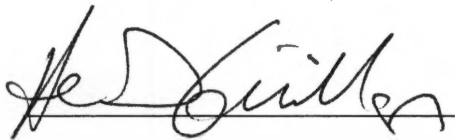
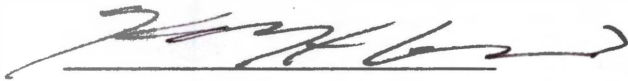


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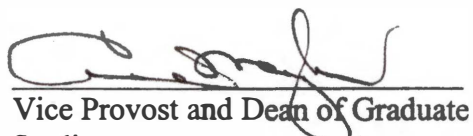
I am submitting herewith a thesis written by Donald J. Kemp, Jr. entitled "Land Use Change and Fluvial System Dynamics in Upper North Potato Creek, Copper Basin, Tennessee." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.


Dr. Carol Harden, Major Professor

We have read this thesis and
recommend its acceptance:



Acceptance for the Council:


Vice Provost and Dean of Graduate
Studies

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Land Use Change and Fluvial System Dynamics in Upper North Potato Creek, Copper Basin, Tennessee

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Donald J. Kemp, Jr.

August, 2002

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Abstract

Disturbances on land may create a situation of dynamic change in the stream as the fluvial system responds to changing driving and resisting forces. This study looks at North Potato Creek in southeast Tennessee, which has been extremely disturbed by logging, rural development, a century-length period of land denudation, and reforestation. It was undertaken to describe the present channel morphology and sediment dynamics of this stream, as a basis for understanding how changes on the land have affected it.

I sought evidence that the fluvial system is adjusting to a history of extended denudation and subsequent reforestation by looking at channel processes and historical land use change. By analyzing GIS images created from aerial photos of the basin, from 1952, 1964 and 1994, I found that bare land has decreased by 39% while forested land has increased by 33%. As bare land is converted to forested land I expect that the sediment yield from the watershed will decrease, causing changes in the fluvial system dynamics in response to the changing driving forces. By conducting measurements of channel geometry and particle size, I compare the processes occurring in different reaches and classify each study site according to the Rosgen classification technique. Lastly, I address the implications for land use management in extremely disturbed watersheds.

North Potato Creek is a bedrock stream and the current fluvial system dynamics are a result of land use disturbance. Observations from the most downstream of the three North Potato Creek sites show that North Potato Creek is not in a steady state, thus, it will continue to adjust until the driving and resisting forces are in equilibrium. It is highly improbable that this stream will recover to pre-impact dynamics, but managers, working with nature and developing a long-term plan can restore this stream to function like other bedrock streams in the Southern Metasedimentary ecoregion. Data collected in this study provide a quantitative baseline for researchers addressing this long-term management plan.

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Chapter 1

Introduction

Background

Fluvial systems are complex systems that respond to changes in climate and land cover, including human land use, with changes in channel dynamics. Ultimately, however, channel form, function, and maintenance are a result of only two sets of factors, the driving and resisting forces of flow. In a simplified model of a drainage basin, the driving forces consist of gravity, and the shear stress of moving water. Similarly, the resisting force in this model would be friction, which is affected by in-channel sediment characteristics and channel form. In a situation where the driving and resisting forces are in balance, the channel is considered to be in a steady state (Leopold, 1997).

Inherently though, this steady state is interrupted by events that lead to changes in the stream channel. At a broad scale, drainage basins become increasingly complicated, as many activities occur within these systems, such as urban development, farming, and deforestation, which can change the driving and resisting forces. For example, removing the riparian vegetation can lead to increased bank erosion and sediment input (Downs and Simon, 2001). Thus, changing land uses directly affect the dynamics of a stream channel.

For a fluvial system to maintain its steady state, it is important that the natural channel be able to accept both high and low flows and their associated sediment loads without long-term changes in channel morphology (Leopold, 1997). In such a situation, aggradation and degradation occur locally but not to any appreciable level. When human activities in a drainage basin change the sediment load or water discharge, the channel

will adjust itself to accommodate these changes (Leopold, 1997). Channel shape, size, gradient, and other properties may be altered. Deforestation is a prime example of a drainage-basin-scale activity that creates change in the fluvial system. Without interception by biota, water simply washes over and through the surface, picking up sediment and transporting it downstream. Thus, deforested basins build up sediment in the stream system as high sedimentation rates surpass the streams' ability to transport it. A study of sediment transport, redistribution, and storage from logging activities in southeastern Australia modeled these changes and found that over 50% of the eroded sediment was held in storage within the channel, directly after logging (Croke et al., 1999). Reid et al. (1981) developed a sediment budget for a logged hillslope and found that downstream channel changes include a sediment flux increase from overwash, increased baseflow, deposition of sediments in the channel, and flows characterized by a flashy flood duration curve.

Effects of Reforestation on River Systems

Although less studied than deforestation, reforestation also has major implications for channel morphology and function. Schumm et al. (1977) predicted that, despite decreased water and sediment discharges, the transport of fine sediment (<0.064 mm) should increase following reforestation. When logging activities remove the forest cover, the soil becomes susceptible to erosion and the stream prone to sedimentation. Forest succession, on the other hand, both natural and artificial, is expected to change the hydrologic regime by decreasing stream discharge and sediment flux as the new vegetation transpires water and intercepts sediment in transit via runoff (Buttle, 1994).

As a stream's discharge decreases, so does its ability to move larger material. When a stream cannot move the larger sediments, it can still actively move fine sediments (Schumm et al., 1977). Accordingly, the resulting channel bed should be composed of cobbles and larger materials that exceed the stream's ability for transport.

After a new forest is established in a previously deforested basin, rainfall runoff may continue to be high for an extended period of time (Mathews and Harden, 1999) because the forest must first establish a canopy layer to intercept precipitation. After years of litter accumulation, a humus layer will form and eventually begin soil-forming processes. Mathews and Harden (1999) found that soil-forming processes in a reforested basin can be extremely slow. In the severely denuded basin they studied, the upper soil horizons had been eroded away, exposing nutrient-poor B and C horizons that did not promote forest regeneration. This resulted in a slow recovery and an extended period of sediment transport to the fluvial system.

Buttle (1994, 1995) first addressed the hydrologic response and subsequent channel changes following reforestation in the headwaters of the Ganaraska River in Ontