.

CHAPTER 6: MODELING APPROACH

An important step in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and instream water quality conditions. This relationship must be representative of the watershed and stream being assessed and must be predictive of future water quality conditions given established source loads. Once this relationship is developed, management options for reducing pollutant loadings to the stream can be evaluated. The best way to establish this predictive linkage between loads and instream water quality is to develop a computer simulation model of the watershed. The watershed model considers the following key processes in establishing this linkage: the spatial and temporal distribution of source loads in the watershed, local climate and precipitation patterns, wash-off and runoff processes, stream hydrology, and the fate and transport of pollutants. This chapter describes the modeling approach used in the development of the Little Calfpasture River sediment TMDL. A watershed model is a useful tool for evaluating various management options and scenarios, but should be used in concert with an instream monitoring program and adaptive management approach to successfully achieve targeted water quality goals (see Chapter 7).

6.1. MODEL DESCRIPTION

A combination of two models was used in the development of the Little Calfpasture River sediment TMDL. The Loading Simulation Program C++ (LSPC) watershed model was used to simulate hydrology and sediment in the Little Calfpasture River above and below Lake Merriweather, and the Environmental Fluid Dynamics Computer Code (EFDC) receiving water model was used to simulate hydrology and sediment within Lake Merriweather (Figure 6-1).

6.1.1. LSPC

LSPC is a public domain watershed model developed by Tetra Tech, Inc. (Tetra Tech, 2005) and maintained as part of USEPA's TMDL Modeling Toolbox. LSPC is a dynamic watershed model that is used to simulate hydrologic processes, sediment, pollutant accumulation, transport, and general water quality. LSPC was developed by streamlining algorithms used in the Hydrologic Simulation Program Fortran (HSPF) model (Duda *et al*., 2001) and rewriting those algorithms in a Microsoft Visual C++ programming architecture. The LSPC model simulates point source and nonpoint source pollutant loadings, performs flow routing through streams, and simulates instream water quality processes. LSPC simulates the runoff of water and accumulated pollutants from both pervious and impervious portions of the watershed. On pervious land surfaces, LSPC simulates sediment detachment, washoff, and scouring according to the distribution of land uses, soils, and geographic features. On impervious land surfaces, LSPC simulates sediment buildup and washoff. LSPC then simulates the routing of water and pollutants through the stream channel network, considering instream processes such as deposition and resuspension.

The Little Calfpasture River watershed above Lake Merriweather was delineated into 12 sub-watersheds (identified as 20-31 in Figure 6-2) to facilitate LSPC modeling. The outflow from sub-watershed 20 was then used as input to the EFDC model of Lake Merriweather. Approximately 5900 acres of the Little Calfpasture River watershed drains directly to Lake Merriweather without first entering the Little Calfpasture River. This area was modeled in LSPC as 8 sub-watersheds (identified as 10-17 in Figure 6-2), each draining directly to Lake Merriweather and constituting an input to the EFDC model. Output from the EFDC model of Lake Merriweather was then used as input to a downstream LSPC model. This downstream LSPC model included runoff from the three sub-watersheds below Lake Merriweather (identified as 1-3 in Figure 6-2) as well as routing output from the lake through the stream reaches.

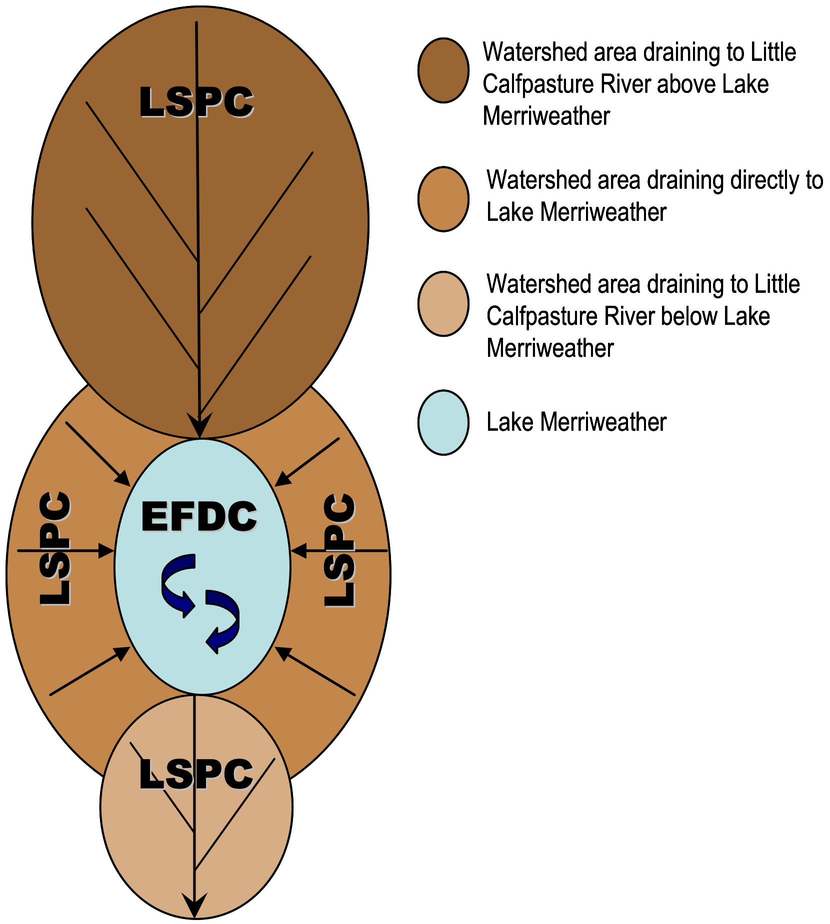

Figure 6-1. Integration of LSPC and EFDC Models in the Little Calfpasture River Sediment TMDL.

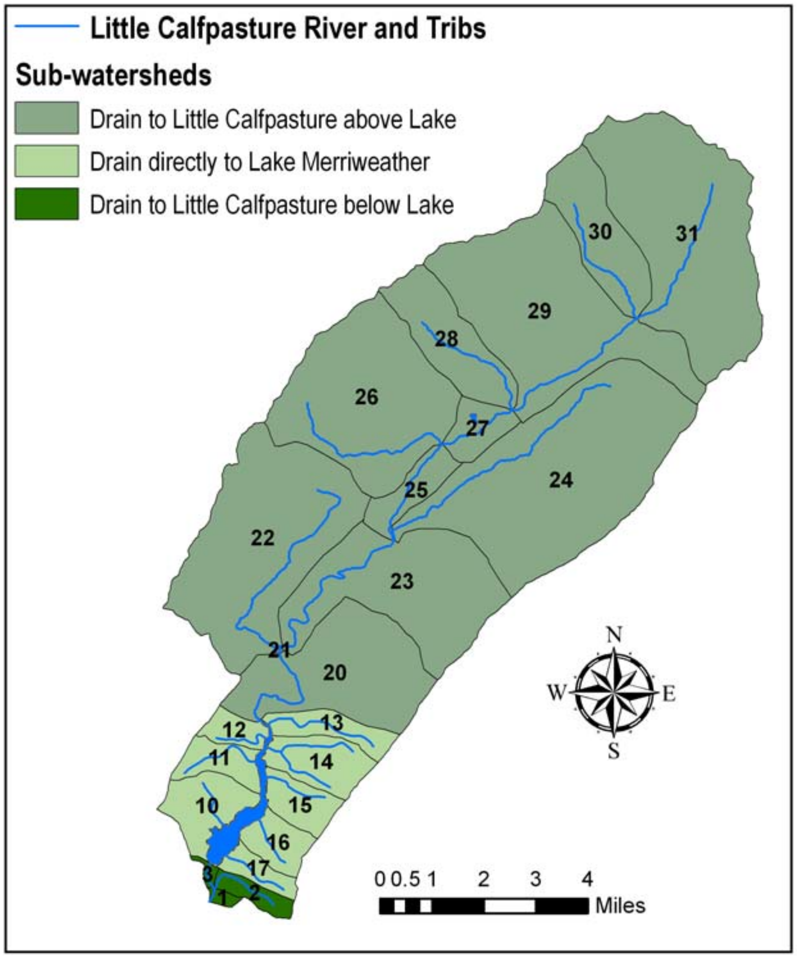

Figure 6-2. Sub-watershed Delineation for Little Calfpasture River LSPC Model.

6.1.2. EFDC

To accurately simulate hydrology and water quality within Lake Merriweather, a more complex model was needed. The EFDC model is a state-of-the-art hydrodynamic and water quality model that can be used to simulate aquatic systems in one, two, or three dimensions. EFDC is also part of USEPA's TMDL Modeling Toolbox and is the preferred choice for modeling lakes and estuaries. The EFDC model solves three-dimensional, vertically hydrostatic, free surface, turbulence averaged equations of motion for a variable density fluid. In addition to hydrodynamics, EFDC includes sediment-contaminant and eutrophication components. EFDC also simulates wetting and drying in shallow areas.

For Lake Merriweather, the EFDC model was set up as a curvilinear grid of 83 cells that represent the size and shape of the lake (Figure 6-3). Each cell was approximately 100 m wide by 200 m in length, for approximately 5.5 acres each. Nine boundary cells received flow and sediment inputs from the LSPC model of upstream and adjacent sub-watersheds (20 and 10-17). One cell represented the Goshen dam and produced flow and sediment outflows that were used as an input to the downstream LSPC model.

The EFDC model of Lake Merriweather was also constructed as a two-dimensional, vertically mixed model. This means that conditions vary throughout the width and length of the lake, but do not vary with depth. Water is assumed to mix freely throughout the depth of the water column. While the lake does stratify during the summer months, limiting vertical mixing, this stratification does not significantly affect sediment transport. If dissolved pollutants were being modeled, it would be important to consider this stratification, but since only hydrology and sediment are being modeled, a two-dimensional vertically mixed model can be assumed.

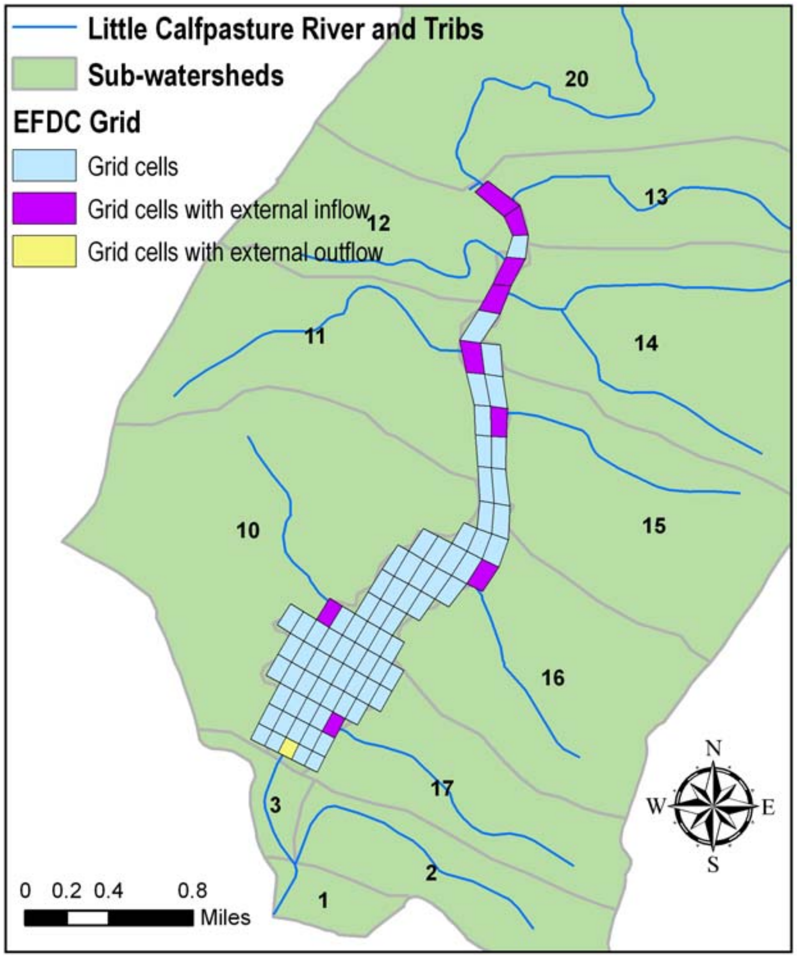

Figure 6-3. EFDC Model Grid of Lake Merriweather.

6.2. INPUT DATA REQUIREMENTS

The LSPC and EFDC models require a wide variety of input data to describe hydrology, pollutant sources, and land use characteristics within the watershed. The different types and sources of input data used to develop the TMDL for the Little Calfpasture River watershed are discussed below. The ArcGIS 9 geographical information system program was used to display and analyze watershed information for input into LSPC and EFDC. Microsoft Access was used to store and manage model input parameters and data. Microsoft Excel was used to summarize and display model output.

6.2.1. Meteorological Data

A number of different meteorological data sets are required to drive the LSPC and EFDC models. Table 6-1 lists the various types of meteorological data and describes how those data sets were developed. All meteorological data were obtained from the National Climatic Data Center (NCDC, 2006). For the Little Calfpasture River TMDL, data were obtained from a total of six weather stations ranging from within the watershed to 21 miles outside of the Little Calfpasture River watershed (Table 6-2 and Figure 6-4). Six different weather stations were used because not all stations collect the same type of data or at the necessary frequency. Using the best available data from each station, a representative meteorological data set for the Little Calfpasture River watershed was developed for the time period of 1/1/2000 through 1/1/2007.

Table 6-1. Meteorological Data Types Used in the Development of the Little Calfpasture River TMDL.

Data Types	Frequency	Used in	Obtained from
Precipitation	Hourly	LSPC, EFDC	Daily data from Craigsville 2S; patched with data from Goshen and Lexington; disaggregated with data from Staunton Sewage Plant and Williamsville 2S
Air Temperature	Hourly	LSPC, EFDC	Daily data from Lexington; patched with data from Staunton Sewage Plant; disaggregated
Solar Radiation	Hourly	LSPC, EFDC	Computed from cloud cover data from Staunton/Shenandoah
Wind Speed	Hourly	LSPC, EFDC	Hourly data from Staunton/Shenandoah
Potential Evapotranspiration	Hourly	LSPC	Computed by Hamon Method from daily minimum and maximum temperatures from Lexington
Dewpoint	Hourly	LSPC	Hourly data from Staunton/Shenandoah
Fractional Cloud Cover	Hourly	EFDC	Hourly data from Staunton/Shenandoah
Wind Direction	Hourly	EFDC	Hourly data from Staunton/Shenandoah
Atmospheric Pressure	Hourly	EFDC	Hourly data from Staunton/Shenandoah
Relative Humidity	Hourly	EFDC	Computed from hourly temperature and dewpoint data from Staunton/Shenandoah

Table 6-2. Weather Stations Used in the Little Calfpasture River TMDL Development.

Station Name	Station ID	Period of Record	Data Frequency	Data Type Used	Elevation (ft)	Distance From Watershed (mi)
Craigsville 2S	442064	1963-2007	Daily	Precipitation	1780	0
Staunton Sewage Plant	448062	1948-2007	Hourly	Precipitation Temperature	1640	10.1
Goshen	443470	1948-2007	Daily	Precipitation	1350	1.4
Lexington	444876	1941-2007	Daily	Precipitation Temperature	1125	9.8
Williamsville 2S	449159	1948-2007	Hourly	Precipitation	1640	10.3
Staunton/ Shenandoah	724105	1973-2007	Hourly	Cloud Cover Wind Speed Wind Direction Dewpoint Atmospheric Pressure	1200	21.3

The primary input to the LSPC watershed model is precipitation. Precipitation controls hydrology, runoff, and sediment loadings in the model. For this reason, it is important to obtain the most representative precipitation data set possible. Fortunately, precipitation is measured at a weather station within the Little Calfpasture River watershed, the Craigsville 2S Station (Figure 6-4). This station was used as the primary source of precipitation data for the Little Calfpasture River TMDL. As with most weather stations, there were occasional gaps in data at the Craigsville 2S Station from either station inactivity or equipment malfunction. These data gaps had to be patched with reliable data from other surrounding stations. Data gaps in the Craigsville 2S data were first patched with data from Goshen (1.4 miles outside of the watershed) and then with data from Lexington (9.8 miles outside of the watershed) if necessary. Overall, only 8.8% of the precipitation data set at Craigsville 2S was patched. Most of that patching was from Goshen, with only one day patched from Lexington (Table 6-3). After a complete daily precipitation data set was obtained, the daily precipitation values were disaggregated using the hourly precipitation patterns observed at the Staunton Sewage Plant Station (10.1 miles outside of the watershed) and the Williamsville 2S Station (10.3 miles outside of the watershed), the two closest stations with hourly precipitation data. This disaggregation of daily rainfall to hourly rainfall was performed using the WDMUtil program available as part of USEPA's BASINS software.

Air temperature and potential evapotranspiration data sets for the Little Calfpasture River watershed were developed from daily minimum and maximum temperatures recorded at the Lexington Station (9.8 miles outside of the watershed). Gaps in the Lexington record were patched with minimum and maximum temperature data from the Staunton Sewage Plant Station (10.1 miles outside of the watershed). Overall, 3.8% of the minimum temperature data set and 2.6% of the maximum temperature data set were patched. After patching, the daily minimum and maximum temperatures were disaggregated to hourly temperatures using the WDMUtil program. WDMUtil was also used to develop an hourly potential evapotranspiration data set. Potential evapotranspiration was computed by the Hamon method (Hamon, 1961) from station latitude and daily minimum and maximum temperatures.

The remaining meteorological data sets needed for the Little Calfpasture River TMDL (solar radiation, wind speed, dewpoint, fractional cloud cover, wind direction, atmospheric pressure, and relative humidity) were either obtained directly or calculated from data from the Staunton/Shenandoah Station (Table 6-1). While this station is 21 miles from the Little Calfpasture River watershed, it is the closest station that records these parameters on an hourly basis.

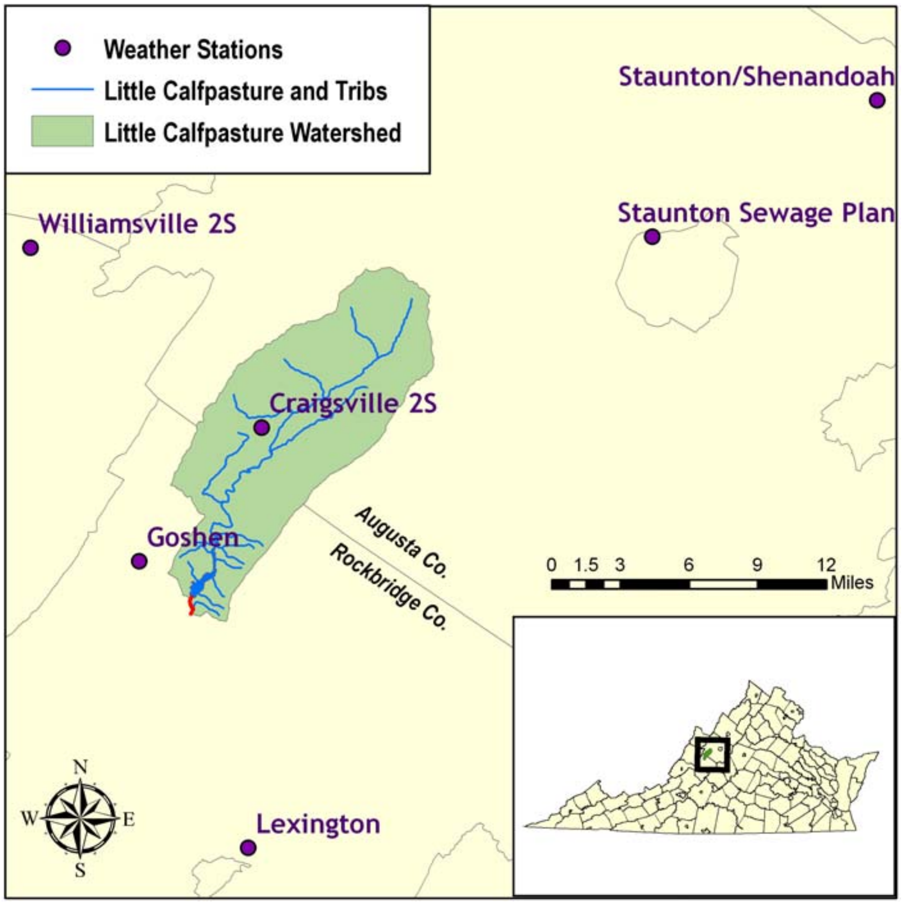

Figure 6-4. Weather Stations Used in Little Calfpasture River TMDL Development.

Table 6-3. Little Calfpasture River TMDL Weather File Patching Summary.

Source	Daily Precipitation		Daily Min. Temp.		Daily Max. Temp.	
	# of Data Points	% of Record	# of Data Points	% of Record	# of Data Points	% of Record
Craigsville 2S	2,332	91.2%				
Goshen	223	8.7%				
Lexington	1	<0.1%	2,460	96.2%	2,489	97.4%
Staunton Sewage Plant			96	3.8%	67	2.6%
Total Patched	224	8.8%	96	3.8%	67	2.6%
Total Data Set	2,556	100%	2,556	100%	2,556	100%

6.2.2. Land Use

Section 3.5 describes the land cover within the Little Calfpasture River watershed. Land cover data for the watershed was obtained from the 2005 Virginia Department of Forestry's (VADOF)

Virginia Land Use Dataset (VADOF, 2005), which is currently the most up-to-date land cover data available for the Little Calfpasture River watershed. To facilitate modeling, some of the land cover categories in the VADOF data set were aggregated and some were disaggregated to produce TMDL land use classifications that have distinctive sediment loadings. Table 6-4 describes how land use classifications used in the Little Calfpasture River TMDL were derived from the VADOF data set and other sources.

Table 6-4. Source of Land Use Classifications Used in the Little Calfpasture River TMDL.

VADOF Land Cover Classifications	TMDL Land Use Classifications	Derived From
Water	Water	VADOF Water
Pavement	Impervious Urban/Transportation	Sum of VADOF Pavement and Rooftop
Rooftop		
Residential/Industrial	Residential	VADOF Residential/Industrial
Quarries/Mines	Transitional	Sum of VADOF Quarries/Mines, Natural Barren, Bare Soil, and Forest Harvest
Natural Barren		
Bare Soil		
Forest Harvest		
Hardwood Forest	Forest	Sum of VADOF Hardwood Forest, Pine Forest, and Mixed Forest
Pine Forest		
Mixed Forest		
Crop/Pasture/Hay	Pasture/Hay	VADOF Crop/Pasture/Hay minus TMDL Degraded Riparian Pasture and TMDL Cropland
	Degraded Riparian Pasture	100 m buffer around streams with visible erosion and cattle access as determined from aerial imagery
	Cropland	VADOF Crop/Pasture/Hay times percentage of NLCD Row Crops to total of NLCD Row Crops and Pasture/Hay
Salt Marsh	N/A	

For those land uses that were aggregated from VADOF classifications, the acreages of the component categories were simply summed to obtain the aggregated acreage. For the crop/pasture/hay land cover classification, additional information was needed to disaggregate this category into separate land uses that vary in sediment loading potential. This category was divided into the following categories: degraded riparian pasture, cropland, and pasture/hay.

Degraded riparian pasture is a land use classification that was developed by the Chesapeake Bay Program in an effort to more accurately represent areas of active bank erosion. This classification represents areas with no riparian vegetation and where cattle have unlimited access to the stream. These areas are locations of high bank erosion rates, because cattle hooves trample and dislodge bank sediments and because the bank soil is not stabilized by riparian vegetation. These areas were identified in the Little Calfpasture River watershed from aerial imagery, and designated as a 100-meter band along either side of a visually eroding stream bank with limited vegetation and cattle access. Figure 6-5 shows the areas within the watershed that were designated as degraded riparian pasture, and Figure 6-6 shows an example of aerial imagery used to designate such areas.

Cropland was disaggregated from the VADOF crop/pasture/hay category using additional information from the 2001 National Land Cover Dataset (NLCD) for Virginia (USGS, 2001). Like the VADOF data set, the NLCD data set was developed from satellite imagery, however, the NLCD data were captured in the late 1990s, so it is not as current as the VADOF data set. This land cover data set, however, classified cropland and pasture/hay land separately. To determine the portion of the VADOF crop/pasture/hay category that is cropland, the percentage of NLCD cropland to NLCD total crop/pasture/hay in each sub-watershed was applied to the VADOF crop/pasture/hay category. This method assumes that while the acreages of crop and pasture land may have changed from the late 1990s to 2005, the percentage of cropland to pasture land has remained constant. After this calculation was made, the acreage of pasture/hay disaggregated from the VADOF data set could be calculated as the crop/pasture/hay acreage minus the derived degraded riparian pasture acreage minus the derived cropland acreage.

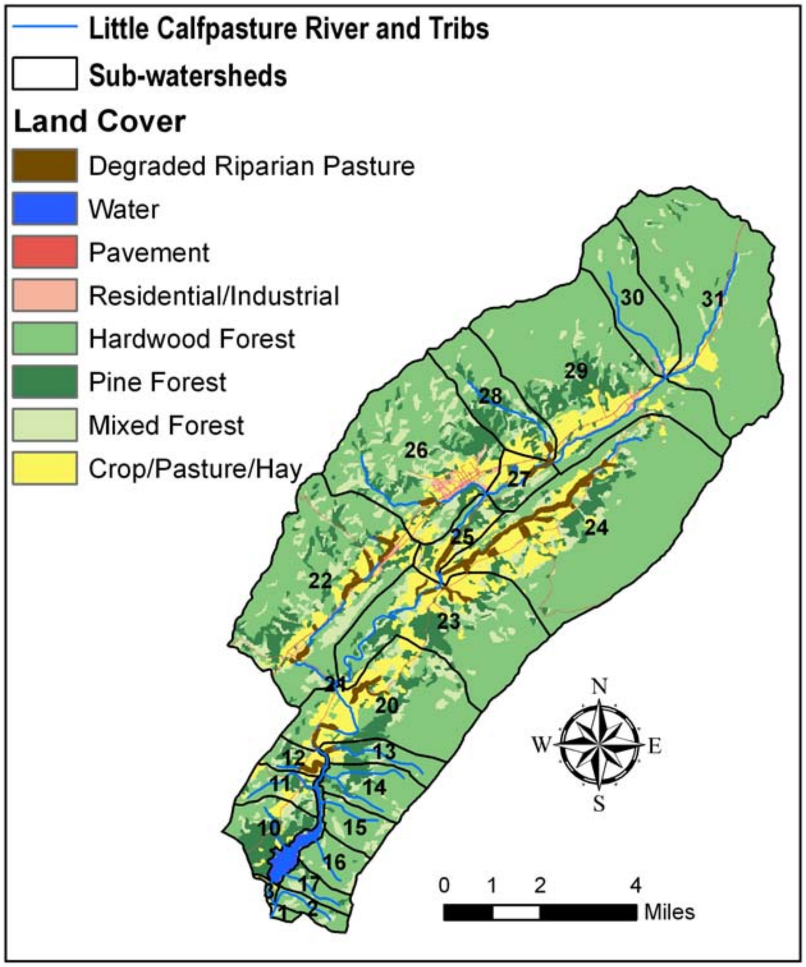

Figure 6-5. Degraded Riparian Pasture Areas in the Little Calfpasture River Watershed.

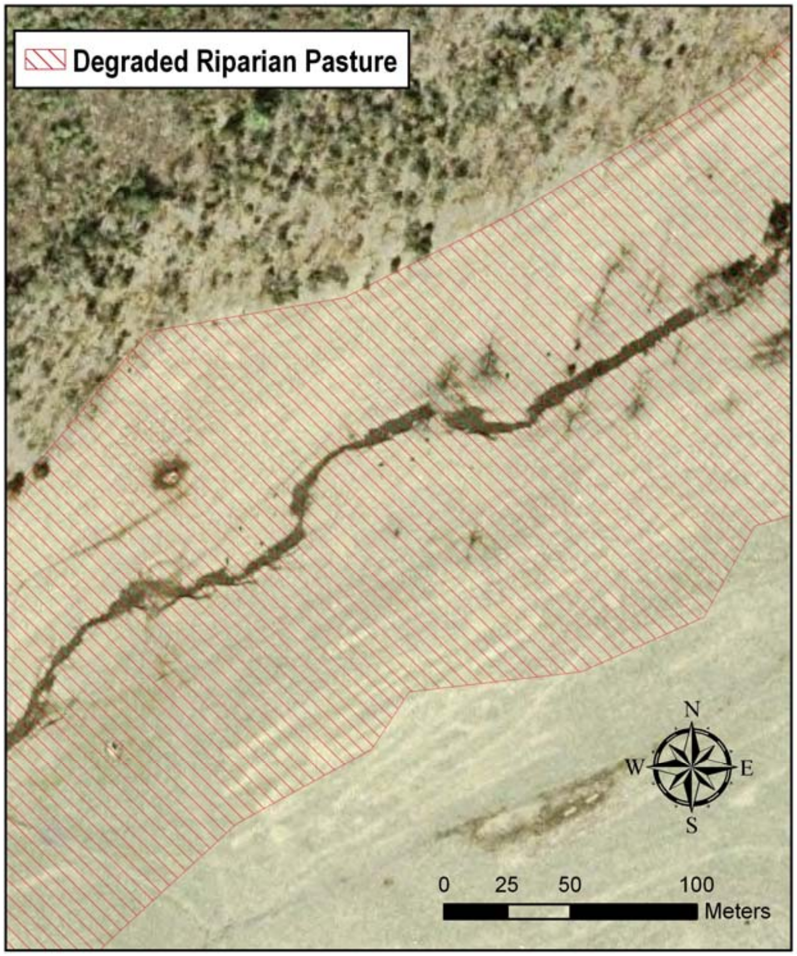

Figure 6-6. Example of Areas Designated as Degraded Riparian Pasture.

After necessary aggregation and disaggregation of the VADOF land cover data set was conducted, a robust land use data set was obtained for the Little Calfpasture River watershed. Table 6-5 shows the land use breakdown in each sub-watershed. These land use values were used to represent the watershed in the LSPC model, and they were used to calculate land use specific sediment loadings for the watershed. The impervious urban/transportation land use was modeled as an impervious land segment, and all other land uses were modeled as pervious land segments.

Table 6-5. Land Use in the Little Calfpasture River Watershed.

Sub-Watershed	Acres in Each Land Use						
	Residential	Cropland	Pasture/Hay	Degraded Riparian Pasture	Forest	Impervious Urban/Trans-portation	Total
1	0	0	8	0	86	0	94
2	0	0	0	0	392	0	392
3	0	0	24	0	54	0	79
10	0	4	89	0	980	13	1086
11	0	9	96	0	546	15	665
12	0	1	97	54	267	5	423
13	0	8	51	19	669	0	746
14	0	1	1	0	1106	0	1108
15	0	0	4	0	723	0	727
16	0	0	0	0	685	0	685
17	0	0	0	0	443	0	443
20	10	51	753	138	2887	27	3866
21	0	0	1	0	6	1	8
22	45	24	567	208	5287	97	6227
23	2	13	710	77	3712	32	4546
24	8	47	934	420	6460	77	7945
25	1	2	222	58	486	22	790
26	143	25	454	30	4649	91	5392
27	10	8	195	41	419	19	692
28	3	1	152	25	1775	6	1962
29	36	34	605	1	5551	57	6285
30	14	0	51	0	1916	2	1984
31	13	12	187	0	6534	39	6785
Total	**284**	**239**	**5198**	**1072**	**45633**	**504**	**52930**
%	**0.54%**	**0.45%**	**9.82%**	**2.03%**	**86.21%**	**0.95%**	**100.00%**

6.2.3. Hydrologic Model Parameters

The LSPC model was constructed to simulate both hydrology and sediment in the Little Calfpasture River. Because the hydrology of the watershed is so important in controlling the loading and concentrations of pollutants in the stream, the hydrology portion of water quality models is developed first and calibrated to available flow gage information. Once the model is accurately representing the hydrology of the watershed, then the sediment loadings are included in the model and the water quality is calibrated to match observed in-stream concentrations. Unfortunately, the Little Calfpasture River is not gaged, so it is not possible to directly calibrate flow for the watershed. In order to overcome this obstacle, hydrologic parameters for the watershed that could not be measured were taken from the calibrated Chesapeake Bay Phase V

Model. The Chesapeake Bay Model is a Hydrologic Simulation Program-Fortran (HSPF) model for simulating sediment and nutrients in the Chesapeake Bay. The Chesapeake Bay model is parameterized on a County (or slightly smaller) scale, and is calibrated at regional flow gaging locations, such as the Maury River at Rockbridge Baths. Therefore, the model parameters do reflect calibrated values, even though the calibration is at a larger scale. Because the Little Calfpasture River watershed is located in Augusta and Rockbridge Counties, calibrated Chesapeake Bay model parameters from western Augusta (C51015) were used for sub-watersheds 23-31, while calibrated Chesapeake Bay model parameters from Rockbridge (A51163) were used for the remaining sub-watersheds.

A number of different model parameters are required in the LSPC model to simulate hydrology. Table 6-6, Table 6-7, and Table 6-8 show the different hydrologic parameters used in the Little Calfpasture River LSPC model to represent hydrology, including the impacts of soil temperature and snow. These tables describe how the value for each parameter was obtained and the variables by which the parameter was altered. Some of the parameters were constants used throughout the model, while others varied by sub-watershed, land use, or month. The source of parameter values used in the model varied depending upon the parameter. Some of the parameters, such as physical characteristics of the stream channel, were specifically measured in the field by VADEQ staff. Other parameters were obtained by analyzing GIS coverages of the watershed. For instance, the slopes of each reach were obtained by combining digital elevation data for the watershed and stream coverages. Other parameters were estimated from literature values. Finally, the majority of parameters were obtained from the calibrated Chesapeake Bay Model. The resulting values for hydrologic parameters in the final Little Calfpasture River LSPC model are listed in APPENDIX A.

Table 6-6. Hydrologic Model Parameters for the Little Calfpasture River LSPC Model.

Parameter	Parameter Description	Varied By	Source[a]
DEPINIT_M	Initial water depth	Sub-watershed	Field measurement
LEN_M	Longitudinal length of the reach	Sub-watershed	GIS measurement
SLOPE	Longitudinal slope of the reach	Sub-watershed	GIS measurement
WID_M	Cross-sectional bankfull width	Sub-watershed	Field measurement

DEP_M	Cross-sectional bankfull depth	Sub-watershed	Field measurement
R1	Ratio of bottom width to bankfull width	Sub-watershed	Field measurement
R2	Upper bank slope	Sub-watershed	Field measurement
W1	Ratio of bank width to bankfull width	Sub-watershed	Field measurement
MANNING_N	Manning's roughness coefficient	Constant	Estimated from literature
CRRAT	Ratio of maximum velocity to mean velocity	Sub-watershed	Estimated from literature
SLSUR	Slope of overland flow	Sub-watershed and Land use	GIS measurement
LSUR	Length of overland flow	Sub-watershed and Land use	GIS measurement
MELEV	Mean watershed elevation	Sub-watershed	GIS measurement
RMELEV	Mean reach elevation	Sub-watershed	GIS measurement
LZSN	Lower zone nominal soil moisture storage	Sub-watershed and Land use	CBM
INFILT	Index to infiltration capacity	Sub-watershed and Land use	CBM
KVARY	Variable groundwater recession	Constant	CBM
AGWRC	Base groundwater recession	Sub-watershed	CBM
PETMAX	Temperature below which evapotranspiration is reduced	Constant	CBM
PETMIN	Temperature below which evapotranspiration is set to zero	Constant	CBM
INFEXP	Exponent in infiltration equation	Constant	CBM
INFILD	Ratio of max/mean infiltration capacities	Constant	CBM
DEEPFR	Fraction of groundwater inflow to deep recharge	Constant	CBM
BASETP	Fraction of remaining evapotranspiration from baseflow	Constant	CBM
AGWETP	Fraction of remaining evapotranspiration from active groundwater	Sub-watershed and Land use	CBM
CEPSC	Interception storage capacity	Sub-watershed, Land use, and Month	CBM
UZSN	Upper zone nominal soil moisture storage	Sub-watershed, Land use and Month	CBM
NSUR	Manning's n for overland flow	Sub-watershed, Land use, and Month	CBM
INTWF	Interflow inflow parameter	Sub-watershed	CBM
IRC	Interflow recession parameter	Sub-watershed	CBM
LZETP	Lower zone evapotranspiration parameter	Sub-watershed, Land use and Month	CBM

[a] CBM = Chesapeake Bay Model.

Table 6-7. Soil Temperature Model Parameters for the Little Calfpasture River LSPC Model.

Parameter	Parameter Description	Varied By	Source[a]
ASLT	Surface layer temperature when air temperature is 0°C	Sub-watershed and Month	CBM
BSLT	Slope of the surface layer temperature regression equation	Sub-watershed, Land use, and Month	CBM
AIFT	Mean difference between interflow temperature and air temperature	Sub-watershed and Month	CBM
BIFT	Smoothing factor in the interflow temperature calculation	Sub-watershed, Land use, and Month	CBM
AGWT	Mean difference between groundwater temperature and air temperature	Sub-watershed and Month	CBM
BGWT	Smoothing factor in groundwater temperature calculation	Constant	CBM
ISLT	Initial surface flow temperature	Constant	CBM
IIFT	Initial interflow temperature	Constant	CBM
IGWT	Initial groundwater temperature	Sub-watershed	CBM
MELEV	Mean watershed elevation	Sub-watershed	GIS measurement
ELDAT	Difference in elevation between the watershed and air temperature gage	Sub-watershed	GIS measurement
RELDAT	Difference in elevation between the reach and air temperature gage	Sub-watershed	GIS measurement
CFSAEX	Correction factor for solar radiation	Constant	CBM
KATRAD	Longwave radiation coefficient	Constant	CBM
KCOND	Conduction-convection heat transport coefficient	Constant	CBM
KEVAP	Evaporation coefficient	Constant	CBM

[a] CBM = Chesapeake Bay Model.

Table 6-8. Snow Model Parameters for the Little Calpasture River LSPC Model.

Parameter	Parameter Description	Varied By	Source[a]
Forest	Fraction of land covered by forest	Sub-watershed and Land use	CBM
LAT	Latitude	Constant	GIS measurement
SHADE	Fraction of land shaded from solar radiation	Sub-watershed and Land use	CBM
SNOWCF	Precipitation to snow multiplier	Constant	CBM
COVIND	Maximum snow pack at which the entire land is covered with snow	Sub-watershed	CBM
RDCSN	Density of cold, new snow relative to water	Constant	CBM
TSNOW	Air temperature below which precipitation will be snow	Constant	CBM

SNOEVP	Adapts sublimation equation to field conditions	Constant	CBM
CCFACT	Adapts snow condensation/convection melt equation	Constant	CBM
MWATER	Maximum water content of snow pack	Constant	CBM
MGMELT	Maximum rate of snow melt by ground heat	Constant	CBM
Pack-Snow	Initial quantity of snow in pack	Sub-watershed	CBM
Pack-Ice	Initial quantity of ice in pack	Constant	CBM
Pack-Water	Initial quantity of water in pack	Constant	CBM
RDENPF	Density of the pack	Constant	CBM
DULL	Index of the dullness of the snow pack surface	Constant	CBM
PAKTMP	Mean temperature of the pack	Constant	CBM
COVINX	Initial snow pack depth	Sub-watershed	CBM
XLNMLT	Current remaining possible increment to ice storage in the pack	Constant	CBM
SKYCLR	Initial fraction of sky which is clear	Constant	CBM

[a] CBM = Chesapeake Bay Model.

6.2.4. Sediment LSPC Model Parameters

Following development of the Little Calfpasture River hydrology model, the LSPC model was expanded to simulate sediment concentrations. A number of different model parameters are required in the LSPC model to simulate sediment washoff and transport. Table 6-9 shows the different sediment parameters used in the Little Calfpasture River LSPC model to simulate sediment. Many of the parameters were based on values from the Chesapeake Bay Model for western Augusta and Rockbridge Counties. A subset of parameters were initially estimated from the Chesapeake Bay Model values or from literature values and then adjusted during the calibration of the sediment model to optimize agreement between simulated and measured suspended sediment concentrations. The resulting values for LSPC sediment parameters in the calibrated Little Calfpasture River LSPC model are listed in APPENDIX B.

Table 6-9. Sediment Parameters for the Little Calfpasture River LSPC Model.

Parameter	Parameter Description	Varied By	Source[a]
SMPF	Supporting management practice factor	Constant	CBM
KRER	Coefficient in the soil detachment equation	Sub-watershed and Land use	CBM
JRER	Exponent in the soil detachment equation	Constant	CBM
AFFIX	Fraction by which detached sediment storage decreases each day as a result of soil compaction	Constant	CBM
COVER	Fraction of land surface shielded from rainfall erosion	Land use and Month	CBM
NVSI	Rate at which sediment enters detached storage from the atmosphere	Sub-watershed and Land use	CBM
KSER	Coefficient in the detached sediment washoff equation	Sub-watershed and Land use	CBM initially, then calibrated
JSER	Exponent in the detached sediment washoff equation	Constant	CBM initially, then calibrated
KGER	Coefficient in the soil scour equation	Constant	CBM
JGER	Exponent in the soil scour equation	Constant	CBM
ACCSDP	Rate at which solids accumulate on the land surface	Land use	CBM initially, then calibrated
REMSDP	Fraction of solids storage which is removed each day when there is no runoff	Land use	CBM
SED_SURO	Background concentration in surface flow	Constant	Calibrated
SED_IFWO	Background concentration in interflow	Constant	Calibrated
SED_AGWO	Background concentration in groundwater	Constant	Calibrated
SAND	Fraction of soil that is sand	Sub-watershed	Local soils data initially, then calibrated
SED_1	Fraction of soil that is silt	Sub-watershed	Local soils data initially, then calibrated
SED_2	Fraction of soil that is clay	Sub-watershed	Local soils data initially, then calibrated
BEDWID	Bed width	Constant	Stream measurements
BEDDEP	Initial bed depth	Constant	Visual observation
POR	Porosity	Constant	Estimated from literature
SEDO	Initial sediment concentration in fluid phase	Sediment class	Estimated from monitoring data
SEDBO	Initial fraction of bed depth that is clay or silt	Sediment class	Visual observation
D	Effective diameter of the particles	Sediment class	Estimated from literature
W	Fall velocity	Sediment class	Calculated from Stokes

			Equation, then calibrated
RHO	Particle density	Sediment class	Estimated from literature, then calibrated
TAUCD	Critical bed shear stress for deposition	Sediment class	Estimated from literature, then calibrated
TAUCS	Critical bed shear stress for scour	Sediment class	Estimated from literature, then calibrated
M	Erodibility coefficient	Sediment class	Estimated from literature

[a] CBM = Chesapeake Bay Model.

6.2.5. Depths of Lake Merriweather

The EFDC model requires depth information for each cell in the model grid. To obtain depths throughout the lake, VADEQ conducted a lake depth survey on 8/22/07. At this time, virtually no water was flowing over the top of the dam, so depth measurements reflect depths from the full pool elevation of 1369 ft. VADEQ staff traversed the lake in seven diagonal passes recording GPS (Global Positioning System) coordinates and depth values at regular intervals. A total of 148 individual depth measurements were made with an acoustic depth-finder. These points and the seven lake transects are shown on Figure 6-7. In addition to the depth measurements, historic topographic maps of the area prior to the construction of the dam were used to estimate depths at key locations in the lake (particularly in the upstream portion of the lake not covered by depth monitoring transects). Based on the measured and estimated depths, a bathymetric map of the lake was constructed (Figure 6-7).

The maximum recorded depth of the lake was 20 ft. This is six feet shallower than the presumed constructed depth of the lake and indicates significant filling of the lake with sediment. Based on the bathymetric map presented in Figure 6-7, the average depth of Lake Merriweather is only 6.68 ft, and the calculated water storage volume of the lake is approximately 2900 acre-ft. Using this storage volume, average retention times were calculated for the lake based on various flow conditions (Figure 6-8). At median flow conditions, the average retention time of Lake Merriweather is 28 days. Under storm conditions, however, this retention time can be much shorter. At the 10^{th} percent highest flows, which is above 267 cfs, retention times in the lake are less than 5.5 days.

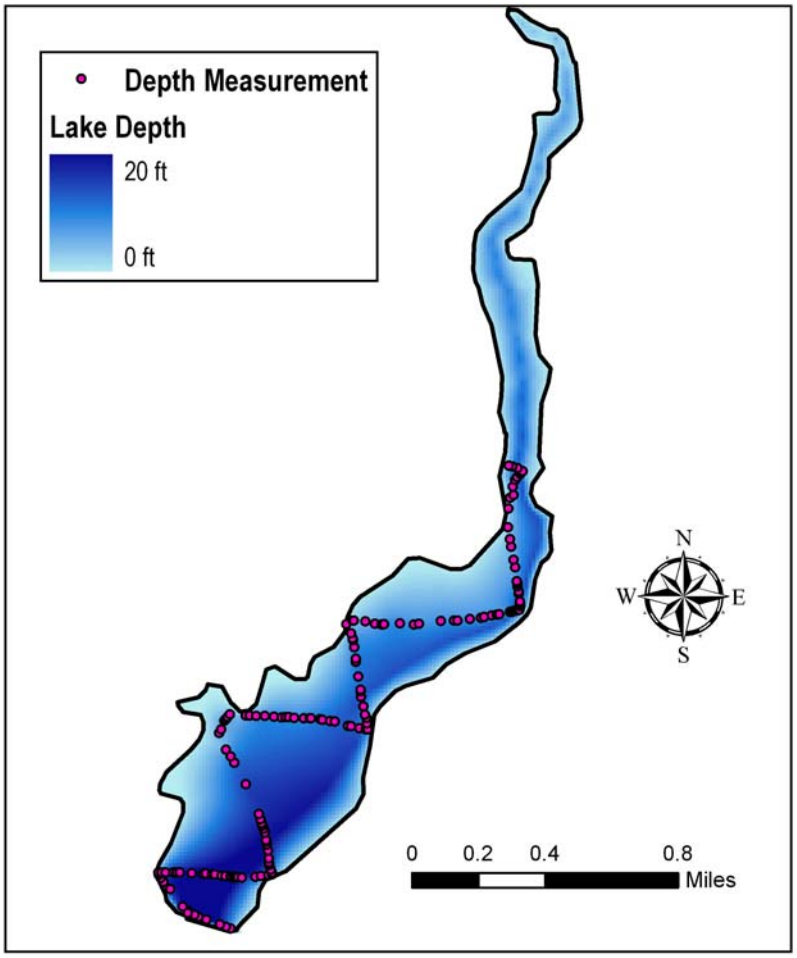

Figure 6-7. Depth Profile of Lake Merriweather.

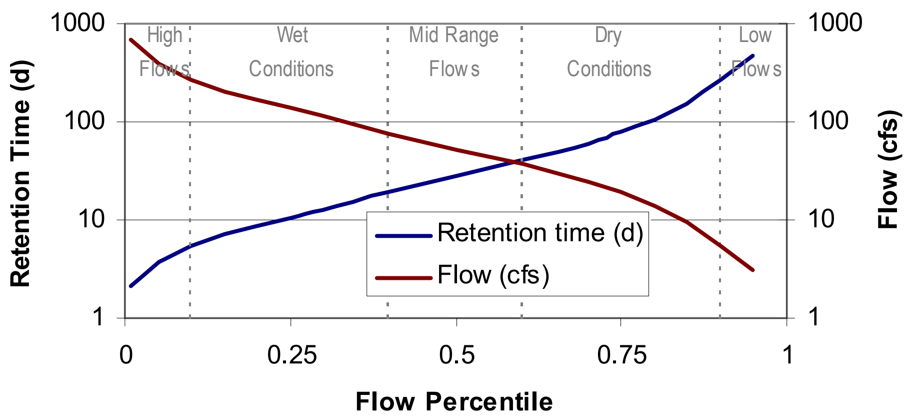

Figure 6-8. Retention Time in Lake Merriweather.

6.2.6. Goshen Dam Operations and Outflow Structure

An important component of the EFDC model for Lake Merriweather was representation of the dam and the outlet structure. Flow through the dam spillway was calculated in the model based on a rating curve that equates height of surface water elevation above the gates to flow. The rating curve shown in Table 6-10 was used to represent flow through the spillway with gates in the full pool position. This rating curve was developed from the equation below for flow over a weir.

$$Q = L * C * H^{1.5}$$

Where,

Q = Flow over the weir (cfs),

L = Length of the weir (130 ft),

C = Constant (3.33), and

H = Head over the weir (ft).

For heads of 11 ft or less, the above equation was used with a weir length of 130 ft, which is the width of the spillway. For head values above 11 ft, flow over the top of the earthen dam face would begin. To calculate flows at these heads, the flow through the spillway was added to flow over the earthen dam face. Flow over the earthen dam face was calculated using the equation above and a 2000 ft weir length.

In addition to flow through the spillway, flow through the cold water release structure was represented. On 8/22/07, when no water was coming over the gates, VADEQ measured flow just downstream of the dam. At this time, both cold water release valves were open. The measured flow was 5.68 cfs coming from the two releases combined. In the model, a constant outflow of 2.84 cfs was used to represent flow through the cold water release, since only one of the valves is typically opened.

Table 6-10. Rating Curve for Flow Through the Dam Spillway.

Surf Elev (ft)	Head (ft)	Flow (cfs)
1369.5	0.5	153
1370	1	433
1370.5	1.5	795
1371	2	1224
1371.5	2.5	1711
1372	3	2249
1373	4	3463
1374	5	4840
1375	6	6362
1376	7	8017
1377	8	9795
1378	9	11688
1379	10	13689
1380	11	15793
1381	12	24660
1390	21	252268

To model the flow and sediment conditions in Lake Merriweather over the past seven years, it was necessary to consider the operation of the spillway gates. As shown in Table 2-1, records show that the dam gates were lowered more than two feet on several occasions, including for large storms and during winter months. These lowering events were represented in the EFDC model by lowering the elevation of the spillway in the model. This modification was conducted during the lowering events shown in Table 6-11. Only recorded lowering events from 2000-

2006 (the modeling period) that were larger than 2 ft and longer than 2 days were modeled. Smaller and shorter lowerings would not have much impact on daily sediment loads and would be difficult to accurately model without specific information on the timing and mechanics of individual lowering events (e.g., which gates were lowered, at what time, and how long did lowering take).

Table 6-11. Modeled Lake Lowering Events.

Dates of Lake Lowering		Spillway Elevation (ft)	Feet Below Full Pool (ft)
From	To		
9/6/2004	10/13/2004	1360	9
10/19/2004	3/28/2005	1360.5	8.5
9/10/2005	10/28/2005	1359	10
12/3/2005	3/4/2006	1361	8
9/5/2006	12/31/2006	1365	4[a]

[a] Table 2-1 indicates a 5.5 ft maximum lowering for maintenance, however, records indicate that the lake was maintained at approximately 4 ft below full pool for the majority of this time period.

During periods when the lake is lowered, the shoreline recedes and the lake bottom is exposed in areas that are typically covered with shallow water. Exposed sediments that were deposited in these shallow areas are then available for washoff into the lake. To account for this phenomenon, an additional sediment loading was modeled during times when the lake was lowered. The area of lake bottom exposed under each different lowering condition was determined based on the bathymetric map and associated depths at full pool. Figure 6-9 shows the exposed area that would be expected under each lowering condition, and Table 6-12 quantifies the acreage. When the lake is lowered just 4 feet, approximately 143 acres of lake bottom would be exposed. At 8 feet below full pool, more than half of the original lake (266 acres) is exposed. At 10 ft below full pool, approximately 319 acres of lake bottom would be exposed.

The acreages of exposed lake bottom under each lake lowering condition were modeled as pervious land segments using LSPC. These land segments were modeled using the precipitation conditions occurring at the time that the lake was lowered to the respective level. Calibrated hydrologic and sediment parameters from the degraded riparian pasture land use were used to characterize these areas, since they are located in close proximity to the waterbody and would be expected to contribute high sediment loads. LSPC was used to generate a time series of flow and sediment loads from these areas. Those loadings were added to a cell in the center of Lake Merriweather in the EFDC model. While the actual loadings would be distributed around the shoreline of the lake, adding the load to the center of the lake greatly simplified the modeling approach and would approximate actual conditions given the mixing of the lake during high flow runoff periods.

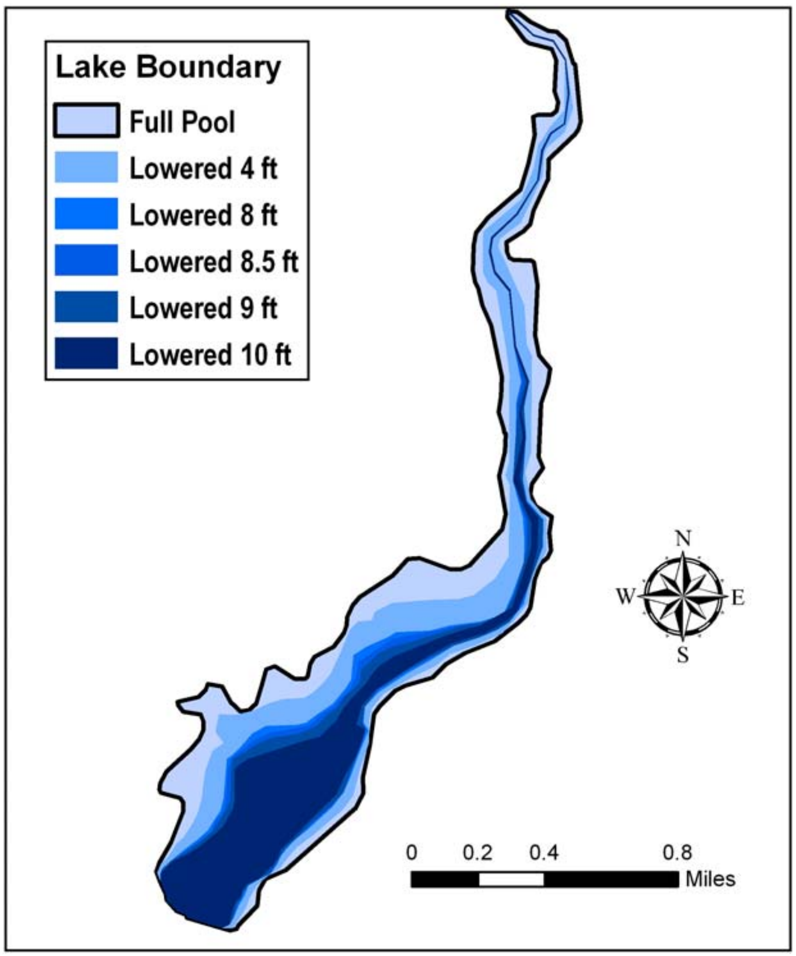

Figure 6-9. Boundaries of Lake Merriweather at Various Depths.

Table 6-12. Acreage of Exposed Lake Bottom at Various Dam Gate Positions.

Gate Position	Wetted Area (acres)	Exposed Lake Bottom (acres)
Full Pool	444	0
Lowered 4 ft	301	143
Lowered 8 ft	178	266
Lowered 8.5 ft	166	278
Lowered 9 ft	155	289
Lowered 10 ft	125	319

6.3. ACCOUNTING FOR POLLUTANT SOURCES

There are a total of 8 permitted point source discharges in the Little Calfpasture River watershed (Section 5.1). During TMDL allocation model runs, permitted point sources were modeled using maximum permitted design flows and permitted monthly average TSS concentrations (see Table 5-1). SFH permits were modeled at 1,000 gal/d and 30 mg/L TSS. Augusta Springs WTP and Craigsville WTP were both modeled using 30 mg/L TSS and 0.072 or 0.012 MGD, respectively. The Craigsville STP was modeled using 30 mg/L TSS at a flow of 0.435 MGD. Casta Line Trout Farm was modeled using the average measured flow conditions and TSS concentrations set to meet the Wallace Mill Stream TMDL. Blue Ridge Lumber Co. was modeled as an impervious area using LSPC.

During calibration and existing condition model runs, permitted point sources were modeled using flows more representative than design flows. Flows for Augusta Springs WTP and Casta Line Trout Farm were based on flows reported by the facility on discharge monitoring reports (DMRs). The Craigsville WTP and STP were modeled with zero flow, since these facilities are not yet constructed and discharging. SFH general permits that did not discharge to perennial streams were also modeled with zero flow during calibration and existing condition model runs. This is because under normal conditions, flow from these discharges would percolate into the soil within dry ditches and not affect sediment concentrations or flows in the Little Calfpasture River.

6.4. ACCOUNTING FOR BEST MANAGEMENT PRACTICES (BMPS)

The Virginia Department of Conservation and Recreation (DCR) tracks all agricultural best management practices (BMPs) that are cost-shared in Virginia. From a search of this database, two BMPs within the Little Calfpasture River watershed were identified (Figure 6-10). Within sub-watershed 26, twenty acres of erodible land were reforested. Within sub-watersheds 20, 12, and 13, a grazing land protection practice was installed. This project included 3930 ft of livestock exclusion fencing that restored 100 acres of degraded riparian pasture. Both of these BMPs were installed in 2008, so their presence should not effect land uses during the model calibration period of 2000-2006. These BMPs, however, will change the future land uses that represent the TMDL scenario. For this reason, future land uses were modified to account for these BMPs (see Section 7.2). It is possible that additional BMPs have been installed voluntarily in the watershed without financial assistance, but lacking any information on those practices, the TMDL considered only those BMPs tracked by DCR.

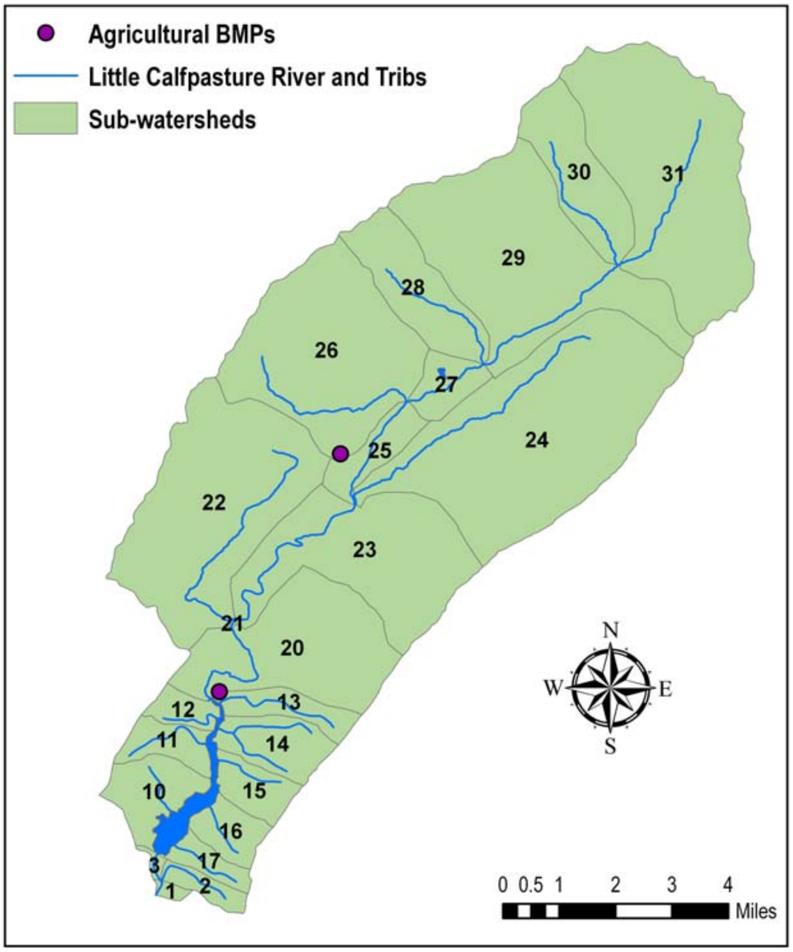

Figure 6-10. Agricultural Best Management Practices Installed in the Little Calfpasture River Watershed through the Virginia Agricultural Cost-Share Program.

6.5. MODEL CALIBRATION AND VALIDATION

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. In this section, the procedures followed for calibrating the watershed model are discussed.

> **Definition:**
>
> Calibration – Calibration is the process of adjusting model parameters until the computer model produces the best possible fit with real-world data.

6.5.1. Hydrology

Because there is no flow gage on the Little Calfpasture River, it was not possible to directly calibrate the hydrologic portion of the Little Calfpasture River model. In lieu of direct hydrologic calibration, the Little Calfpasture River model used hydrologic parameters from the Chesapeake Bay Model that were calibrated for western Augusta and Rockbridge Counties. The Chesapeake Bay Model used an automated routine to calibrate land use-specific hydrologic parameters for each hydrologic response unit. Parameters were calibrated to match gaged hydrology at multiple stations receiving flow from given hydrologic response units. These calibrated parameters for the Little Calfpasture River watershed are believed to adequately represent the hydrologic conditions of the Little Calfpasture River.

While it was not possible to directly calibrate hydrology in the Little Calfpasture River, model results were tested by using simulated Little Calfpasture River flows and gaged Calfpasture River flows to reconstruct Maury River flows. The Calfpasture River is gaged approximately 5 miles upstream from its confluence with the Little Calfpasture River, and the Maury River is gaged approximately 5 miles downstream from the confluence of the Calfpasture and Little Calfpasture Rivers (Figure 6-11). To test the validity of simulated Little Calfpasture River flows, the observed flow in the Maury River was compared to the sum of simulated Little Calfpasture River flows, gaged Calfpasture River flows, and area-proportioned flows for the remainder of the Maury River watershed. Above the gage at Rockbridge Baths, the Maury River has a total drainage area of 210,560 acres, which includes the 53,395-acre Little Calfpasture River watershed, the 90,240-acre gaged Calfpasture River watershed, and a remaining 66,925 acres not accounted for by the Calfpasture River gage or the Little Calfpasture River. Flows from this remaining area were estimated as 31.78% of Maury River flow. If modeled hydrology in the Little Calfpasture River is representative, then the sum of simulated Little Calfpasture River flows, gaged Calfpasture River flows, and estimated flows from the remaining area should match gaged flows in the Maury River.

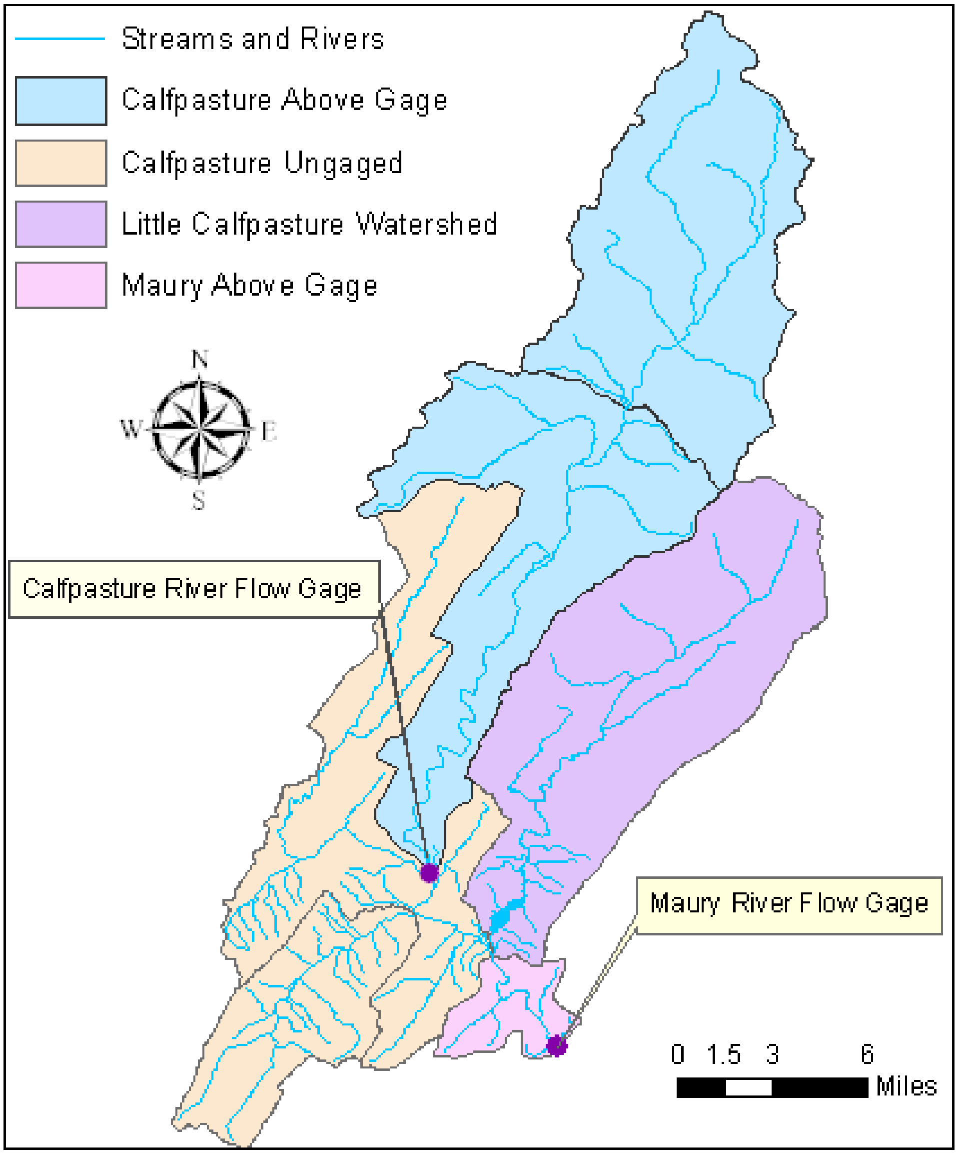

Figure 6-11. Location of Flow Gages on the Maury River and Upstream Watersheds.

Comparison of the modeled (i.e., sum of Little Calfpasture modeled flows, Calfpasture gaged flows, and area-proportioned flows for the remainder of the watershed) and observed flows from the Maury River gage show considerable agreement both in daily values (Figure 6-12) and monthly values (Figure 6-13). Table 6-13 shows the error statistics between the two data sets. Compared to typical calibration criteria, the simulated flows match nicely. All statistics were within typical calibration criteria. The observed agreement between the two approaches indicates that the model developed for the Little Calfpasture River watershed represents the hydrologic conditions in the watershed and can be used to reasonably predict flows in the Little Calfpasture River.

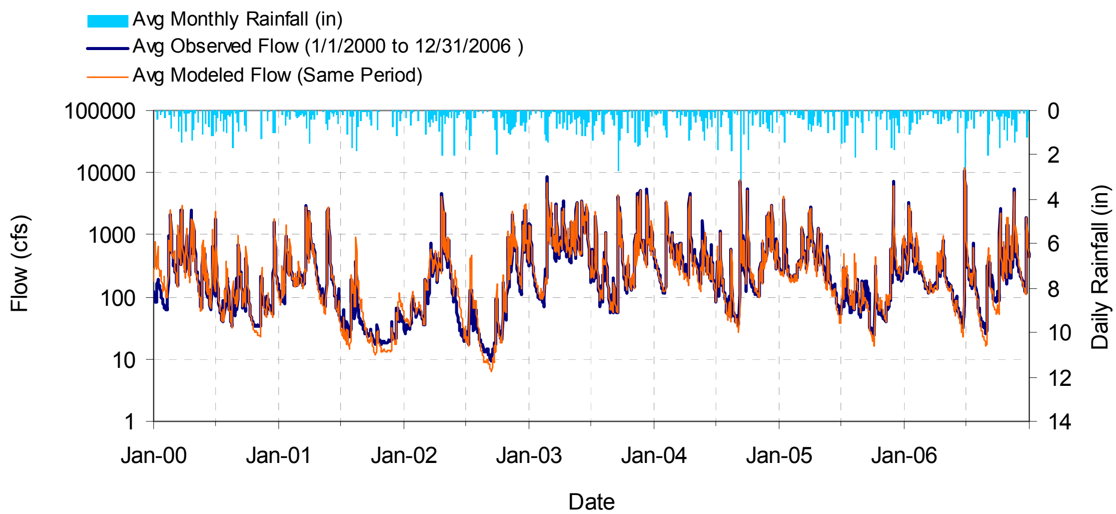

Figure 6-12. Comparison of Daily Calculated and Measured Flows in the Maury River.

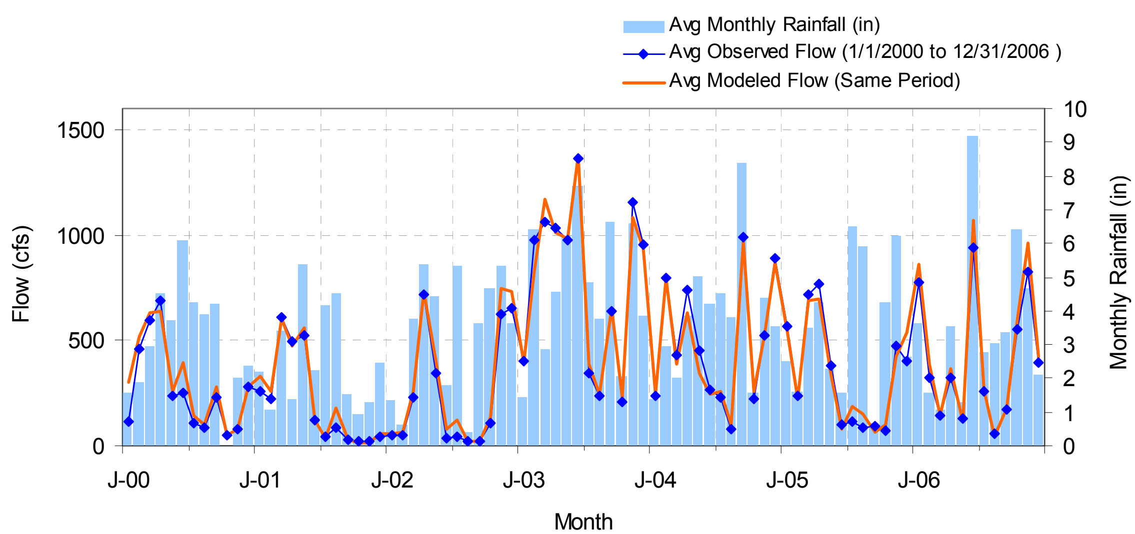

Figure 6-13. Comparison of Monthly Calculated and Measured Flows in the Maury River.

Table 6-13. Error Statistics for Calculated Flows Compared to Measured Maury River Flows (2001-2006).

Statistics	Calculated (in/yr)	Observed (in/yr)	Error (%)	Typical Criteria (%)
Total volume	16.71	16.00	4.46	10
Volume of 50% lowest flows	7.93	7.74	8.93	10
Volume of 10% highest flows	1.81	1.66	2.48	15
Seasonal volume - Summer	2.18	1.95	11.61	30
Seasonal volume - Fall	4.47	4.21	6.10	30
Seasonal volume - Winter	4.73	4.51	4.87	30
Seasonal volume - Spring	5.34	5.33	0.20	30
Total storm volume	8.19	7.57	8.27	20
Summer storm volume	1.20	1.06	12.98	50
Coefficient of Determination (r^2)	0.9719			

6.5.2. Sediment Calibration

Sediment is one of the most difficult water quality parameters to calibrate in watershed and water quality models. For the Little Calfpasture River, a "weight of evidence" approach was used to calibrate sediment, following the recommendations of Donigian and Love (2003) and USEPA (2006). This weight of evidence approach involved the following steps:

- Estimate target sediment loading rates from the landscape using the Revised Universal Soil Loss Equation (RUSLE). Then compare target values to simulated loading rates and adjust sediment washoff parameters to achieve best overall fit.

- Adjust scour, deposition, and transport parameters to match field observations of sediment bed behavior.

- Estimate target sediment fluxes using the relationship between available flow data and observed sediment concentrations. Then compare target fluxes with simulated sediment fluxes and adjust parameters as necessary.

- Compare simulated sediment concentrations to observed sediment concentrations upstream of Lake Merriweather. Station 2-LCF007.00, upstream of Lake Merriweather, was used to calibrate sediment parameters for the LSPC watershed model.

- Compare simulated sediment concentrations to observed sediment concentrations downstream of Lake Merriweather. Station 2-LCF000.02, downstream of Lake Merriweather, was used to calibrate sediment parameters for the EFDC water quality model for the lake.

- Compare the response of the modeled sediment concentrations during individual storm events with observed patterns.

The first step of estimating target land-based sediment loadings was accomplished using the RUSLE2 software (USDA, 2003). RUSLE2 was used to estimate average annual erosion rates for each land use according to the measured slope and overland flow path characteristics in each sub-watershed. The estimated erosion rates were then adjusted by a sediment delivery factor according to the following equation from Donigian and Love (2003):

$$SDR = 0.417762 * A^{-0.134958} - 0.127097$$

Where,
SDR = Sediment Delivery Ratio, and
A = drainage area (mile^2).

The adjusted erosion rates were then summed for each land use area in a sub-watershed, and the estimated annual land-based sediment load was obtained. This estimated target was then compared to the simulated annual loadings from each sub-watershed over the 2000-2006 simulation period. Figure 6-14 shows that the range of annual simulated sediment loadings for the 7 years between 2000 and 2006 nicely matched the annual sediment loading targets estimated from RUSLE2. The estimated target was outside of the simulated range for only 4 of the 23 sub-watersheds. Overall, average simulated sediment loadings differed by only 17% from the estimated annual targets. This indicates that the calibrated sediment washoff parameters produce reasonable and predictable sediment loadings for the watershed.

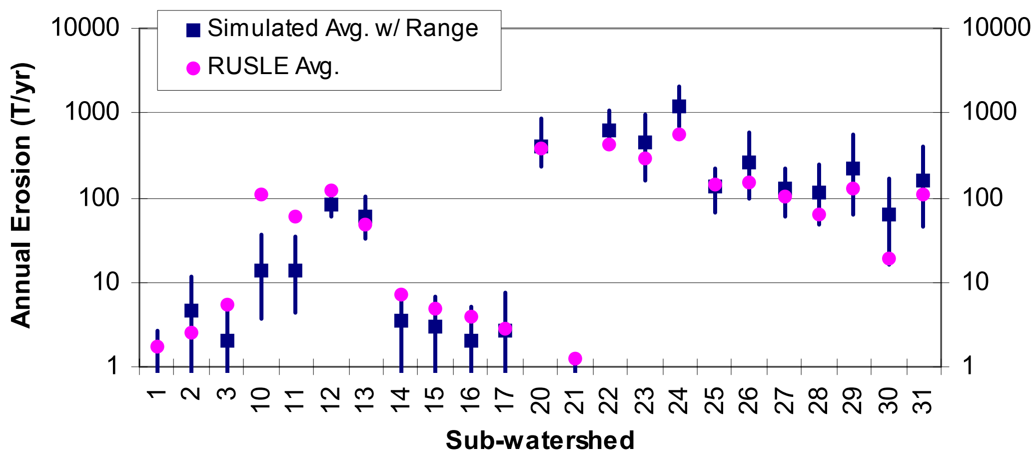

Figure 6-14. Comparison of Simulated Annual Land-based Sediment Loadings to RUSLE2 Calculated Loadings.

The next step in calibration was to adjust scour, deposition, and transport parameters to match field observations of sediment bed behavior. In general, field observations revealed that the Little Calfpasture River (above Lake Merriweather) was a reasonably high gradient mountainous zone stream with minimal sediment deposition. To match these observations, scour and deposition parameters were adjusted to simulate occasional sediment deposition under low bed shear stress conditions and frequent scouring of deposited material during high flow events. Figure 6-15 shows the total sediment deposition (per square meter of stream bottom) in each of the watershed reaches during the 7-year simulation period. Model results indicate that in most tributaries to the Little Calfpasture River, virtually no sediment deposition occurs. Sediment deposition occurs primarily in the main stem, and deposition is generally higher in the more downstream reaches, where slopes decrease and the channel widens. Sediment deposition is also minimal, with less than 0.08% of transported sediment depositing on the stream bed.

Model results also show that sediment deposits are relatively transient and easily scoured during storm events. For example, Figure 6-16 shows the mass of sediment stored on the stream bed in sub-watershed 20 over the duration of the simulation period. Deposition periodically occurs when flows are relatively low and there is minimal bed shear stress. The mass of stored bed sediment is also frequently removed by storm events. These results are consistent with field observations that upstream of Lake Merriweather the stream substrate is relatively clean and free of sediment at most times.

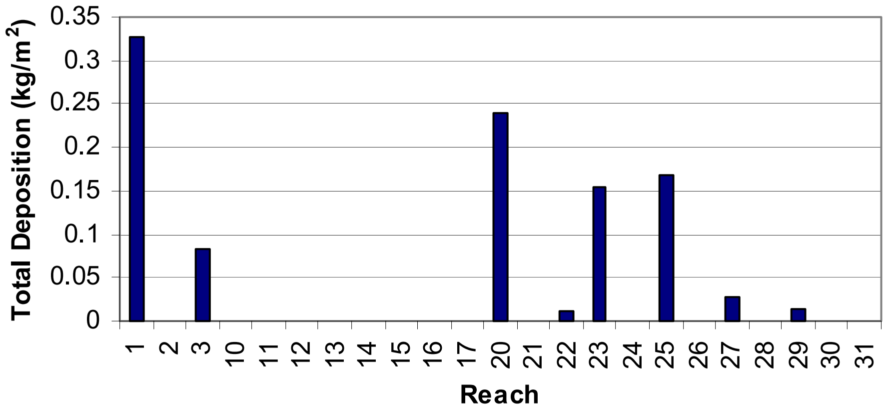

Figure 6-15. Total Sediment Deposition in Reaches of the Little Calfpasture River Watershed.

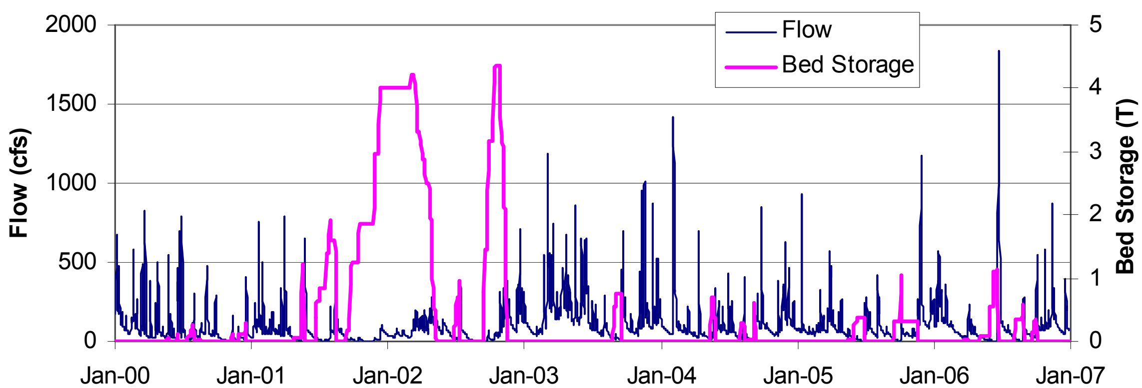

Figure 6-16. Simulated Sediment Stored on the Stream Bed in Sub-watershed 20.

The next step in sediment calibration was to estimate target sediment fluxes and compare those target fluxes with simulated sediment fluxes. A regression was developed based on measured TSS concentrations at Station 2-LCF007.00 and simulated flows at the time of sample collection. The resulting regression is shown in Figure 6-17. Using this relationship between TSS concentration and flow, annual sediment fluxes were estimated for 2000-2006. Figure 6-18 compares the simulated sediment fluxes for 2000-2006 to the target sediment fluxes estimated from the regression. On average, simulated sediment fluxes were 15% higher than sediment fluxes estimated from the regression. Overall, both methods compared nicely, demonstrating that simulated sediment fluxes are in line with fluxes that might be expected based on measured TSS concentrations and flow conditions.

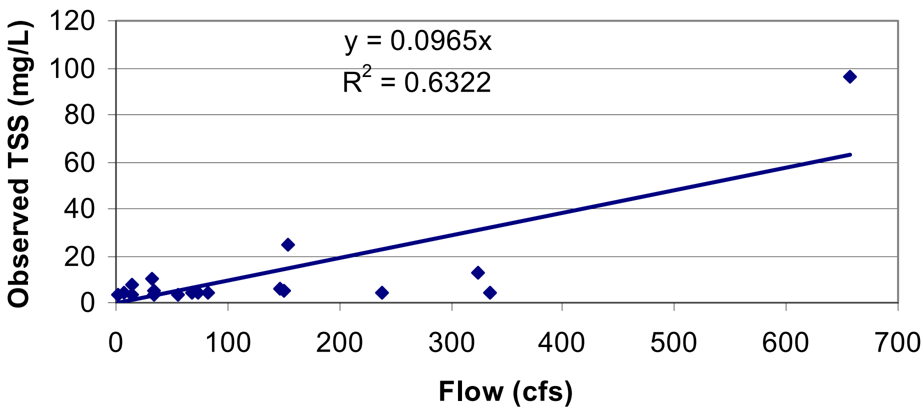

Figure 6-17. Regression of Observed TSS Concentraion at Station 2-LCF007.00 with Simulated Flow.

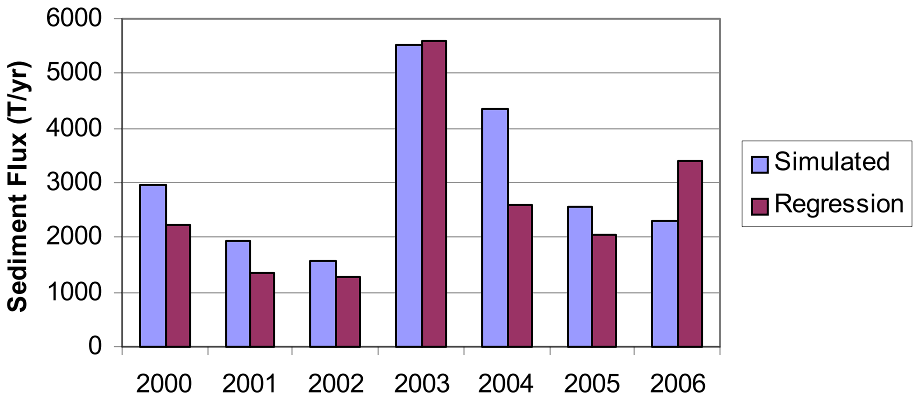

Figure 6-18. Comparison of Simulated Sediment Fluxes at Station 2-LCF007.00 and Target Sediment Fluxes Estimated from a Regression Model.

The next step in the calibration of sediment was to compare simulated sediment concentrations to observed sediment concentrations upstream of Lake Merriweather. Figure 6.19 and Figure 6-20 show the observed and simulated suspended sediment concentrations at Station 2-LCF007.00. Simulated TSS concentrations peak very quickly during storm events and then return very quickly to background levels near 0 mg/L. Because of the very flashy nature of TSS concentrations, grab samples tend to capture those high TSS concentrations very infrequently. Indeed, this is the case with observed TSS samples from 2-LCF007.00. Thirty-seven of the 51 grab samples were at or below the TSS detection limit of 3 mg/L. The highest observed TSS concentration was 96 mg/L on 9/28/04.

Table 6-14 compare the observed TSS values from grab samples to the range of simulated hourly TSS concentration on the day of sampling as well as the day before and the day after. This 3-day window is used because, precipitation inputs to the model are based on disaggregated daily values and the timing of individual storm events could be off by as much as 24 hours in one direction or the other. The flashy nature of TSS spikes means that peaks could easily be missed if focus is placed only on the day of sampling. A grab sample taken early on a given day may better reflect actual conditions on the day before and a grab sample taken late on a given day may better reflect actual conditions on the day after. Using this 3-day window approach, all but 3 of the 51 observed values fell within the range of simulated hourly TSS values surrounding the observation. This shows a relatively good agreement between simulated TSS concentrations and observed values above Lake Merriweather.

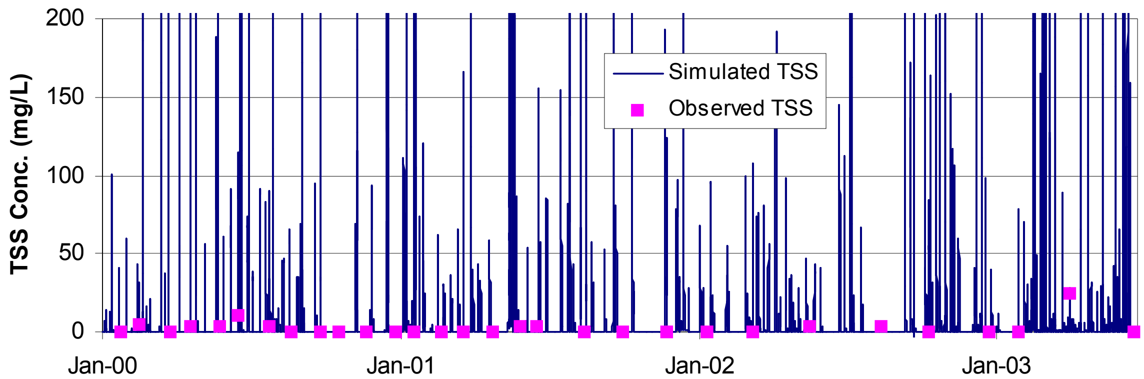

Figure 6-19. Observed and Simulated Suspended Sediment Concentrations at 2-LCF007.00 from 2000 to 2003.

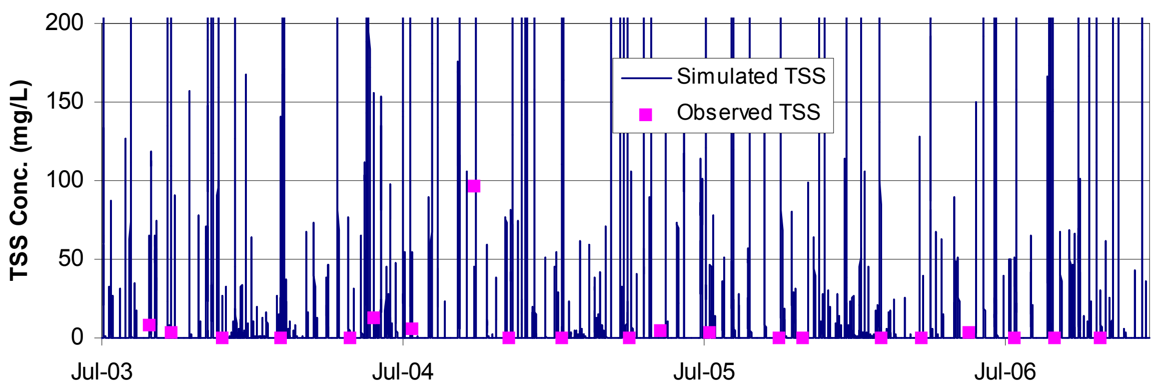

Figure 6-20. Observed and Simulated Suspended Sediment Concentrations at 2-LCF007.00 from 2003 to 2006.

Table 6-14. Comparison of Observed and Simulated Suspended Sediment Concentrations at Station 2-LCF007.00.

Sampling Date	Observed Value	Simulated Values Within 72-hr Range			Within Range?
		Min	Max	Average	
1/24/2000	<3	<3	<3	<3	Y
2/14/2000	5	<3	31	4	Y
3/23/2000	<3	<3	<3	<3	Y
4/17/2000	4	<3	295	20	Y
5/25/2000	3	<3	<3	<3	Y
6/15/2000	10	<3	112	15	Y
7/24/2000	4	<3	90	16	Y
8/21/2000	<3	<3	<3	<3	Y
9/25/2000	<3	<3	227	14	Y
10/19/2000	<3	<3	<3	<3	Y
11/20/2000	<3	<3	<3	<3	Y
12/28/2000	<3	<3	<3	<3	Y
1/18/2001	<3	<3	260	26	Y
2/21/2001	<3	<3	<3	<3	Y
3/20/2001	<3	<3	166	10	Y
4/26/2001	<3	<3	<3	<3	Y
5/29/2001	4	<3	14	<3	Y
6/19/2001	3	<3	143	6	Y
8/16/2001	<3	<3	<3	<3	Y
10/4/2001	<3	<3	<3	<3	Y
11/27/2001	<3	<3	124	27	Y
1/16/2002	<3	<3	<3	<3	Y
3/12/2002	<3	<3	108	10	Y
5/23/2002	3	<3	<3	<3	Y
8/19/2002	3	<3	<3	<3	Y
10/15/2002	<3	<3	84	12	Y
12/30/2002	<3	<3	<3	<3	Y
2/4/2003	<3	<3	79	10	Y
4/9/2003	25	<3	28	<3	Y
6/25/2003	<3	<3	<3	<3	Y
8/28/2003	8	<3	117	27	Y
9/24/2003	4	<3	375	19	Y
11/24/2003	<3	<3	26	<3	Y
2/5/2004	<3	<3	302	42	Y
4/28/2004	<3	<3	77	10	Y
5/27/2004	13	<3	155	12	Y
7/13/2004	6	<3	470	31	Y
9/28/2004	96	<3	668	40	Y
11/9/2004	<3	<3	<3	<3	Y
1/12/2005	<3	<3	111	<3	Y
4/6/2005	<3	<3	<3	<3	Y
5/12/2005	5	<3	<3	<3	N
7/11/2005	4	<3	<3	<3	N
10/5/2005	<3	<3	<3	<3	Y

11/3/2005	<3	<3	<3	<3	Y
2/6/2006	<3	<3	570	32	Y
3/28/2006	<3	<3	40	6	Y
5/24/2006	4	<3	<3	<3	N
7/19/2006	<3	<3	51	4	Y
9/7/2006	<3	<3	<3	<3	Y
11/2/2006	<3	<3	30	<3	Y

The next step in calibrating sediment in the Little Calfpasture River model was to compare observed TSS concentrations measured below Lake Merriweather to simulated values. A total of 32 TSS grab samples were collected at station 2-LCF000.02 during the model simulation period of 2000-2006. Simulated TSS concentrations were compared to these measured values, and adjustment of the EFDC model parameters (particle size and settling velocity) were made to obtain the best possible fit. Figure 6-21 and Figure 6-22 show the observed and simulated TSS concentrations at station 2-LCF000.02. With the exception of a few measurements in 2002, the simulated TSS concentrations matched observed values nicely. Records of dam operation during 2002 were not available from the Boy Scouts, and gate positions were assumed to be at full pool during this time period. It is possible that undocumented gate lowering events during this period could have produced higher TSS concentrations than values simulated under the assumption of full pool conditions. Overall, the model performed well at predicting TSS concentrations at the watershed outlet.

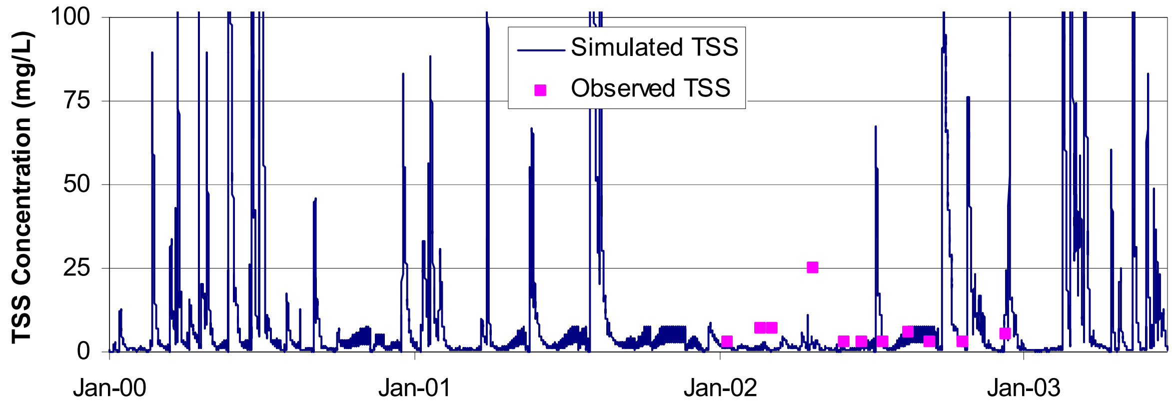

Figure 6-21. Observed and Simulated Suspended Sediment Concentrations at 2-LCF000.02 from 2000 to 2003.

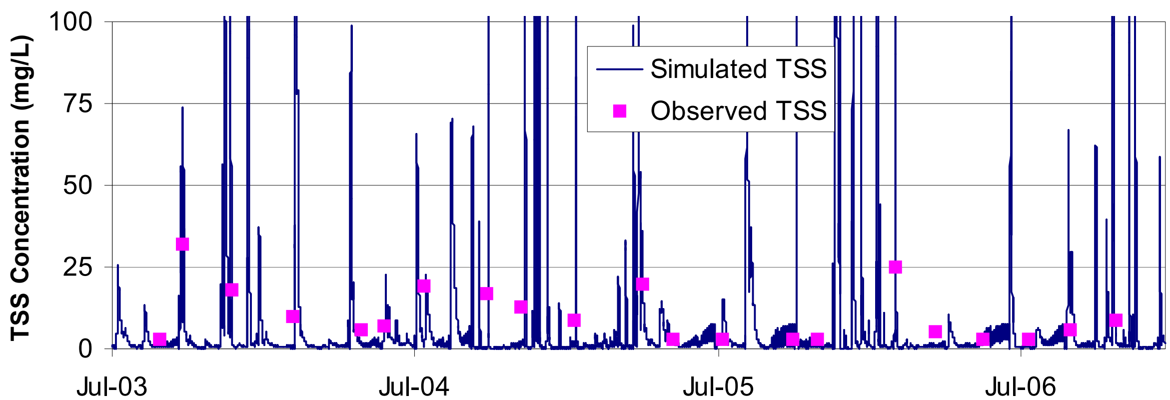

Figure 6-22. Observed and Simulated Suspended Sediment Concentrations at 2-LCF000.02 from 2003 to 2006.

Lastly, the response of the modeled sediment concentrations during individual storm events was evaluated. The analysis of measured turbidity values above and below Lake Merriweather provided several general observations about the pattern of suspended sediment concentrations following storm events. Figure 6-23 showed that on the day of individual storm events, suspended sediment (or turbidity) above the lake was often higher than below the lake, but for several days following a storm event, turbidity levels were higher below the lake. Some time before 8 days, turbidity levels below the lake would return to normal. This pattern of response was compared to simulated suspended sediment concentrations during storm events. Figure 6-23 shows the simulated suspended sediment concentrations during a representative storm event on 2/6/2006. Similar to the pattern observed for turbidity, simulated TSS concentrations were much higher above the lake on the day of the storm event, but were elevated below the lake for several days following the storm event. For the storm event on 2/6/2006, suspended sediment concentrations below the lake were elevated for about 3 days following the storm event. Larger storm events produced longer periods of elevated TSS concentrations following the storm, and smaller storms produced shorter periods or no elevated TSS concentrations. In most cases, TSS concentrations below the lake returned to baseline levels within about 3 to 8 days following the storm event. This matched nicely the observed pattern of turbidity and provided additional information supporting the validity of the model.

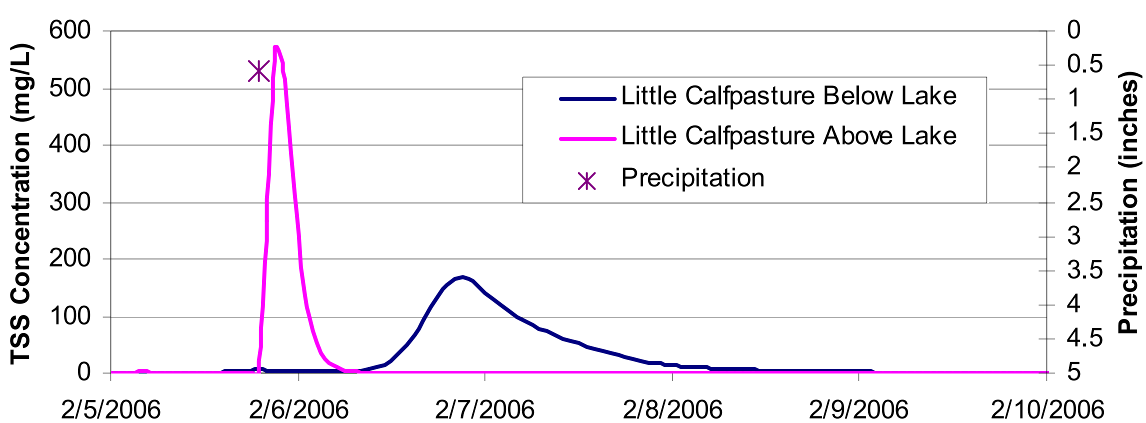

Figure 6-23. Simulated Suspended Sediment Concentrations Above and Below Lake Merriweather During a Representative Storm Event.

On several occasions, TSS measurements were made on the same day above and below Lake Merriweather. These data provided an opportunity to evaluate the predictive ability of the sediment model to simulate TSS concentrations above and below Lake Merriweather during individual storm events. Figure 6-24 compares the simulated and observed TSS concentrations during four storm events. In two of the events, measured TSS concentrations above the lake were higher than below the lake on the day of monitoring. In the other two events, measured TSS concentrations were higher below the lake on the day of monitoring. In each case, the model performed well in simulating TSS concentrations. The simulated time series was able to explain the differences in TSS levels observed above and below Lake Merriweather on individual days. On days where observed upstream TSS levels were higher, the simulated time series demonstrated that the timing of sample collection occurred during the storm hydrograph above the lake, but because of retention within the lake, the storm hydrograph had not yet reached below the lake. On days where observed downstream TSS levels were higher, the simulated time series demonstrated that sample collection occurred after the storm hydrograph above the lake, but during the delayed hydrograph below the lake. These comparisons with observed data during individual storm events support the model's ability to represent the hydrologic and sediment transport conditions in the Little Calfpasture River.

In summary, various steps were taken to calibrate and evaluate the sediment model. The weight of evidence from these steps indicates that the LSPC and EFDC models adequately represent hydrologic and suspended sediment conditions in the Little Calfpasture River.

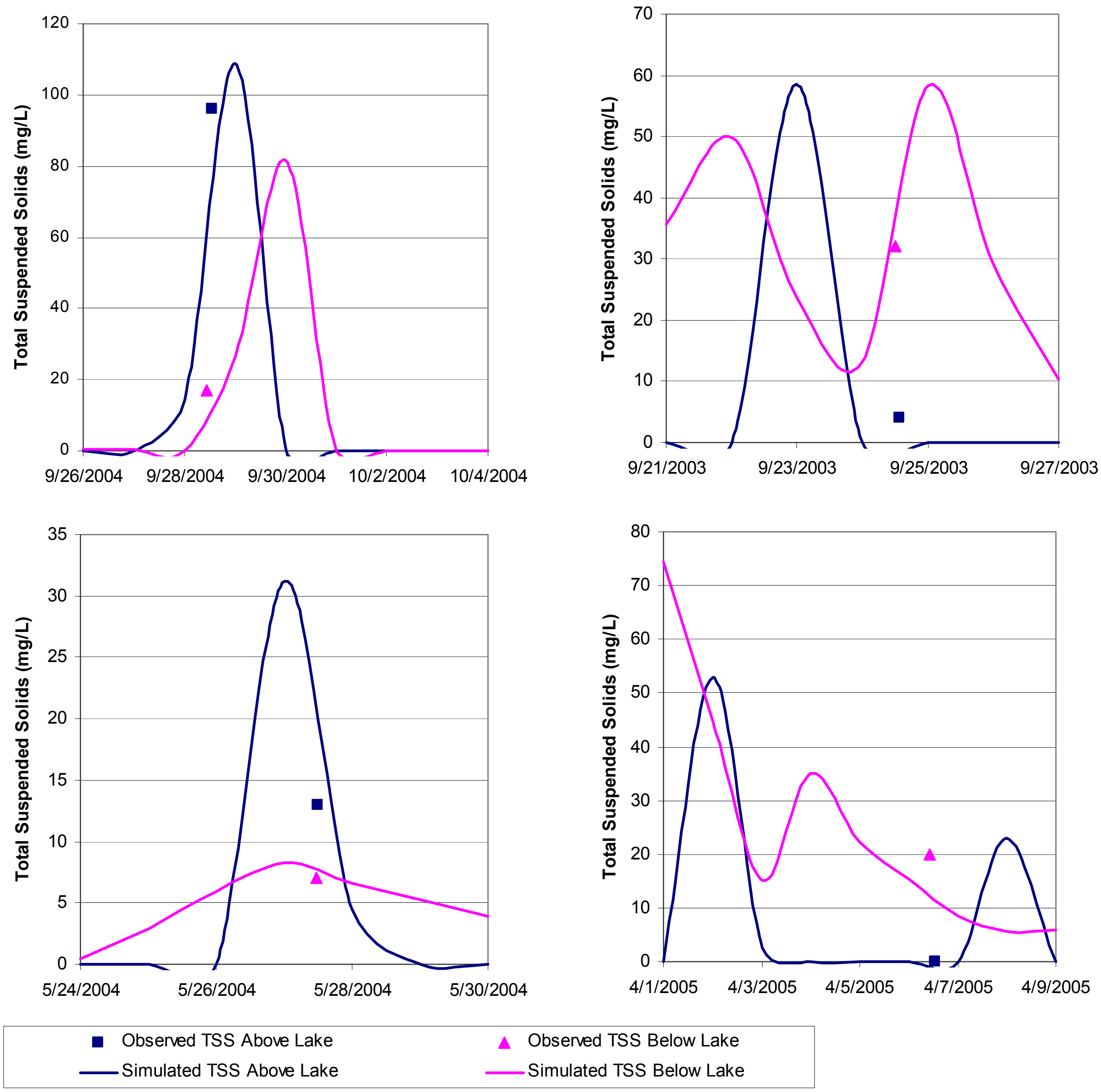

Figure 6-24. Comparison of Observed and Simulated Total Suspended Sediment Concentrations During Individual Storm Events.

CHAPTER 7: TMDL ALLOCATIONS

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991a). To achieve this objective, existing conditions were first simulated and calibrated. Then future conditions were projected, and various reduction scenarios were adjusted until water quality standards were met.

7.1. EXISTING CONDITIONS

Following calibration of the Little Calfpasture River LSPC and EFDC models, the models were used to simulate existing conditions. Existing conditions were simulated using weather inputs for 2000 to 2006, source information described in Chapter 5, and calibrated model parameters.

7.1.1. Suspended Sediment Concentrations

Under existing conditions, simulated suspended sediment concentrations at the watershed outlet of the Little Calfpasture River ranged from less than 0.1 to 564 mg/L during the 2000 – 2006 simulation period (Figure 7-1). Following storm events, TSS concentrations often spiked over 10 mg/L and then returned to a baseline of around 1 mg/L. The cumulative distribution function of TSS concentrations (Figure 7-2) shows that 50% of values were less than 1.82 mg/L. Values exceeded 3 mg/L 36% of the time and 10 mg/L 15% of the time.

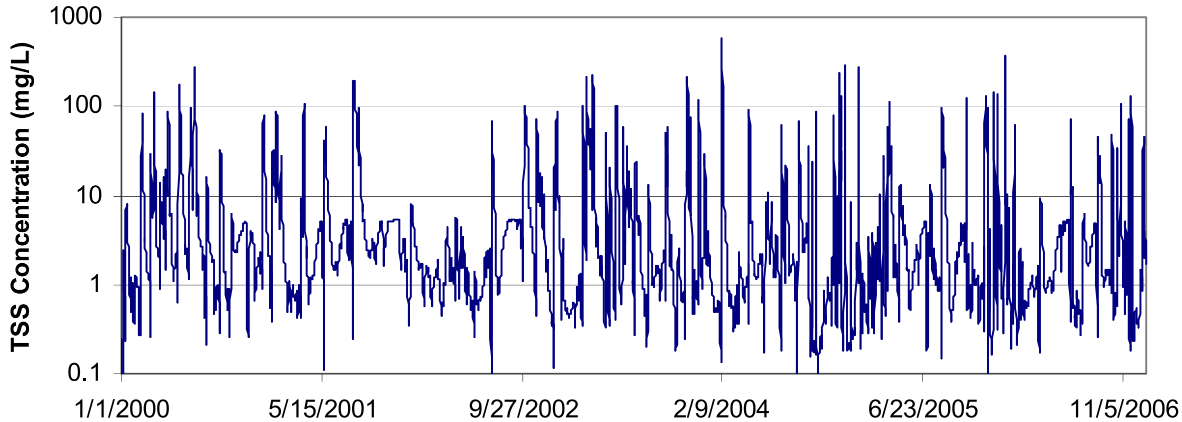

Figure 7-1. Simulated Suspended Sediment Concentrations at the Mouth of the Little Calfpasture River Under Existing Conditions.

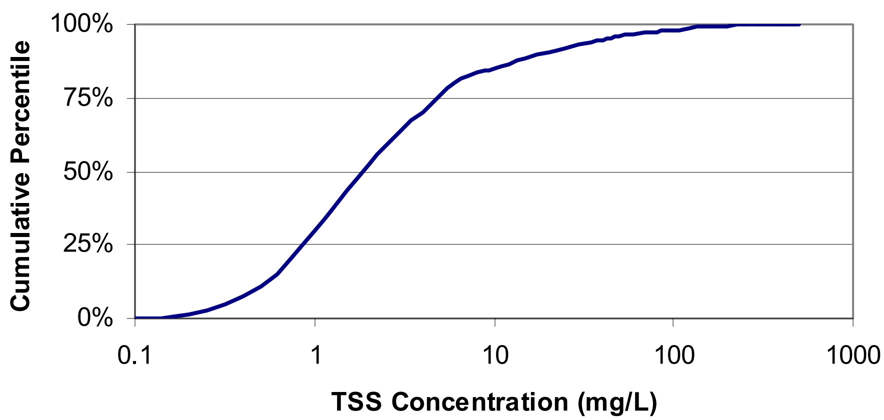

Figure 7-2. Cumulative Distribution Function of Suspended Sediment Concentrations at the Mouth of the Little Calfpasture River Under Existing Conditions.

7.1.2. Suspended Sediment Loads

Section 5.2 discusses the contribution of sediment from the various sources in the Little Calfpasture River watershed. Above Lake Merriweather approximately half of the sediment (52%) comes from degraded riparian pasture. Below Lake Merriweather, nearly all (99%) of the sediment comes from flow over the Goshen Dam. The relative contributions of sediment from various sources under existing conditions were used to make informed decisions regarding appropriate and effective TMDL allocations.

Table 7-1 and Figure 7-3 show the annual sediment loads in the Little Calfpasture River under existing conditions. In general, sediment loads at the watershed outlet are lower than sediment loads entering Lake Merriweather. On average, sediment loads are estimated at 3395 tonnes/yr above Lake Merriweather and 2595 tonnes/yr at the watershed outlet. This equates to an approximate 24% capture of sediment in the lake. From year to year, however, sediment loads and reduction percentages through the lake are much more variable. In 2002, 65% of sediment was captured in the lake, while in 2004, only 9% of sediment was captured in the lake.

Table 7-1. Annual Sediment Loads in the Little Calfpasture River.

Year	Sediment Load (tonnes/yr)		
	Above Lake	Below Lake	% decrease
2000	3207	2141	33.25%
2001	2161	1198	44.54%
2002	1856	658	64.57%
2003	5861	4887	16.61%
2004	5131	4668	9.03%
2005	2885	2349	18.59%
2006	2665	2268	14.92%
Average	3395	2595	23.55%
Min	1856	658	
Max	5861	4887	
Total	23766	18168	23.55%

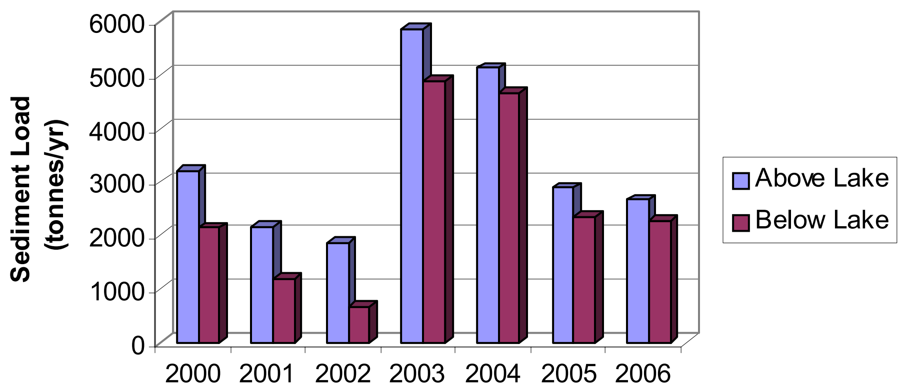

Figure 7-3. Annual Sediment Loads in Little Calfpasture River.

This finding (of generally lower sediment loads below the lake) begs the following question: How can a benthic impairment below the Goshen Dam be associated with sediment if sediment loads below the dam are lower than above the dam? This is because of the time over which benthic organisms are exposed to elevated TSS concentrations. Peak concentrations in suspended sediment during storm events are lower below the Goshen Dam, but the duration of the elevated suspended sediment concentrations is longer. Figure 7-6 demonstrates this point for a representative storm event. During this event on 2/5/06, the peak in suspended sediment was much higher above the lake (514 mg/L above the lake and 167 mg/L below the lake), but the duration of elevated suspended sediment concentrations was much longer below the lake. Above the lake, suspended sediment concentrations exceeded 3 mg/L for 13 hours during this storm event. Below the lake, suspended sediment concentrations exceeded 3 mg/L for 61 hours. Overall, there was a 12% reduction in the sediment load through the lake during this storm, however, benthic organisms below the lake were exposed to elevated TSS concentrations more than 4 times longer than organisms above the lake. Figure 7-4 and Figure 7-5 also demonstrate this point. Figure 7-4 presents the number of days that given TSS concentrations are exceeded above and below the lake, and Figure 7-5 shows the percentage of time that given TSS concentrations are exceeded. Very high TSS concentrations (above 200 mg/L) are exceeded more often above the lake, but TSS concentrations between 1 and 10 mg/L are exceeded more often below the lake. For instance, TSS concentrations above the lake exceeded 3 mg/L on 546 days (21% of the 5-yr simulation period), while TSS concentrations below the lake exceeded 3 mg/L on 928 days (36% of the 7-yr simulation period). The presence of the lake extends the duration of elevated suspended sediment concentrations following storm events. This increases the exposure of stream organisms to suspended sediment. In addition, the extended duration of elevated suspended sediment concentrations means increased deposition of suspended sediment downstream. Figure 7-6 shows how the delay in TSS peak below the lake causes the peak to occur at a lower flow condition than above the lake. While the TSS peak occurs at a flow of 455 cfs above the lake, the TSS peak occurs at a flow of only 371 cfs below the lake. This lower flow means that the suspended sediment has a greater opportunity to settle downstream of the lake and fill interstitial spaces, further impacting the benthic community.

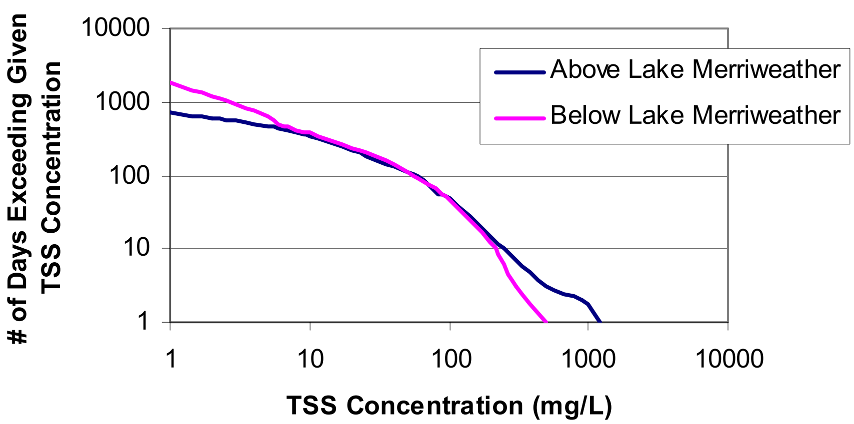

Figure 7-4. Duration of Elevated Suspended Sediment Concentrations Above and Below Lake Merriweather.

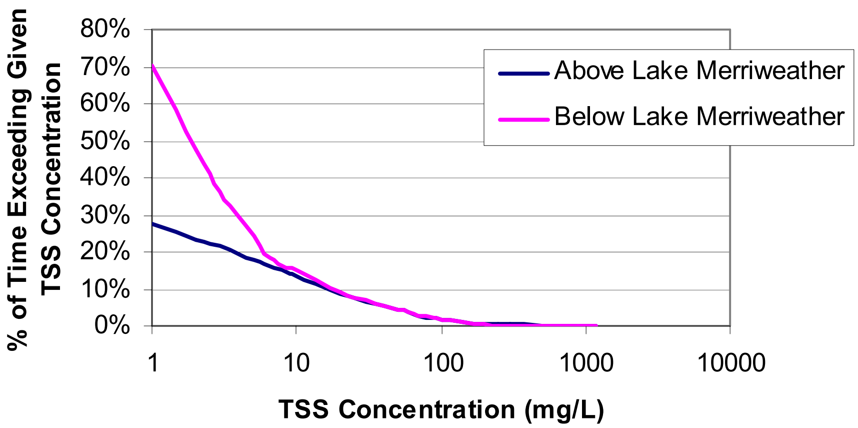

Figure 7-5. Frequency of Elevated Suspended Sediment Concentrations Above and Below Lake Merriweather.

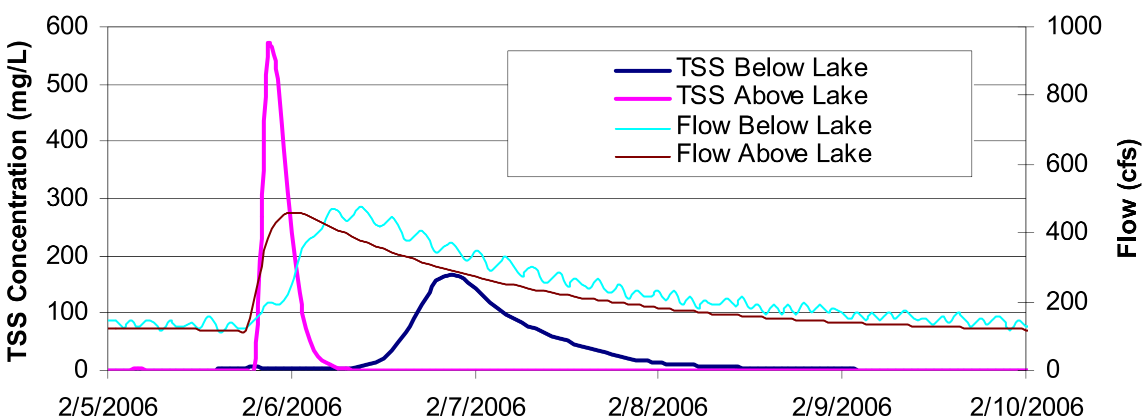

Figure 7-6. Simulated Flow and Suspended Sediment Concentrations Above and Below Lake Merriweather During a Representative Storm Event (2/5/06).

7.1.3. Impact of Lowering Goshen Dam Gates

During model runs under existing conditions, raising and lowering of the Goshen Dam gates were simulated as described in Section 6.2.6. The simulation included 5 gate lowering events that ranged from 4 ft to 10ft (Table 6-11). To evaluate the impact of these events on suspended sediment concentrations, the existing conditions were also modeled without the gate lowering events (i.e., assuming that the lake was maintained at full pool for the duration of the 2000-2006 simulation period). For each lake lowering event, suspended sediment loads discharged from the lake were higher than they would have normally been during that same time period had the lake not been lowered (Figure 7-7). The lake lowering events increased discharged sediment loads by 15% to 335%. On an average daily basis, lake lowering increased discharged sediment loads by 1.25 – 3.08 tonnes/day. This analysis demonstrates the importance of maintaining the lake at full pool (with the exception of emergency conditions) as specified in the Goshen Dam Operation Protocol (The Boy Scouts of America, 1998) and the Special Order (SWCB, 1998).

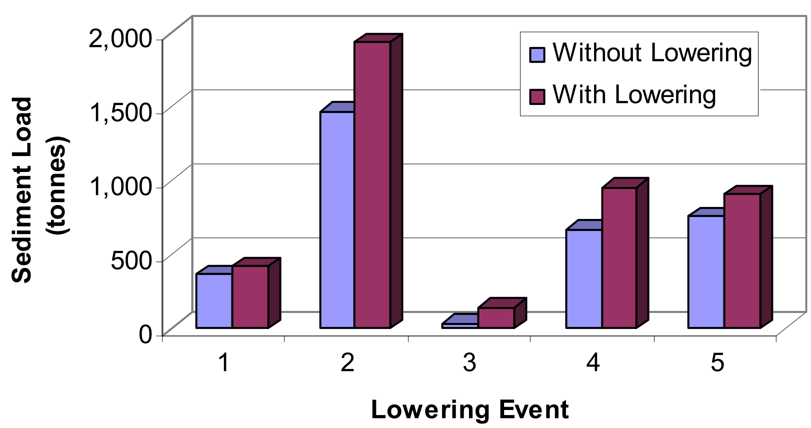

Figure 7-7. Simulated Suspended Sediment Loads From Lake Merriweather With and Without Lake Lowering.

Table 7-2. Increases in Suspended Sediment Loads Resulting from Lake Lowering Events.

Lowering Event	Dates of Lake Lowering		Duration of Lowering (d)	Magnitude of Lowering (ft)	Sediment Load (tonnes)		% Increase
	From	To			Without Lowering	With Lowering	
1	9/6/2004	10/13/2004	37	9	361	415	15%
2	10/19/2004	3/28/2005	160	8.5	1,469	1,932	31%
3	9/10/2005	10/28/2005	48	10	32	140	335%
4	12/3/2005	3/4/2006	91	8	672	952	42%
5	9/5/2006	12/31/2006	118	4	758	905	19%

7.2. FUTURE CONDITIONS

The Little Calfpasture River TMDL was developed to consider further growth and future conditions in the watershed. TMDLs do impose caps on the amount of pollutants discharged in a watershed, however, the reductions called for in the TMDL may take several years to achieve. Changes in populations and land use are likely to continue as the TMDL is being implemented, so the TMDL considers those changes. For the Little Calfpasture River TMDL, a projection of future conditions in the year 2020 was used. 2020 represents a reasonable time frame for this TMDL to be implemented.

For future condition projections, the county comprehensive plans for Augusta and Rockbridge Counties were consulted. According to the Rockbridge County Comprehensive Plan, all of the Little Calfpasture River watershed is either public land or within a rural planning area (Rockbridge County, 2003). The county land use plan goals discourage development in the rural planning areas unless the uses are related to and supportive of active agricultural and forestry activities. Based on this planning policy, the lack of infrastructure in the area, and the general rural character, there is not likely to be significant development within the Rockbridge County portion of the Little Calfpasture River watershed. For this reason, the land use estimates that were used to model existing conditions were kept constant in future condition scenarios for sub-watersheds located entirely within Rockbridge County (sub-watersheds 1-3, 10-17, and 20-21).

The Augusta County Comprehensive Plan designated urban service areas, community development areas, and rural conservation areas within the Little Calfpasture River watershed (Augusta County Comprehensive Plan, 2007). Primarily, these areas surround Craigsville and follow the Rt. 42 corridor north and south of Craigsville, including portions of sub-watersheds 22-29. According to the county comprehensive plan, growth in the county is to be directed towards urban service areas, community development areas, and to a lesser extent, rural conservation areas. Based on this plan, growth can be expected in sub-watersheds 22-29.

To determine the amount of growth and land use change in these areas, projected growth scenarios from the comprehensive plan were used. The comprehensive plan projects county growth from 65,615 in 2000 to 79,387 in 2015. This represents a growth rate of 1.4% per year. Using this same rate, growth would be projected to increase by 14% from the time of TMDL approval (projected in 2010) to 2020. This 14% growth rate was used to increase residential and impervious urban/transportation land uses in sub-watersheds 22-29. In each of these sub-watersheds, the existing residential acreage and the existing impervious urban/transportation acreage were increased by 14% to represent future conditions in 2020. To offset increases in these residential and urban land uses, area-weighted decreases were made to pasture, cropland, and forest land uses.

In addition, agricultural BMPs (identified in Section 6.4) that have been installed since the 2005 land use dataset was developed were incorporated into the future land use dataset. This resulted in the conversion of 20 acres of pasture in sub-watershed 26 to forest. In sub-watershed 20, 27.33 acres of degraded riparian pasture was converted to 3.6 acres of forest and 23.73 acres of pasture. In sub-watershed 12, 53.98 acres of degraded riparian pasture was converted to 0.4 acres of forest and 53.58 acres of pasture. In sub-watershed 13, 18.98 acres of degraded riparian pasture was converted to 2.3 acres of forest and 16.68 acres of pasture. Overall, agricultural BMPs and future growth resulted in projected losses of 100 acres of degraded riparian pasture and 53 acres of forest; and projected gains of 35 residential acres, 63 acres of pasture/hay, and 56 acres of impervious urban/transportation land uses (Table 7-3).

Table 7-3. Projected Future Growth Land Use Changes in the Little Calfpasture River Watershed.

Sub-watershed	Change in Land Use Acreage (acres)					
	Residential	Cropland	Pasture/Hay	Degraded Riparian Pasture	Forest	Impervious Urban/ Transportation
12	0	0	+54	-54	0	0
13	0	0	+17	-19	+2	0
20	0	0	+24	-27	+4	0
22	+6	0	-2	0	-18	+14
23	0	0	-1	0	-4	+4
24	+1	0	-1	0	-10	+11
25	0	0	-1	0	-2	+3
26	+20	0	-23	0	-10	+13
27	+1	0	-1	0	-3	+3
28	0	0	0	0	-1	+1
29	+5	0	-1	0	-12	+8
Total	**+35**	**0**	**+63**	**-100**	**-53**	**+56**

Lastly, the future condition scenarios assume that the existing consent order with the Boy Scouts of America will be followed. This consent order calls for the lake to remain at full pool except in the event of emergency flooding conditions. All future condition and TMDL scenarios were modeled assuming that the lake will be at this full pool elevation.

7.3. TMDL ENDPOINT

The sediment TMDL is being developed to address the aquatic life (benthic) impairment in the Little Calfpasture River. The TMDL, therefore, must represent a sediment load that is protective of the aquatic life use. There are several options for developing this protective TMDL endpoint. The most commonly used approach for sediment is a reference watershed comparison. In this approach, a similar watershed with unimpaired benthic conditions is modeled to determine a unit area sediment load that supports a healthy benthic community. The problem with this approach is that similar but unimpaired reference watersheds are often difficult to find. Another option is to develop the TMDL to meet a certain instream pollutant concentration. For suspended sediment, however, the Commonwealth of Virginia does not have established water quality standards.

To determine the TMDL endpoint for the Little Calfpasture River, VADEQ evaluated benthic monitoring results in conjunction with sediment modeling. Figure 7-8 shows the benthic monitoring results for the Little Calfpasture River near the mouth. At this location, SCI scores were unimpaired (above 60) in the fall of 2001. This means that sediment loading conditions immediately preceding this time period were conducive to supporting a healthy benthic community. Comparing these results with sediment modeling results reveals that sediment loads in 2001 were indeed among the lowest (Figure 7-3). Based on these findings, the 2001 sediment yield (1198 tonnes/yr) minus a 5% margin of safety was used as the TMDL endpoint. Sediment reductions were set to produce simulated average annual loads of less than 1138 tonnes (the annual load in 2001 minus a 5% margin of safety).

In addition, sediment reductions were set to reduce the frequency of elevated TSS concentrations (>3 mg/L) to background levels simulated above Lake Merriweather, where benthic conditions are consistently unimpaired. As previously described in Section 7.1.2, sediment loads above Lake Merriweather (where benthic conditions are unimpaired) are actually higher than below the lake (where benthic conditions are impaired). This is because the lake traps some sediment, but releases the remaining sediment over a longer time period. This produces longer exposure periods to high TSS concentrations. For example, TSS concentrations above Lake Merriweather exceeded 3 mg/L 22% of the time, while TSS concentrations below Lake Merriweather exceeded 3 mg/L 38% of the time. To remedy the TSS exposure duration issue, an additional TMDL endpoint was implemented. Sediment reductions were set to produce simulated TSS concentrations that exceed 3 mg/L no more than 22% of the time.

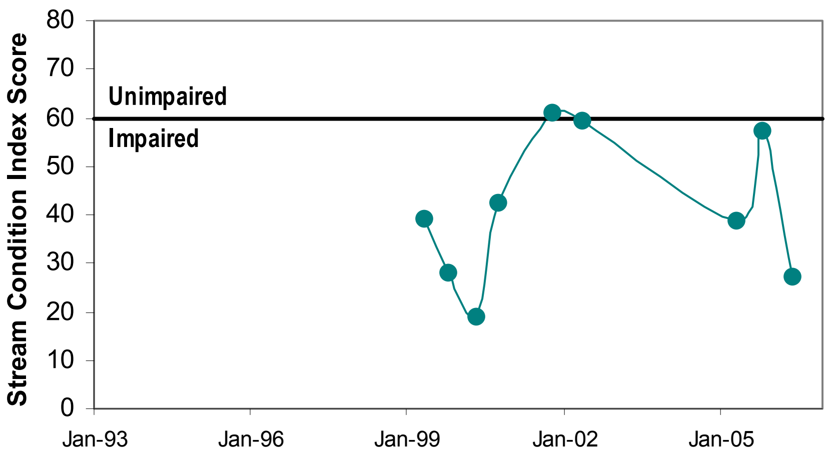

Figure 7-8. Benthic Stream Condition Index (SCI) Scores at the Mouth of the Little Calfpasture River.

7.4. ALLOCATION SCENARIOS

LSPC and EFDC model simulations for 2000 to 2006 were used to develop TMDL allocations. This period represents a range of environmental conditions, including dry and wet years. A variety of allocation scenarios were evaluated against the TMDL criteria. As described above, a successful TMDL allocation was one with an average annual sediment load of less than 1138 tonnes/yr and a frequency of elevated TSS concentrations (>3 mg/L) no more than 22%.

Table 7-4 shows various allocation scenarios representing different combinations of sediment load reductions from the various sources. These scenarios represent a combination of sediment source reductions and lake sediment management options. Sediment source reductions decrease the amount of sediment entering the Little Calfpasture River and/or Lake Merriweather through best management practices that limit erosion from the land surface. Lake sediment management options decrease the amount of sediment leaving Lake Merriweather without impacting sediment sources. The most conventional lake sediment management option is dredging, which removes deposited sediment from the lake bottom. Downstream sediment loads are reduced by dredging because the increased lake depth reduces resuspension and increases retention time, enhancing particle settling. Lake sediment management options were modeled during TMDL scenarios by increasing the depth of the lake; however, other lake sediment management options (besides dredging) that result in equivalent sediment reductions could also be considered. The combination of sediment source reductions and improved lake management strategies can be used to restore aquatic life and meet water quality standards in the Little Calfpasture River.

Another option which was not modeled was the return of the Little Calfpasture to a riverine system. This could be accomplished through removal of the Goshen Dam or alteration of the spillway to allow continuous passage of the Little Calfpasture River at the original stream elevation. If the Little Calfpasture were returned to a riverine system, the influence of the lake's sediment deposition, resuspension, and erosion processes would be removed. Based on the results of the stressor analysis and upstream monitoring data, the restoration of the Little Calfpasture River to a riverine system would likely eliminate the existing impairment once a natural channel was established and floodplain areas were revegetated. While this option can continue to be considered, it was not selected as the TMDL scenario because there is no reasonable assurance that it would be implemented. Lake Merriweather and the Goshen Dam are privately owned by the National Capitol Area Boy Scouts of America, and restoration of the Little Calfpasture to a riverine system would be a completely voluntary action on the part of the Boy Scouts.

The first two scenarios shown in Table 7-4 represent the existing conditions (as described in Section 7.1) and future conditions (described in Section 7.2), respectively. The future condition scenario produces an average annual sediment load of 2369 tonnes/yr at the watershed outlet, which is slightly less than the existing condition scenario. This is likely due to the reduction in sediment from BMPs installed in the watershed since 2006. TSS concentrations above 3 mg/L were experienced 36% of the time under existing conditions and 38% of the time under future conditions. The third scenario evaluates the results of reducing all anthropogenic nonpoint sources of sediment by 50%. This scenario meets the elevated TSS frequency criterion, but does not meet the target average annual sediment load. Scenario 4 increases anthropogenic nonpoint source reductions to 75%. This scenario easily meets both criteria, but demonstrates that criteria could be met with less restrictive reductions. Scenarios 5 and 6 optimize reduction levels that meet the TMDL criteria. Scenario 6 represents 61% reductions from cropland, pasture, degraded riparian pasture, residential, and urban areas. Scenario 7 increases reductions for the largest contributor of sediment (degraded riparian pasture) to 72% and decreases reductions for other land uses to 50%.

Scenarios 8-11 evaluate the impacts of lake sediment management options. As lake depths are increased by 1 to 6 feet, the average annual sediment loads decrease by 8 to 32%, but none of the scenarios (up to a depth increase of 6 ft averaged across the lake) meet the target sediment load. Lake sediment management options also do not greatly affect the frequency of elevated TSS concentrations, which remained at 29 or 30% in scenarios 8-11.

Figure 7-9 shows the impact of sediment source reductions and lake sediment management options on average annual sediment loads. As source reductions are increased, average annual sediment loads are decreased almost linearly. At 61% reductions, the TMDL target is met. Increases in lake depth also decrease average annual sediment loads almost linearly, except at a slower rate. TMDL targets would not be met by lake sediment management options alone unless lake depth increased by over 10 ft. This magnitude of depth increase is not feasible given the initial construction of Lake Merriweather. At construction, the lake was 26 feet deep near the dam. Measurements made by DEQ in 2007 showed a maximum depth of only 18 feet near the dam, indicating approximately 8 feet of accumulated sediment in the deepest portions of the lake. The depth of accumulated sediment obviously decreases in more shallow areas of the lake. For this reason, an average 4 ft increase in depth is likely the maximum feasibly attainable in Lake Merriweather. Another lake management option would be to re-establish “full pool” of the lake at 22ft, instead of the current depth of 26ft, to reduce shoreline erosion from lake draw-down before storm events. This could result, however, in a higher rate of resuspension of sediment from the bottom, and may not be a feasible option.

By combining feasible lake sediment management options with source reductions, the magnitude of source reductions can be decreased by 61%. Scenario 12 provides an allocation option that combines a 4 ft increased depth with source reductions optimized to meet the TMDL targets. This scenario met both TMDL targets with a source reduction of 47%. Scenario 13 provides another option by including a 2 ft increase in depth, 66% reduction from degraded riparian pasture, and 40% reduction from residential, pasture, cropland, and urban land uses. Scenario 13 was selected as the TMDL allocation scenario, because it provides the most equity between lake sediment management options and source reductions. Scenarios 6, 7, and 12 provide other reasonable alternatives that meet the TMDL targets and could be selected during TMDL implementation planning if supported by the planning team.

In the TMDL allocation scenario (Scenario 13), lake sediment management was modeled by increasing the depth of the lake by 2 ft. The TMDL does not necessarily prescribe this lake sediment management practice. Other lake sediment management practices would be acceptable if they were able to achieve equivalent reductions in sediment output. To quantify the reductions from the modeled 2-ft increased depth, sediment loads into and out of the lake were calculated under Scenario 13. Under this scenario, sediment loads through the lake were reduced by 34%. Therefore, any lake sediment management options that reduce sediment by 34% would be acceptable for meeting the TMDL scenario.

Table 7-4. Sediment Allocation Scenarios for the Little Calfpasture River.

Scenario[1]	Sediment Loading Reductions (%)							Lake Mgmt. Equivalent to Increased Depth (ft)	TMDL Criteria	
	Residential Runoff	Cropland Runoff	Pasture Runoff	Degraded Riparian Pasture Runoff	Forest Runoff	Urban Runoff	Point Sources		Average Annual Sediment Load (tonnes/yr)	Frequency of TSS Concs. >3mg/L (% of time)
Existing Condition	0%	0%	0%	0%	0%	0%	0%	0	2595	36%
Future Condition	0%	0%	0%	0%	0%	0%	0%	0	2369	38%
3	50%	50%	50%	50%	0%	50%	0%	0	1371	21%
4	75%	75%	75%	75%	0%	75%	0%	0	866	16%
5	65%	65%	65%	65%	0%	65%	0%	0	1067	18%
6	61%	61%	61%	61%	0%	61%	0%	0	1123	19%
7	50%	50%	50%	72%	0%	50%	0%	0	1117	18%
8	0%	0%	0%	0%	0%	0%	0%	1	2229	30%
9	0%	0%	0%	0%	0%	0%	0%	2	2099	30%
10	0%	0%	0%	0%	0%	0%	0%	4	1864	30%
11	0%	0%	0%	0%	0%	0%	0%	6	1649	29%
12	47%	47%	47%	47%	0%	47%	0%	4	1108	22%
13	40%	40%	40%	66%	0%	40%	0%	2	1136	20%

[1] Scenarios highlighted in yellow represent reasonable reduction levels that meet the TMDL criteria. Scenario 13 was selected as the TMDL scenario. Scenarios 6, 7, and 12 represent other reasonable alternatives that could be implemented to achieve the TMDL.

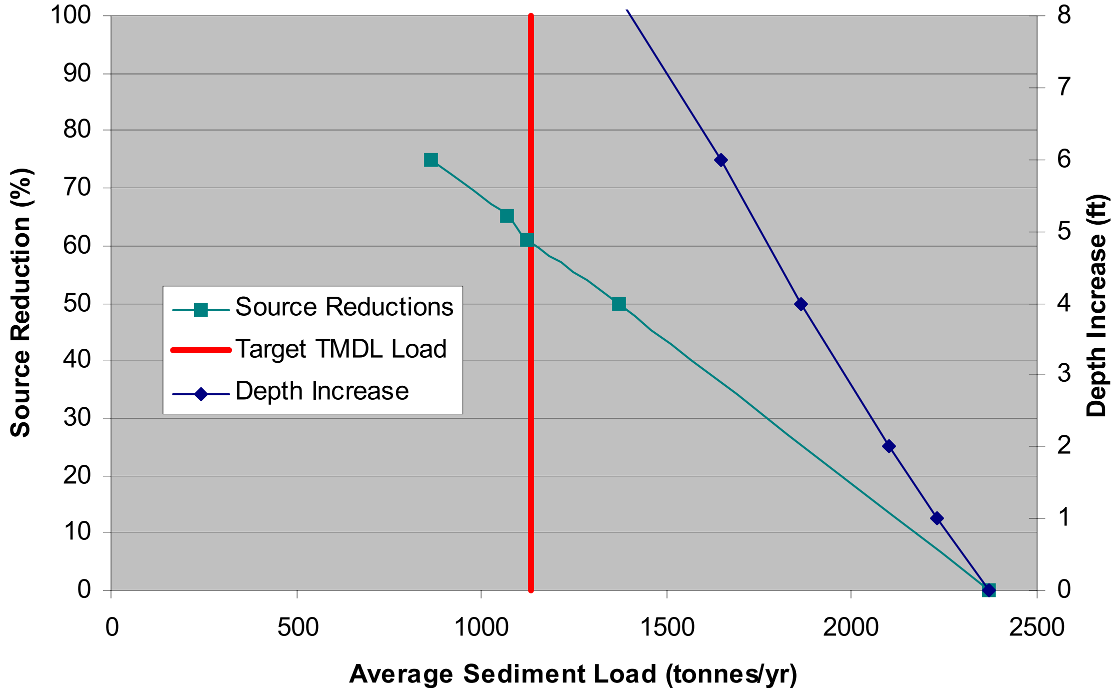

Figure 7-9. Impact of Sediment Source Reductions and Lake Sediment Management Options on Average Sediment Loads at the Mouth of the Little Calfpasture River.

7.5. THE LITTLE CALFPASTURE RIVER TMDL

The objective of a TMDL is to determine the reductions in pollutant loadings from point and nonpoint sources that are required to meet state water quality standards. As described above, the criteria for meeting this objective is a TMDL allocation with an average annual sediment load of less than 1138 tonnes/yr and a frequency of elevated TSS concentrations (>3 mg/L) no more than 22%. Allocation scenario 13 meets these criteria and was selected as the TMDL scenario. This scenario calls for a 40% reduction in sediment from cropland, pasture, residential areas, and urban areas. This scenario also calls for a 66% reduction in sediment from degraded riparian pasture and lake sediment management strategies equivalent to a 34% reduction.

Figure 7-10 shows the daily sediment loads in the Little Calfpasture River under the TMDL scenario compared to the existing conditions. Sediment loads are greatly reduced during all storm events and flow conditions under the TMDL scenario. Figure 7-11 and Table 7-5 show annual sediment loads in the Little Calfpasture River. Annual sediment loads are reduced by 46% to 69% in individual years. Overall, sediment loads in the Little Calfpasture River are reduced by 56% under the TMDL scenario. The resulting average annual sediment load under the TMDL scenario is 1136 tonnes/yr, which meets the TMDL criteria of 1138 tonnes/yr (2001 sediment load with a 5% margin of safety).

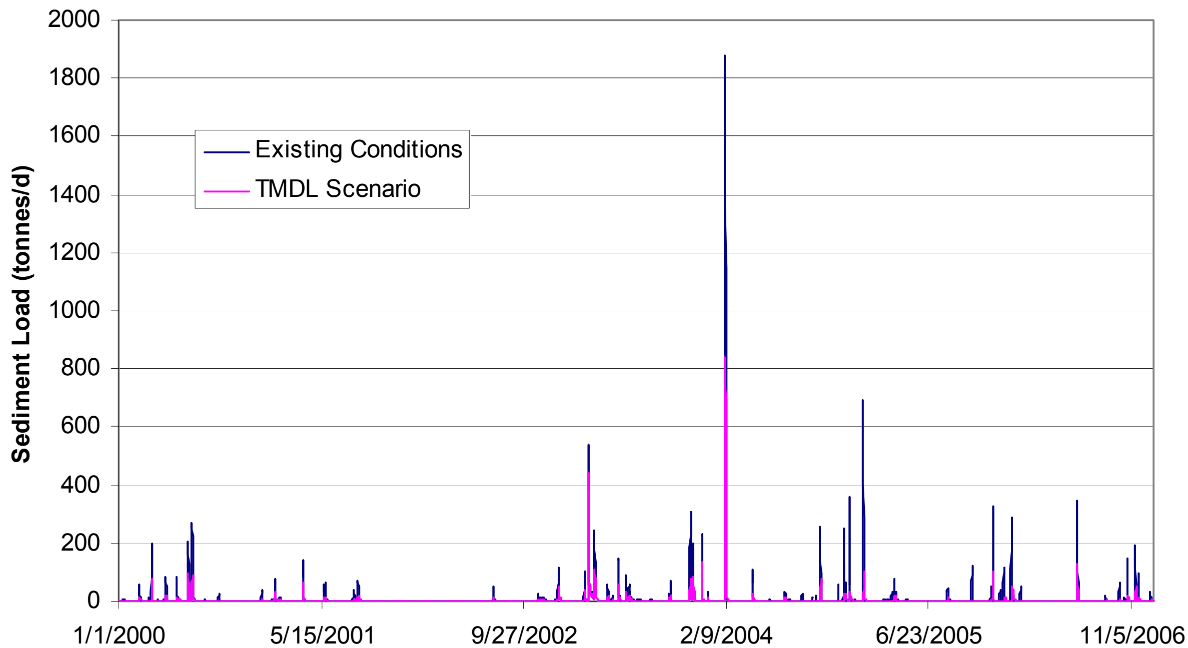

Figure 7-10. Daily Sediment Loads at the Mouth of the Little Calfpasture River Under Existing Conditions and TMDL Scenario.

Table 7-5. Annual Sediment Loads at the Mouth of the Little Calfpasture River Under Existing Conditions and TMDL Scenario.

Year	Existing Conditions (tonnes/yr)	TMDL Scenario (tonnes/yr)	% Reduction (%)
2000	2141	815	62%
2001	1198	466	61%
2002	658	247	62%
2003	4887	2640	46%
2004	4668	2336	50%
2005	2349	738	69%
2006	2268	708	69%
Total	18168	7951	56%
Average	2595	1136	56%

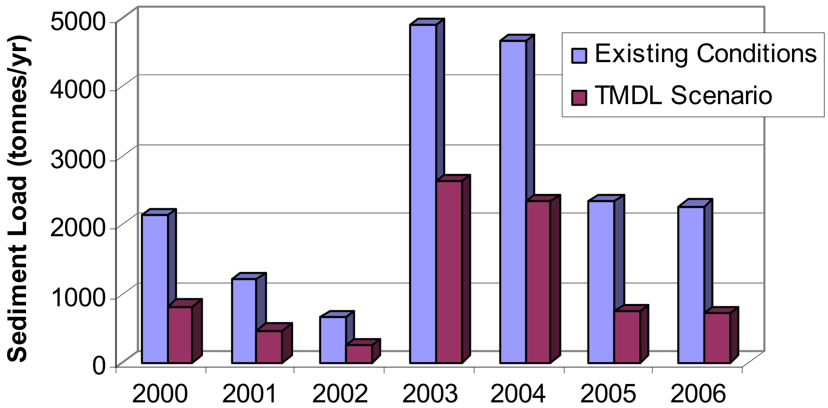

Figure 7-11. Annual Sediment Loads at the Mouth of the Little Calfpasture River Under Existing Conditions and TMDL Scenario.

Figure 7-12 shows the daily TSS concentration at the mouth of the Little Calfpasture River under existing conditions and the TMDL scenario. TSS concentrations are greatly reduced over a range of flow regimes. Figure 7-13 compares the cumulative distribution function of TSS concentrations under the existing conditions and TMDL scenario. TSS concentrations under the TMDL scenario decreased at all percentiles. Under the TMDL scenario, the 90th percentile TSS concentration dropped from 18 mg/L to 9.4 mg/L. The 50th percentile TSS concentration dropped from 1.8 mg/L to 0.59 mg/L. Due to the decreases in the TSS concentrations under the TMDL scenario, the percent of time exceeding given TSS concentrations also decreased. Figure 7-14 shows this relationship. The percent of time exceeding 3 mg/L was decreased from 36% to 20% under the TMDL scenarios. The percent of time exceeding 10 mg/L was decreased from 15% to 9.3%.

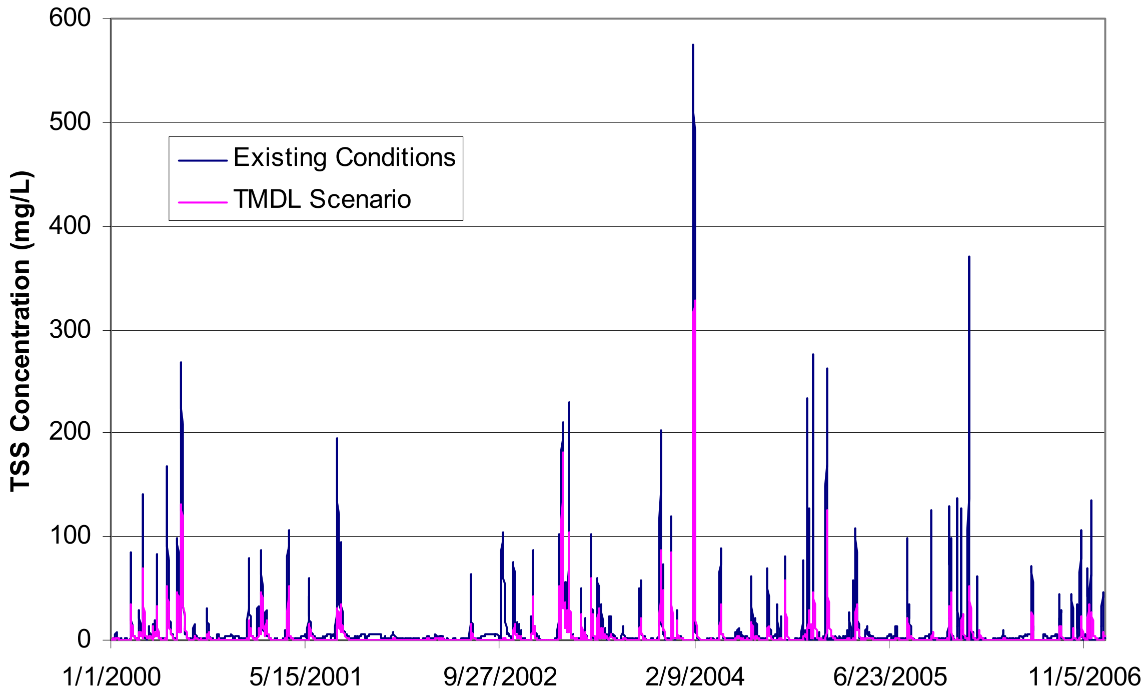

Figure 7-12. Total Suspended Solids Concentration at Mouth of the Little Calfpasture River Under Existing Conditions and TMDL Scenario.

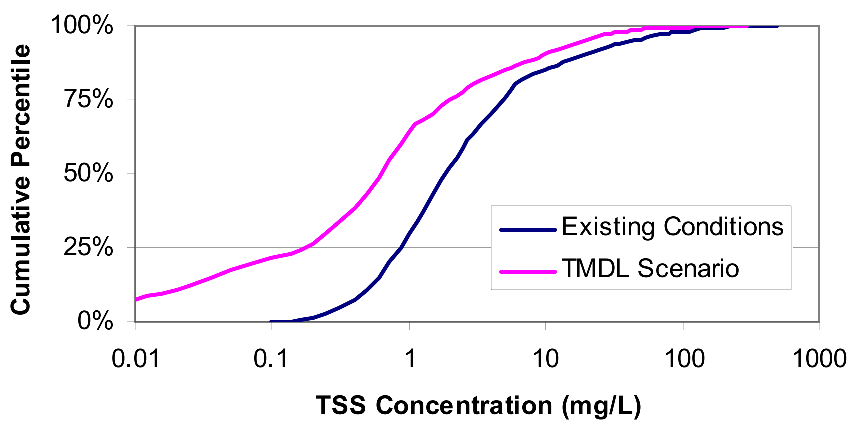

Figure 7-13. Cumulative Distribution Function of Total Suspended Solids at the Mouth of the Little Calfpasture River Under Existing Conditions and TMDL Scenario.

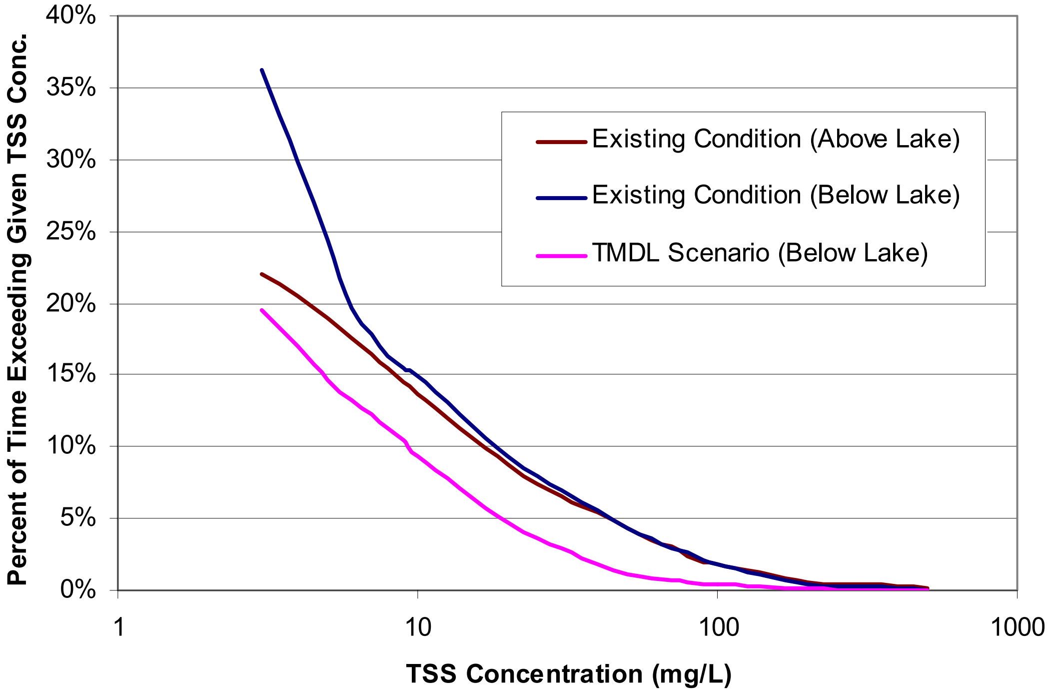

Figure 7-14. Percent of Time Exceeding Various TSS Concentrations in the Little Calfpasture River Under Existing Conditions and TMDL Scenario.

The TMDL considers all sources of sediment to the Little Calfpasture River, including point (or direct) and nonpoint (or indirect) sources. The TMDL can be shown to represent these sources as defined in the following equation:

TMDL = WLA + LA + MOS [7-1]

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

7.5.1. Wasteload Allocation

The wasteload allocation (or WLA) portion of the TMDL includes sediment (in the form of TSS) contributions from 8 VPDES permits in the Little Calfpasture River watershed. Section 5.1 describes the calculation of WLAs for these facilities. In general, wasteload allocations were determined based on permitted design flows and TSS concentrations. No reductions in sediment loadings from permitted point sources are called for under the TMDL scenario. Table 7-6 presents the wasteload allocations for permitted point sources in the Little Calfpasture River watershed on both an annual and a daily basis.

Currently, no stormwater construction general permits are issued within the watershed, but these permits will undoubtedly be issued in the future to accommodate even slight growth. For this reason, a wasteload allocation was assigned to stormwater construction general permits. Based on land use changes projected for the future TMDL scenario condition (see Section 7.2), a total of 91 acres is estimated to be developed within the watershed from 2010-2020. Assuming that this development will be spread over the 10 years and each construction project will be completed within 2 years, an average of 18.2 acres of developing land will be under disturbance each year. Using the following equation from (Schueler, 1987), a wasteload allocation of 2.0 tonnes/yr was calculated for the 18.2 acres of disturbed land.

$$L = P * Rv * A * C * 0.0001134$$

Where,
L = Sediment load (tonnes/yr)
P = Average annual precipitation; 42.39 inches
Rv = 0.050+0.009 * percent impervious; 0.23
A = Disturbed area; 18.2 acres
C = Average concentration in runoff; 100 mg/L

The total WLA for the Little Calfpasture River is 30.4 tonnes/yr on an annual basis and 0.191 tonnes/d on a daily basis.

Table 7-6. TMDL Wasteload Allocations for Permitted Point Sources in the Little Calfpasture River Watershed.

Facility	Permit #	Permitted Flow (MGD)	Permitted TSS Conc. (mg/L)[a]	Wasteload Allocation	
				Annual WLA (tonnes/yr)	Daily WLA (tonnes/d)
Augusta Springs WTP	VA0090395	0.072	30/60	2.99	0.0164
Casta Line Trout Farm	VA0091227			2.13[b]	0.00584
Craigsville STP	VA0091821	0.435	30/45	18.1	0.0741
Craigsville WTP	VA0092487	0.012	30/60	0.497	0.00273
Blue Ridge Lumber Co.	VAR050879		100	4.66[c]	0.0861[c]
3 Single Family Home General Permits	Various	0.003	30	0.125	0.000341
Construction Stormwater General Permits	Unspecified		100	2.01	0.00551
			Total	30.4	0.191

[a] When two numbers are given, the first is the average monthly limit and the second is the maximum or average weekly limit.
[b] Wasteload allocation from the Wallace Mill Stream TMDL. This wasteload allocation was 2,814 lbs/yr organic solids. The allocation was converted to total suspended solids using a 60% organic solids content. Conversion to T/yr equals 2.13 T/yr. No additional reductions (beyond those required in the Wallace Mill Stream TMDL) are required from this facility to meet water quality standards in the Little Calfpasture River.
[c] Wasteload allocation was determined from modeling 12.8 acres of impervious area.

7.5.2. Margin of Safety

A margin of safety (or MOS) of 5% was used in the Little Calfpasture River TMDL. The TMDL criteria was an average annual load of 1198 tonnes/yr. Subtracting a 5% margin of safety of 60 tonnes/yr, the target for allocated loads under the TMDL scenario was 1138 tonnes/yr.

7.5.3. Load Allocation

The load allocation (LA) portion of the Little Calfpasture River TMDL represents the contributions from all nonpoint sources. This value is calculated as the difference of the TMDL and the sum of the WLA and MOS under the modeled TMDL scenario condition. For the Little Calfpasture River watershed, the LA is 1107.6 tonnes/yr on an annual basis and 11.0 tonnes/d on a daily basis.

The TMDL scenario for the Little Calfpasture River calls for reductions from most nonpoint sources. The TMDL calls for a 40% reduction in sediment from residential, crop, pasture, and urban land uses; a 66% reduction in sediment from degraded riparian pasture; and improved lake sediment management practices that are equivalent to a 34% reduction.

7.5.4. TMDL Expressions

The sediment TMDL in the Little Calfpasture River is designed to restore aquatic life uses by reducing sedimentation and improving benthic habitat. While sediment loadings are very dynamic, the accumulation of sediment in the stream is reflective of conditions over extended time periods, ranging from seasonal to annual. Consequently, the most relevant expression of sediment loadings in the Little Calfpasture River TMDL is the annual average loading. Table 7-7 shows the wasteload allocation, the load allocation, the margin of safety, and total load for the Little Calfpasture River expressed as an average annual load. No sediment reductions to the point sources are required. The recommended allocations for nonpoint sources call for 40% reductions from cropland, pasture, residential, and urban sources; 66% reductions from degraded riparian pasture, and lake sediment management strategies equivalent to a 34% recduction. Overall, the sediment load in the Little Calfpasture River watershed must be reduced by 56% in order to meet the established TMDL endpoints.

Table 7-7. Total Maximum Daily Load of Sediment for the Little Calfpasture River Expressed as an Average Annual Load.

WLA (tonnes/yr)	LA (tonnes/yr)	MOS (tonnes/yr)	TMDL (tonnes/yr)
30.4	1107.6	60	1198

In order to comply with current USEPA guidance (USEPA, 2007), the Little Calfpasture River sediment TMDL was also expressed as a daily load by evaluating the variability and distribution of simulated loads (Table 7-8). The following formula from USEPA's *Technical Support Document for Water Quality-Based Toxics Control* (USEPA, 1991b) and USEPA's draft *Options for Expressing Daily Loads in TMDLs* (USEPA, 2007) was used to calculate the daily expression of the TMDL:

$$MDL = LTA * \exp(Z_p \sigma_y - 0.5\sigma_y^2) \qquad [7.2]$$

Where,

MDL = Maximum daily load,

LTA = Long term average, which in this case is the average daily load calculated as the average annual load divided by 365,

Z_p = p^{th} percentage point of the standard normal distribution (95th percentile was used),

$\sigma_y = \sqrt{\ln(CV^2 + 1)}$, and

CV = Coefficient of variation (calculated as the standard deviation of simulated daily sediment loads divided by the mean of simulated daily sediment loads).

The total maximum daily load was determined from Equation 7.2 using a 95th percentile , a CV of 7.73, and a long term average of 3.28. It should be noted that the maximum daily load expression represents extreme conditions (with a 5% frequency of occurrence), and routine loadings of this level would not meet average annual loadings that are necessary to restore aquatic life health.

Table 7-8. Total Maximum Daily Load of Sediment for the Little Calfpasture River Expressed as a Daily Load.

WLA (tonnes/d)	LA (tonnes/d)	MOS (tonnes/d)	TMDL (tonnes/d)
0.191	11.0	0.590	11.8

According to Federal regulations at 40 CFR Part 130.7, TMDLs must comply with eight specific requirements. These requirements are listed below with a description of how the Little Calfpasture River TMDL complies with these requirements.

- Designed to implement applicable water quality standards – The applicable water quality standard is Virginia's general standard for aquatic life (9VAC25-260-20). This standard is implemented through the use of biological sampling and comparison to a Virginia Stream Condition Index (VSCI) score of 60. The Little Calfpasture River sediment TMDL was set to achieve a VSCI score above 60 by basing targeted loads on the 2001 annual sediment load, which resulted in a VSCI score of 61 (see Sections 2.2 and 7.3).

- Include a total allowable load as well as individual waste load allocations and load allocations – The Little Calfpasture River TMDL was calculated as 1198 tonnes/yr. This load was divided into an allocation for point sources (WLA) and an allocation for nonpoint sources (LA). The resulting WLA was 30.4, and the resulting LA was 1107.6 (see Section 7.5.4).

- Consider background pollutant contributions – The Little Calfpasture River TMDL considered all sediment sources including stream bank erosion and washoff from cropland, pasture, forest, residential and urban land uses (see Section 5.2).

- Consider critical environmental conditions – The Little Calfpasture River TMDL was modeled over a multi-year period that included a wide range of climatic conditions, including dry and wet periods.

- Consider seasonal environmental variations – The Little Calfpasture River TMDL was modeled over a multi-year period, and included seasonal variations in climate, precipitation, flow, vegetative cover, and sediment loading rates.

- Include a margin of safety – The Little Calfpasture River TMDL included an explicit margin of safety of 5%. This margin of safety was subtracted from the targeted 2001 sediment load.

- Provide reasonable assurance that the TMDL can be met – Chapter 8 discusses the reasonable assurance for the Little Calfpasture River TMDL. In short, the TMDL WLA will be met through ensuring that all issued VPDES permits are in conformance with the TMDL. The LA will be met through the development of a TMDL Implementation Plan and nonpoint source programs that provide cost share for best management practices.

- Be subject to public participation – Public participation was included throughout the development of the Little Calfpasture River TMDL (Chapter 8). An initial public meeting was held to inform the public of the TMDL effort. A Technical Advisory Committee was then developed to assist and guide VADEQ with local knowledge as the TMDL was being developed. Once a draft of the TMDL was available, a second public meeting was held to solicit public comment on the draft.

CHAPTER 8: TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

Once a TMDL has been approved by USEPA, measures must be taken to reduce pollution levels from both point and nonpoint sources. The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

8.1. CONTINUING PLANNING PROCESS AND WATER QUALITY MANAGEMENT PLANNING

As part of the Continuing Planning Process, VADEQ staff will present both USEPA-approved TMDLs and TMDL implementation plans to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

> **Frequently Asked Question:**
>
> *What happens after the TMDL Study is complete?*
> The TMDL will be submitted to EPA for approval. The next step is then to develop a TMDL Implementation Plan. This plan lays out the actions and costs necessary to implement the pollutant reductions called for in the TMDL.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as in the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in VADEQ's public participation guidelines (VADEQ, 2004b), which can be found on VADEQ's web site at: http://www.deq.state.va.us/tmdl/pdf/ppp.pdf.

8.2. STAGED IMPLEMENTATION

In general, Virginia intends for the required control actions, including Best Management Practices (BMPs), to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. The iterative implementation of pollution control actions in the watershed has several benefits:

1. It enables tracking of water quality improvements following implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on implementation levels and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

8.3. IMPLEMENTATION OF WASTE LOAD ALLOCATIONS

Federal regulations require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). All such permits should be submitted to USEPA for review.

For the implementation of the WLA component of the TMDL, the Commonwealth utilizes the Virginia NPDES program. Requirements of the permit process should not be duplicated in the TMDL process, and permitted sources are not usually addressed through the development of any TMDL implementation plans.

8.3.1. Stormwater

VADEQ and VADCR coordinate separate state permitting programs that regulate the management of pollutants carried by stormwater runoff. VADEQ regulates stormwater discharges associated with industrial activities through its VPDES program, while VADCR regulates stormwater discharges from construction sites, and from municipal separate storm sewer systems (MS4s) through the VSMP program. Stormwater discharges from coal mining operations are permitted through NPDES permits by the Department of Mines, Minerals and Energy (DMME). As with non-stormwater permits, all new or revised stormwater permits must be consistent with the assumptions and requirements of any applicable TMDL WLA. If a WLA is based on conditions specified in existing permits, and the permit conditions are being met, no additional actions may be needed. If a WLA is based on reduced pollutant loads, additional pollutant control actions will need to be implemented.

8.3.2. TMDL Modifications for New or Expanding Dischargers

Permits issued for facilities with wasteload allocations developed as part of a TMDL must be consistent with the assumptions and requirements of these wasteload allocations (WLA), as per USEPA regulations. In cases where a proposed permit modification is affected by a TMDL WLA, permit and TMDL staff must coordinate to ensure that new or expanding discharges meet this requirement. In 2005, VADEQ issued guidance memorandum 05-2011 describing the available options and the process that should be followed under those circumstances, including public participation, USEPA approval, State Water Control Board actions, and coordination between permit and TMDL staff (VADEQ, 2005). The guidance memorandum is available on VADEQ's web site at http://www.deq.virginia.gov/waterguidance/.

8.4. IMPLEMENTATION OF LOAD ALLOCATIONS

The TMDL program does not impart new implementation authorities. Therefore, the Commonwealth intends to use existing programs to the fullest extent in order to attain its water quality goals. The measures for nonpoint source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the TMDL implementation plan.

8.4.1. Implementation Plan Development

For the implementation of the TMDL's LA component, a TMDL implementation plan will be developed that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19.7. State law directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters". The implementation plan "shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments". USEPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process" (USEPA, 1999). The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

In order to qualify for other funding sources, such as USEPA's Section 319 grants, additional plan requirements may need to be met. The detailed process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 (VADCR, 2003) and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ, VADCR, and other cooperating agencies are technical resources to assist in this endeavor.

With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

8.4.2. Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. In 2005, the Secretary of Natural Resources developed tributary strategies for the major basins discharging to the Chesapeake Bay (VASNR, 2005). These strategies set nutrient and sediment reductions for the basins and highlight practices to achieve those reductions. Many of the BMPs that will be used to reduce sediment in the Little Calfpasture River will also be effective in reducing nutrients and sediment contributions as part of the James River Basin Tributary Strategy. For example, livestock fencing and riparian buffers will be essential components of the Little Calfpasture River Implementation Plan. These same BMPs are elements of the James River Tributary Strategy to reduce nutrient and sediment inputs to the Chesapeake Bay. More information on the James River Basin Tributary Strategy can be found at:

http://www.naturalresources.virginia.gov/Initiatives/WaterQuality/FinalizedTribStrats/james.pdf.

8.4.3. Implementation Funding Sources

The implementation of pollutant reductions from non-regulated nonpoint sources relies heavily on incentive-based programs. Therefore, the identification of funding sources for non-regulated implementation activities is a key to success. Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans" (VADCR, 2003). The TMDL Implementation Plan Guidance Manual contains information on a variety of funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

Some of the major potential sources of funding for non-regulated implementation actions may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, USEPA Section 319 funds, the Virginia State Revolving Loan Program (also available for permitted activities), Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits and landowner contributions.

With additional appropriations for the Water Quality Improvement Fund during the last two legislative sessions, the Fund has become a significant funding stream for agricultural BMPs and wastewater treatment plants. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found at http://www.deq.virginia.gov/bay/wqif.html and at

http://www.dcr.virginia.gov/soil_&_water/wqia.shtml.

8.5. FOLLOW-UP MONITORING

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient and biological monitoring programs. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with VADEQ Guidance Memo No. 03-2004 (VADEQ, 2004a), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study. Since there may be a lag time of one-to-several years before any improvement in the benthic community will be evident, follow-up biological monitoring may not have to occur in the fiscal year immediately following the implementation of control measures.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, in cooperation with VADCR staff, the Implementation Plan Steering Committee and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30 of each year.

VADEQ will continue to monitor benthic aquatic life in the Little Calfpasture River above and below Lake Merriweather at stations 2-LCF004.80 and 2-LCF000.02. VADEQ will also continue to monitor water quality at stations 2-LCF007.00 and 2-LCF000.02 according to its ambient monitoring program. When an Implementation Plan is developed for the Little Calfpasture River and implementation of that plan begins, VADEQ may increase the frequency of monitoring at these sites to assess water quality progress as improvements are implemented.

VADEQ staff, in cooperation with VADCR staff, the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient and benthic monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plan. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or Implementation plan has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one year period.

8.6. ATTAINABILITY OF DESIGNATED USES

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use.

In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses will be attained by implementing effluent limits required under §301b and §306 of Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentration prevents the attainment of the use;

2. Natural, ephemeral, intermittent or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation;

3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;

4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;

5. Physical conditions related to natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or

6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

In conjunction with this TMDL, a designated use change was proposed for a section of the Little Calfpasture River immediately below the Goshen Dam. This designated use change is further discussed in Section 4.7.2 of this report. In general, the use modification was necessary because the existence of the dam precluded attainment of existing uses for some distance downstream regardless of any pollutant reduction efforts. The stressor analysis identified that the existence of the dam resulted in hydrodynamic and ecological changes (i.e., change in available food supply) that resulted in perpetually impaired aquatic life directly below the dam (at station 2-LCF000.76). Federal regulations specifically allow designated use changes under these conditions, as identified in #4 above. The modified designated use in the Little Calfpasture River allows for a zone of recovery from dam impacts that cannot be mitigated, but ensures that the general standard is maintained within 0.74 miles downstream (at station 2-LCF000.02).

CHAPTER 9: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive input from stakeholders and to apprise the stakeholders of the progress made. Public participation was encouraged through holding public meetings in the watershed and by forming a TMDL Technical Advisory Committee. The Technical Advisory Committee was a group of local citizens, landowners, organizations, and government entities that could provide local input and assistance to VADEQ during the TMDL Study. The goal of the Technical Advisory Committee was to make sure that the technical aspects of the study (including model inputs and assumptions) were accurate as well as acceptable to the community.

On April 14, 2009, VADEQ held a public meeting at the Rockbridge Baths Volunteer Fire Hall to explain the Little Calfpasture River impairment to local citizens and describe the TMDL Study that would take place. The meeting was advertised through e-mail announcements to local contacts, letters to VPDES permit holders, notice publication in the Virginia Register, and announcement through local conservation and civic groups. Approximately 100 people attended the meeting. At the meeting, VADEQ explained the aquatic life impairment in the Little Calfpasture River, presented the results of a stressor analysis, described the TMDL process, and provided an open invitation to participate on the Technical Advisory Committee. Handouts of the presentation were made available to attendees of the meeting and were distributed electronically upon request to those that were not able to attend the meeting.

The Technical Advisory Committee met on June 22, 2009, July 30, 2009, and again on September 16, 2009. At the first meeting, the committee reviewed stressor analysis results, land use, and sediment source data. At the second meeting, the committee reviewed model results and TMDL allocations. VADEQ responded to all substantive comments from the stakeholder meetings in a follow-up document. Comments were also used to select appropriate TMDL allocation options. The Third Technical Committee was held to review the draft of the TMDL, the scenarios chosen and begin to plan for the Final Public Meeting.

On November 19, 2009, a second public meeting was held in the Little Calfpasture River area. This meeting was once again advertised through e-mail announcements, notice publication in the Virginia Register, and through local conservation and civic groups. Approximately 35 people attended this final public meeting. At the meeting, VADEQ presented the draft TMDL report to the public and explained its development and conclusions. Handouts of the presentation and the executive summary of the draft report were made available to the public at the meeting. The full report was made available on the VADEQ website at:

http://gisweb.deq.virginia.gov/tmdlapp/tmdl_draft_reports.cfm.

Following the meeting, a 30-day public comment period on the draft was initiated. Comments were addressed in a Response to Comments Document and appropriate modifications were made to the draft report.

CHAPTER 10: REFERENCES

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APPENDIX A:
Hydrologic Model Parameters

Table A-1. Hydrologic Reach Parameters for Little Calfpasture River LSPC Model.

Sub-watershed	DEPINIT_M	LEN_M	SLOPE	WID_M	DEP_M	R1	R2	W1	MANNING_N	CRRAT
1	0.4	429	0.002331002	20	1.5	0.6	0.05	2	0.04	1.5
2	0.1	2418	0.110421836	3	0.75	0.5	1	1	0.04	1.5
3	0.4	888	0.007882883	20	1.5	0.6	0.05	2	0.04	1.5
10	0.1	1477	0.058903182	3	0.75	0.5	1	1	0.04	1.5
11	0.1	2669	0.052454103	3	0.75	0.5	1	1	0.04	1.5
12	0.1	1782	0.056116723	3	0.75	0.5	1	1	0.04	1.5
13	0.1	3685	0.072455902	3	0.75	0.5	1	1	0.04	1.5
14	0.1	2833	0.063183904	3	0.75	0.5	1	1	0.04	1.5
15	0.1	1919	0.093798854	3	0.75	0.5	1	1	0.04	1.5
16	0.1	1588	0.113350126	3	0.75	0.5	1	1	0.04	1.5
17	0.1	2128	0.137218045	3	0.75	0.5	1	1	0.04	1.5
20	0.4	4065	0.001722017	20	1.3	0.6	0.05	0.75	0.04	1.5
21	0.5	218	0.004587156	20	2	0.5	0.5	0.4	0.04	1.5
22	0.2	7957	0.010808094	11	1.3	0.45	2	0.45	0.04	1.5
23	0.4	6604	0.002725621	11	1.4	0.68	0.05	1.8	0.04	1.5
24	0.3	9156	0.01037571	8	1	0.375	0.1	2.5	0.04	1.5
25	0.2	3553	0.003940332	10	1.2	0.8	0.05	2	0.04	1.5
26	0.1	5749	0.03009219	2	0.75	0.5	0.1	2.5	0.04	1.5
27	0.4	2534	0.00789266	12	1.8	0.417	0.2	2.08	0.04	1.5
28	0.1	4321	0.035177042	2	1	0.5	0.1	2.5	0.04	1.5
29	0.3	5105	0.008031342	10	2.5	0.3	0.05	1.5	0.04	1.5
30	0	4386	0.084587323	2	0.5	0.5	0.167	2	0.04	1.5
31	0.1	5458	0.018504947	8	1	0.5	0.167	0.625	0.04	1.5

Table A-2. Hydrologic Watershed Parameters for Sub-watersheds 1-3 in the Little Calfpasture River LSPC Model.

Sub-watershed	Land use	SLSUR	LSUR	MELEV	RMELEV
1	Residential	0.01	0	1587	1334
	Cropland	0.025	0	1587	1334
	Pasture/Hay	0.01	244.28	1587	1334
	Degraded Riparian Pasture	0.02	164	1587	1334
	Forest	0.2	2661.3	1587	1334
	Impervious Urban/Transportation	0.01	25	1587	1334
2	Residential	0.01	0	2000	1673
	Cropland	0.025	0	2000	1673
	Pasture/Hay	0.03	0	2000	1673
	Degraded Riparian Pasture	0.02	164	2000	1673
	Forest	0.19	2150.5	2000	1673
	Impervious Urban/Transportation	0.01	25	2000	1673
3	Residential	0.01	0	1363	1345
	Cropland	0.025	7.0198	1363	1345
	Pasture/Hay	0.02	354.5	1363	1345
	Degraded Riparian Pasture	0.02	164	1363	1345
	Forest	0.02	811.97	1363	1345
	Impervious Urban/Transportation	0.01	25	1363	1345

Table A-3. Hydrologic Watershed Parameters for Sub-watersheds 10-17 in the Little Calfpasture River LSPC Model.

Sub-watershed	Land use	SLSUR	LSUR	MELEV	RMELEV
10	Residential	0.01	0	1506	1432
	Cropland	0.025	38.457	1506	1432
	Pasture/Hay	0.1	797.98	1506	1432
	Degraded Riparian Pasture	0.02	164	1506	1432
	Forest	0.1	8803	1506	1432
	Impervious Urban/Transportation	0.01	25	1506	1432
11	Residential	0.01	0	1622	1559
	Cropland	0.025	42.29	1622	1559
	Pasture/Hay	0.06	475.06	1622	1559
	Degraded Riparian Pasture	0.02	164	1622	1559
	Forest	0.06	2715	1622	1559
	Impervious Urban/Transportation	0.01	25	1622	1559
12	Residential	0.01	0	1574	1470
	Cropland	0.025	3.7259	1574	1470
	Pasture/Hay	0.06	723.14	1574	1470
	Degraded Riparian Pasture	0.02	164	1574	1470
	Forest	0.08	1987.1	1574	1470
	Impervious Urban/Transportation	0.01	25	1574	1470
13	Residential	0.01	0	1824	1665
	Cropland	0.025	28.598	1824	1665
	Pasture/Hay	0.02	182.41	1824	1665
	Degraded Riparian Pasture	0.02	164	1824	1665

	Forest	0.12	2409.1	1824	1665
	Impervious Urban/Transportation	0.01	25	1824	1665
14	Residential	0.01	0	1794	1587
	Cropland	0.025	3.9509	1794	1587
	Pasture/Hay	0.04	6.2086	1794	1587
	Degraded Riparian Pasture	0.02	164	1794	1587
	Forest	0.11	5180.6	1794	1587
	Impervious Urban/Transportation	0.01	25	1794	1587
15	Residential	0.01	0	1772	1564
	Cropland	0.025	0	1772	1564
	Pasture/Hay	0.02	25.382	1772	1564
	Degraded Riparian Pasture	0.02	164	1772	1564
	Forest	0.15	4999.9	1772	1564
	Impervious Urban/Transportation	0.01	25	1772	1564
16	Residential	0.01	0	1813	1610
	Cropland	0.025	0	1813	1610
	Pasture/Hay	0.02	0	1813	1610
	Degraded Riparian Pasture	0.02	164	1813	1610
	Forest	0.16	5729.7	1813	1610
	Impervious Urban/Transportation	0.01	25	1813	1610
17	Residential	0.01	0	1838	1704
	Cropland	0.025	0	1838	1704
	Pasture/Hay	0.02	0	1838	1704
	Degraded Riparian Pasture	0.02	164	1838	1704
	Forest	0.16	2764	1838	1704
	Impervious Urban/Transportation	0.01	25	1838	1704

Table A-4. Hydrologic Watershed Parameters for Sub-watersheds 20-31 in the Little Calfpasture River LSPC Model.

Sub-watershed	Land use	SLSUR	LSUR	MELEV	RMELEV
20	Residential	0.01	31.408	1751	1380
	Cropland	0.025	166.98	1751	1380
	Pasture/Hay	0.04	2458.1	1751	1380
	Degraded Riparian Pasture	0.02	164	1751	1380
	Forest	0.14	9428.1	1751	1380
	Impervious Urban/Transportation	0.01	25	1751	1380
21	Residential	0.01	0	1431	1388
	Cropland	0.025	0	1431	1388
	Pasture/Hay	0.04	60.936	1431	1388
	Degraded Riparian Pasture	0.02	164	1431	1388
	Forest	0.1	358.84	1431	1388
	Impervious Urban/Transportation	0.01	25	1431	1388
22	Residential	0.01	74.941	1778	1529
	Cropland	0.025	39.763	1778	1529
	Pasture/Hay	0.04	945.61	1778	1529
	Degraded Riparian Pasture	0.02	164	1778	1529
	Forest	0.11	8820.3	1778	1529
	Impervious Urban/Transportation	0.01	25	1778	1529
23	Residential	0.01	4.5818	1880	1424
	Cropland	0.025	25.196	1880	1424
	Pasture/Hay	0.04	1427.8	1880	1424

	Degraded Riparian Pasture	0.02	164	1880	1424
	Forest	0.15	7460.2	1880	1424
	Impervious Urban/Transportation	0.01	25	1880	1424
24	Residential	0.01	11.204	1933	1523
	Cropland	0.025	67.946	1933	1523
	Pasture/Hay	0.02	1353.6	1933	1523
	Degraded Riparian Pasture	0.02	164	1933	1523
	Forest	0.14	9365.6	1933	1523
	Impervious Urban/Transportation	0.01	25	1933	1523
25	Residential	0.01	2.0771	1589	1463
	Cropland	0.025	7.7398	1589	1463
	Pasture/Hay	0.06	827.88	1589	1463
	Degraded Riparian Pasture	0.02	164	1589	1463
	Forest	0.09	1815.2	1589	1463
	Impervious Urban/Transportation	0.01	25	1589	1463
26	Residential	0.01	329.4	1960	1642
	Cropland	0.025	57.158	1960	1642
	Pasture/Hay	0.02	1047.2	1960	1642
	Degraded Riparian Pasture	0.02	164	1960	1642
	Forest	0.07	10735	1960	1642
	Impervious Urban/Transportation	0.01	25	1960	1642
27	Residential	0.01	53.588	1625	1510
	Cropland	0.025	40.301	1625	1510
	Pasture/Hay	0.03	1019	1625	1510
	Degraded Riparian Pasture	0.02	164	1625	1510
	Forest	0.18	2197.4	1625	1510
	Impervious Urban/Transportation	0.01	25	1625	1510
28	Residential	0.01	9.906	2049	1724
	Cropland	0.025	1.7101	2049	1724
	Pasture/Hay	0.02	465.51	2049	1724
	Degraded Riparian Pasture	0.02	164	2049	1724
	Forest	0.08	5453.6	2049	1724
	Impervious Urban/Transportation	0.01	25	2049	1724
29	Residential	0.01	93.967	2058	1595
	Cropland	0.025	89.553	2058	1595
	Pasture/Hay	0.02	1573.5	2058	1595
	Degraded Riparian Pasture	0.02	164	2058	1595
	Forest	0.09	14432	2058	1595
	Impervious Urban/Transportation	0.01	25	2058	1595
30	Residential	0.01	43.748	2540	2014
	Cropland	0.025	0	2540	2014
	Pasture/Hay	0.02	155.14	2540	2014
	Degraded Riparian Pasture	0.02	164	2540	2014
	Forest	0.14	5797.8	2540	2014
	Impervious Urban/Transportation	0.01	25	2540	2014
31	Residential	0.01	30.829	2374	1812
	Cropland	0.025	29.638	2374	1812
	Pasture/Hay	0.06	454.29	2374	1812
	Degraded Riparian Pasture	0.02	164	2374	1812
	Forest	0.13	15892	2374	1812
	Impervious Urban/Transportation	0.01	25	2374	1812

Table A-5. Hydrologic Parameter Group 1 for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	LZSN	INFILT	KVARY	AGWRC
W. Augusta	23-31	Residential	3.500276	0.035417	0	0.948395
		Cropland	3.500276	0.066407	0	0.948395
		Pasture/Hay	3.500276	0.066407	0	0.948395
		Degraded Riparian Pasture	3.500276	0.035417	0	0.948395
		Forest	3.500276	0.070834	0	0.948395
		Impervious Urban/Transportation	3.500276	0	0	0.948395
Rockbridge	1-3, 10-17, 20-22	Residential	4.132104	0.10115	0	0.97121
		Cropland	4.132104	0.189656	0	0.97121
		Pasture/Hay	4.132104	0.189656	0	0.97121
		Degraded Riparian Pasture	4.132104	0.10115	0	0.97121
		Forest	4.132104	0.202299	0	0.97121
		Impervious Urban/Transportation	4.132104	0	0	0.97121

Table A-6. Hydrologic Parameter Group 2 for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
W. Augusta	23-31	Residential	40	35	2	2	0	0	0.1
		Cropland	40	35	2	2	0	0	0.05
		Pasture/Hay	40	35	2	2	0	0	0.075
		Degraded Riparian Pasture	40	35	2	2	0	0	0.005
		Forest	40	35	2	2	0	0	0.3
		Impervious Urban/Transportation	40	35	2	2	0	0	0.1
Rockbridge	1-3, 10-17, 20-22	Residential	40	35	2	2	0	0	0.1
		Cropland	40	35	2	2	0	0	0.05
		Pasture/Hay	40	35	2	2	0	0	0.075
		Degraded Riparian Pasture	40	35	2	2	0	0	0.005
		Forest	40	35	2	2	0	0	0.3
		Impervious Urban/Transportation	40	35	2	2	0	0	0.1

Table A-7. Hydrologic Parameter Group 3 for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	CEPS	UZSN	NSUR	INTFW	IRC	LZETP
W. Augusta	23-31	Residential	0.05	0.350028	0.25	2.558349	0.42813	0.6
		Cropland	0.05	0.7	0.25	2.558349	0.42813	0.6
		Pasture/Hay	0.05	0.350028	0.25	2.558349	0.42813	0.5
		Degraded Riparian Pasture	0.05	0.245019	0.15	2.558349	0.42813	0.1
		Forest	0.05	0.420033	0.4	3.197936	0.42813	0.6
		Impervious Urban/Transportation	0.05	0.350028	0.25	2.558349	0.42813	0.6
Rockbridge	1-3, 10-17, 20-22	Residential	0.05	0.41321	0.25	4	0.412451	0.6
		Cropland	0.05	0.7	0.25	4	0.412451	0.6
		Pasture/Hay	0.05	0.41321	0.25	4	0.412451	0.5
		Degraded Riparian Pasture	0.05	0.289247	0.15	4	0.412451	0.1
		Forest	0.05	0.495852	0.4	5	0.412451	0.6
		Impervious Urban/Transportation	0.05	0.41321	0.25	4	0.412451	0.6

Table A-8. Monthly Interception Storage (CEPS) Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	0.072	0.07	0.072	0.104	0.148	0.15	0.15	0.148	0.148	0.104	0.075	0.074
		Cropland	0.067	0.065	0.062	0.06	0.064	0.085	0.138	0.15	0.146	0.109	0.087	0.077
		Pasture/Hay	0.063	0.06	0.065	0.079	0.097	0.1	0.1	0.097	0.097	0.078	0.073	0.067
		Degraded Riparian Pasture	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		Forest	0.08	0.08	0.08	0.13	0.2	0.2	0.2	0.2	0.2	0.13	0.08	0.08
		Impervious Urban/Transportation	0.072	0.07	0.072	0.104	0.148	0.15	0.15	0.148	0.148	0.104	0.076	0.074
Rockbridge	1-3, 10-17, 20-22	Residential	0.072	0.07	0.072	0.104	0.148	0.15	0.15	0.148	0.148	0.104	0.076	0.074
		Cropland	0.067	0.065	0.062	0.06	0.064	0.085	0.138	0.15	0.146	0.109	0.087	0.077
		Pasture/Hay	0.063	0.06	0.065	0.079	0.097	0.1	0.1	0.097	0.097	0.078	0.073	0.067
		Degraded Riparian Pasture	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		Forest	0.08	0.08	0.08	0.13	0.2	0.2	0.2	0.2	0.2	0.13	0.08	0.08
		Impervious Urban/Transportation	0.072	0.07	0.072	0.104	0.148	0.15	0.15	0.148	0.148	0.104	0.076	0.074

Table A-9. Monthly Upper Zone Nominal Storage (UZSN) Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028
		Cropland	0.294	0.294	0.294	0.294	0.294	0.343	0.4655	0.49	0.49	0.392	0.343	0.3185
		Pasture/Hay	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028
		Degraded Riparian Pasture	0.245019	0.245019	0.245019	0.245019	0.245019	0.245019	0.245019	0.245019	0.245019	0.245019	0.245019	0.245019
		Forest	0.420033	0.420033	0.420033	0.420033	0.420033	0.420033	0.420033	0.420033	0.420033	0.420033	0.420033	0.420033
		Impervious Urban/Transportation	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028	0.350028
Rock-bridge	1-3, 10-17, 20-22	Residential	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321
		Cropland	0.3471	0.3471	0.3471	0.3471	0.3471	0.4049	0.5496	0.5785	0.5785	0.4628	0.4049	0.376
		Pasture/Hay	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321
		Degraded Riparian Pasture	0.289247	0.289247	0.289247	0.289247	0.289247	0.289247	0.289247	0.289247	0.289247	0.289247	0.289247	0.289247
		Forest	0.495852	0.495852	0.495852	0.495852	0.495852	0.495852	0.495852	0.495852	0.495852	0.495852	0.495852	0.495852
		Impervious Urban/Transportation	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321	0.41321

Table A-10. Monthly Lower Zone Evapotranspiration (LZEPT) Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
		Cropland	0.232	0.221	0.208	0.2	0.218	0.312	0.547	0.6	0.582	0.416	0.322	0.276
		Pasture/Hay	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		Degraded Riparian Pasture	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Forest	0.4	0.4	0.4	0.524	0.7	0.7	0.7	0.7	0.7	0.524	0.4	0.4
		Impervious Urban/Transportation	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Rockbridge	1-3, 10-17, 20-22	Residential	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
		Cropland	0.232	0.221	0.208	0.2	0.218	0.312	0.547	0.6	0.582	0.416	0.322	0.276
		Pasture/Hay	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		Degraded Riparian Pasture	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Forest	0.4	0.4	0.4	0.524	0.7	0.7	0.7	0.7	0.7	0.524	0.4	0.4
		Impervious Urban/Transportation	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Table A-11. Monthly Mannings n Values for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
		Cropland	0.2435	0.2435	0.2342	0.2258	0.2453	0.3656	0.3971	0.3971	0.3966	0.2667	0.2537	0.2434
		Pasture/Hay	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
		Degraded Riparian Pasture	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
		Forest	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
		Impervious Urban/Transportation	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Rockbridge	1-3, 10-17, 20-22	Residential	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
		Cropland	0.243	0.243	0.2337	0.2253	0.2452	0.3658	0.3975	0.3975	0.3971	0.266	0.2533	0.243
		Pasture/Hay	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
		Degraded Riparian Pasture	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
		Forest	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
		Impervious Urban/Transportation	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Table A-12. Snow Parameter Group 1 for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	FOREST	LAT	SHADE	SNOWCF	COVIND
W. Augusta	23-31	Residential	0.054279	38	0.2	1.3	4.89
		Cropland	0	38	0.05	1.3	4.89
		Pasture/Hay	0	38	0.1	1.3	4.89
		Degraded Riparian Pasture	0	38	0.1	1.3	4.89
		Forest	0.189554	38	0.311	1.3	4.89
		Impervious Urban/Transportation	0	38	0.05	1.3	4.89
Rockbridge	1-3, 10-17, 20-22	Residential	0.073593	38	0.2	1.3	2.49
		Cropland	0	38	0.05	1.3	2.49
		Pasture/Hay	0	38	0.1	1.3	2.49
		Degraded Riparian Pasture	0	38	0.1	1.3	2.49
		Forest	0.159875	38	0.286	1.3	2.49
		Impervious Urban/Transportation	0	38	0.05	1.3	2.49

Table A-13. Snow Parameter Group 2 for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	RDCSN	TSNOW	SNOEVP	CCFACT	MWATER	MGMELT
W. Augusta	23-31	Residential	0.12	32	0.13	0.5	0.03	0.03
		Cropland	0.12	32	0.13	0.5	0.03	0.03
		Pasture/Hay	0.12	32	0.13	0.5	0.03	0.03
		Degraded Riparian Pasture	0.12	32	0.13	0.5	0.03	0.03
		Forest	0.12	32	0.13	0.5	0.03	0.03
		Impervious Urban/Transportation	0.12	32	0.13	0.5	0.03	0.03
Rockbridge	1-3, 10-17, 20-22	Residential	0.12	32	0.13	0.5	0.03	0.03
		Cropland	0.12	32	0.13	0.5	0.03	0.03
		Pasture/Hay	0.12	32	0.13	0.5	0.03	0.03
		Degraded Riparian Pasture	0.12	32	0.13	0.5	0.03	0.03
		Forest	0.12	32	0.13	0.5	0.03	0.03
		Impervious Urban/Transportation	0.12	32	0.13	0.5	0.03	0.03

Table A-14. Snow Initial Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	PACK-SNOW	PACK-ICE	PACK-WATR	RDENPF	DULL	PAKTMP	COVINX	XLNMLT	SKYCLR
W. Augusta	23-31	Residential	2.982	0	0	0.15	100	30	4.89	0	0.9
		Cropland	2.982	0	0	0.15	100	30	4.89	0	0.9
		Pasture/Hay	2.982	0	0	0.15	100	30	4.89	0	0.9
		Degraded Riparian Pasture	2.982	0	0	0.15	100	30	4.89	0	0.9
		Forest	2.982	0	0	0.15	100	30	4.89	0	0.9
		Impervious Urban/Transportation	2.982	0	0	0.15	100	30	4.89	0	0.9
Rockbridge	1-3, 10-17, 20-22	Residential	1.008	0	0	0.15	100	30	2.49	0	0.9
		Cropland	1.008	0	0	0.15	100	30	2.49	0	0.9
		Pasture/Hay	1.008	0	0	0.15	100	30	2.49	0	0.9
		Degraded Riparian Pasture	1.008	0	0	0.15	100	30	2.49	0	0.9
		Forest	1.008	0	0	0.15	100	30	2.49	0	0.9
		Impervious Urban/Transportation	1.008	0	0	0.15	100	30	2.49	0	0.9

Table A-15. Soil Temperature Constant Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	ISLT	IIFT	IGWT	CFSAEX	KATRAD	KCOVD	KEVAP
W. Augusta	23-31	Residential	0	0	5.1287556	0.8	9.37	6.12	2.24
		Cropland	0	0	5.1287556	0.8	9.37	6.12	2.24
		Pasture/Hay	0	0	5.1287556	0.8	9.37	6.12	2.24
		Degraded Riparian Pasture	0	0	5.1287556	0.8	9.37	6.12	2.24
		Forest	0	0	5.1287556	0.8	9.37	6.12	2.24
		Impervious Urban/Transportation	0	0	5.1287556	0.8	9.37	6.12	2.24
Rockbridge	1-3, 10-17, 20-22	Residential	0	0	5.1835944	0.8	9.37	6.12	2.24
		Cropland	0	0	5.1835944	0.8	9.37	6.12	2.24
		Pasture/Hay	0	0	5.1835944	0.8	9.37	6.12	2.24
		Degraded Riparian Pasture	0	0	5.1835944	0.8	9.37	6.12	2.24
		Forest	0	0	5.1835944	0.8	9.37	6.12	2.24
		Impervious Urban/Transportation	0	0	5.1835944	0.8	9.37	6.12	2.24

Table A-16. Monthly Soil Temperature ASLT Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	7.494	2.483	3.211	5.533	8.628	14.056	16.011	14.356	8.006	9.028	9.306	6.472
		Cropland	7.494	2.483	3.211	5.533	8.628	14.056	16.011	14.356	8.006	9.028	9.306	6.472
		Pasture/Hay	7.494	2.483	3.211	5.533	8.628	14.056	16.011	14.356	8.006	9.028	9.306	6.472
		Degraded Riparian Pasture	7.494	2.483	3.211	5.533	8.628	14.056	16.011	14.356	8.006	9.028	9.306	6.472
		Forest	7.494	2.483	3.211	5.533	8.628	14.056	16.011	14.356	8.006	9.028	9.306	6.472
		Impervious Urban/Transportation	7.494	2.483	3.211	5.533	8.628	14.056	16.011	14.356	8.006	9.028	9.306	6.472
Rockbridge	1-3, 10-17, 20-22	Residential	7.478	2.150	4.594	9.411	9.833	9.239	12.583	18.611	12.322	8.561	7.106	5.222
		Cropland	7.478	2.150	4.594	9.411	9.833	9.239	12.583	18.611	12.322	8.561	7.106	5.222
		Pasture/Hay	7.478	2.150	4.594	9.411	9.833	9.239	12.583	18.611	12.322	8.561	7.106	5.222
		Degraded Riparian Pasture	7.478	2.150	4.594	9.411	9.833	9.239	12.583	18.611	12.322	8.561	7.106	5.222
		Forest	7.478	2.150	4.594	9.411	9.833	9.239	12.583	18.611	12.322	8.561	7.106	5.222
		Impervious Urban/Transportation	7.478	2.150	4.594	9.411	9.833	9.239	12.583	18.611	12.322	8.561	7.106	5.222

Table A-17. Monthly Soil Temperature BSLT Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
		Cropland	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
		Pasture/Hay	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
		Degraded Riparian Pasture	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
		Forest	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		Impervious Urban/Transportation	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Rockbridge	1-3, 10-17, 20-22	Residential	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
		Cropland	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
		Pasture/Hay	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
		Degraded Riparian Pasture	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
		Forest	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		Impervious Urban/Transportation	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52

Table A-18. Monthly Soil Temperature AIFT Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	7.883	2.872	4.989	9.811	15.739	24.167	27.900	26.244	17.006	13.694	12.194	7.583
		Cropland	7.883	2.872	4.989	9.811	15.739	24.167	27.900	26.244	17.006	13.694	12.194	7.583
		Pasture/Hay	7.883	2.872	4.989	9.811	15.739	24.167	27.900	26.244	17.006	13.694	12.194	7.583
		Degraded Riparian Pasture	7.883	2.872	4.989	9.811	15.739	24.167	27.900	26.244	17.006	13.694	12.194	7.583
		Forest	7.883	2.872	4.989	9.811	15.739	24.167	27.900	26.244	17.006	13.694	12.194	7.583
		Impervious Urban/Transportation	7.883	2.872	4.989	9.811	15.739	24.167	27.900	26.244	17.006	13.694	12.194	7.583
Rockbridge	1-3, 10-17, 20-22	Residential	7.867	2.539	6.372	13.689	16.944	19.350	24.472	30.500	21.322	13.228	9.994	6.333
		Cropland	7.867	2.539	6.372	13.689	16.944	19.350	24.472	30.500	21.322	13.228	9.994	6.333
		Pasture/Hay	7.867	2.539	6.372	13.689	16.944	19.350	24.472	30.500	21.322	13.228	9.994	6.333
		Degraded Riparian Pasture	7.867	2.539	6.372	13.689	16.944	19.350	24.472	30.500	21.322	13.228	9.994	6.333
		Forest	7.867	2.539	6.372	13.689	16.944	19.350	24.472	30.500	21.322	13.228	9.994	6.333
		Impervious Urban/Transportation	7.867	2.539	6.372	13.689	16.944	19.350	24.472	30.500	21.322	13.228	9.994	6.333

Table A-19. Monthly Soil Temperature BIFT Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
		Cropland	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
		Pasture/Hay	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
		Degraded Riparian Pasture	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
		Forest	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Impervious Urban/Transportation	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Rockbridge	1-3, 10-17, 20-22	Residential	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
		Cropland	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
		Pasture/Hay	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
		Degraded Riparian Pasture	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
		Forest	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Impervious Urban/Transportation	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11

Table A-20. Monthly Soil Temperature AGWT Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	5.128	10.583	13.772	12.694	15.378	15.556	15.556	15.556	15.556	15.878	14.878	6.867
		Cropland	5.128	10.583	13.772	12.694	15.378	15.556	15.556	15.556	15.556	15.878	14.878	6.867
		Pasture/Hay	5.128	10.583	13.772	12.694	15.378	15.556	15.556	15.556	15.556	15.878	14.878	6.867
		Degraded Riparian Pasture	5.128	10.583	13.772	12.694	15.378	15.556	15.556	15.556	15.556	15.878	14.878	6.867
		Forest	5.128	10.583	13.772	12.694	15.378	15.556	15.556	15.556	15.556	15.878	14.878	6.867
		Impervious Urban/Transportation	5.128	10.583	13.772	12.694	15.378	15.556	15.556	15.556	15.556	15.878	14.878	6.867
Rockbridge	1-3, 10-17, 20-22	Residential	5.183	8.306	11.011	12.644	15.556	15.556	15.556	15.556	13.456	14.433	11.472	5.722
		Cropland	5.183	8.306	11.011	12.644	15.556	15.556	15.556	15.556	13.456	14.433	11.472	5.722
		Pasture/Hay	5.183	8.306	11.011	12.644	15.556	15.556	15.556	15.556	13.456	14.433	11.472	5.722
		Degraded Riparian Pasture	5.183	8.306	11.011	12.644	15.556	15.556	15.556	15.556	13.456	14.433	11.472	5.722
		Forest	5.183	8.306	11.011	12.644	15.556	15.556	15.556	15.556	13.456	14.433	11.472	5.722
		Impervious Urban/Transportation	5.183	8.306	11.011	12.644	15.556	15.556	15.556	15.556	13.456	14.433	11.472	5.722

Table A-21. Monthly Soil Temperature BGWT Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	0	0	0	0	0	0	0	0	0	0	0	0
		Cropland	0	0	0	0	0	0	0	0	0	0	0	0
		Pasture/Hay	0	0	0	0	0	0	0	0	0	0	0	0
		Degraded Riparian Pasture	0	0	0	0	0	0	0	0	0	0	0	0
		Forest	0	0	0	0	0	0	0	0	0	0	0	0
		Impervious Urban/Transportation	0	0	0	0	0	0	0	0	0	0	0	0
Rockbridge	1-3, 10-17, 20-22	Residential	0	0	0	0	0	0	0	0	0	0	0	0
		Cropland	0	0	0	0	0	0	0	0	0	0	0	0
		Pasture/Hay	0	0	0	0	0	0	0	0	0	0	0	0
		Degraded Riparian Pasture	0	0	0	0	0	0	0	0	0	0	0	0
		Forest	0	0	0	0	0	0	0	0	0	0	0	0
		Impervious Urban/Transportation	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX B:
Sediment Model Parameters

Table B-1. Land-based Sediment Parameter Group 1 for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	SMPF	KRER	JRER	AFFIX	COVER	NVSI	KSER	JSER	KGER	JGER	ACCS DP	REMS DP
W. Augusta	23-31	Residential	1	0.391343	2	0.07675	0.9	6.082192	0.126	1.5	0	4	0	0
		Cropland	1	1.333871	2	0.07675	0.9	61.80822	0.525	1.5	0	4	0	0
		Pasture/Hay	1	3.005332	2	0.07675	0.9	30.73973	0.525	1.5	0	4	0	0
		Degraded Riparian Pasture	1	12.60884	2	0.07675	0.9	292.0274	0.525	1.5	0	4	0	0
		Forest	1	0.477474	2	0.07675	0.9	3.369863	0.1	1.5	0	4	0	0
		Impervious Urban/Transportation	1	0	2	0.07675	0.9	0	0.336	1.5	0	4	0.002	0.1
Rock-bridge	1-3, 10-17, 20-22	Residential	1	1.347195	2	0.07675	0.9	6.082192	3.15	1.5	0	4	0	0
		Cropland	1	5.787214	2	0.07675	0.9	35.67123	3.15	1.5	0	4	0	0
		Pasture/Hay	1	20	2	0.07675	0.9	81.36986	3.15	1.5	0	4	0	0
		Degraded Riparian Pasture	1	20	2	0.07675	0.9	773.0138	3.15	1.5	0	4	0	0
		Forest	1	1.806935	2	0.07675	0.9	2.794521	3.15	1.5	0	4	0	0
		Impervious Urban/Transportation	1	0	2	0.07675	0.9	0	0.35	1.5	0	4	0.002	0.1

Table B-2. Land-based Sediment Parameter Group 2 for the Little Calfpasture River LSPC Model.

Sub-watershed	SED_SURO	SED_IFWO	SED_AGWO	SAND	SED_1	SED_2
1	0	0	0	0.115	0.25795	0.2559
2	0	0	0	0.115	0.25795	0.2559
3	0	0	0	0.1	0.503	0.276
10	0	0	0	0.1	0.503	0.276
11	0	0	0	0.115	0.25795	0.2559
12	0	0	0	0.115	0.25795	0.2559
13	0	0	0	0.1	0.503	0.276
14	0	0	0	0.115	0.25795	0.2559
15	0	0	0	0.115	0.25795	0.2559
16	0	0	0	0.115	0.25795	0.2559
17	0	0	0	0.115	0.25795	0.2559
20	0	0	0	0.1	0.503	0.276
21	0	0	0	0.1	0.503	0.276
22	0	0	0	0.1	0.543	0.256
23	0	0	0	0.1	0.503	0.276
24	0	0	0	0.1	0.503	0.276
25	0	0	0	0.115	0.25795	0.2559
26	0	0	0	0.185	0.39105	0.2221
27	0	0	0	0.185	0.39105	0.2221
28	0	0	0	0.185	0.39105	0.2221
29	0	0	0	0.185	0.39105	0.2221
30	0	0	0	0.185	0.39105	0.2221
31	0	0	0	0.185	0.39105	0.2221

Table B-3. Monthly Cover Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	0.9	0.9	0.9	0.91	0.93	0.93	0.93	0.93	0.93	0.91	0.9	0.9
		Cropland	0.061	0.061	0.055	0.15	0.2553	0.4055	0.6422	0.7	0.7915	0.7883	0.068	0.061
		Pasture/Hay	0.9	0.9	0.9	0.91	0.93	0.93	0.93	0.93	0.93	0.91	0.9	0.9
		Degraded Riparian Pasture	0.9	0.9	0.9	0.91	0.93	0.93	0.93	0.93	0.93	0.91	0.9	0.9
		Forest	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
		Impervious Urban/Transportation	0.9	0.9	0.9	0.91	0.93	0.93	0.93	0.93	0.93	0.91	0.9	0.9
Rockbridge	1-3, 10-17, 20-22	Residential	0.9	0.9	0.9	0.91	0.93	0.93	0.93	0.93	0.93	0.91	0.9	0.9
		Cropland	0.061	0.061	0.055	0.15	0.245	0.39	0.637	0.733	0.83	0.827	0.068	0.061
		Pasture/Hay	0.9	0.9	0.9	0.91	0.93	0.93	0.93	0.93	0.93	0.91	0.9	0.9
		Degraded Riparian Pasture	0.9	0.9	0.9	0.91	0.93	0.93	0.93	0.93	0.93	0.91	0.9	0.9
		Forest	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
		Impervious Urban/Transportation	0.9	0.9	0.9	0.91	0.93	0.93	0.93	0.93	0.93	0.91	0.9	0.9

Table B-4. Monthly Sediment Input Parameters for the Little Calfpasture River LSPC Model.

County	Sub-watershed	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Augusta	23-31	Residential	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Cropland	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Pasture/Hay	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Degraded Riparian Pasture	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Forest	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
		Impervious Urban/Transportation	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Rockbridge	1-3, 10-17, 20-22	Residential	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Cropland	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Pasture/Hay	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Degraded Riparian Pasture	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Forest	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
		Impervious Urban/Transportation	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table B-5. Stream-based Sediment Parameter Group 1 for the Little Calfpasture River LSPC Model.

BEDWID	BEDDEP	POR
5	0.25	0.5

Table B-6. Stream-based Sediment Parameter Group 2 for the Little Calfpasture River LSPC Model.

SED_ID	SEDFLG	SEDO	SEDBO	D	W	RHO	TAUCD	TAUCS	M
1	1	0	0	0.0006	0.0005	2.3	0.068	0.13	0.003
2	2	0	0	0.0001	0.00005	2	0.04	0.1	0.003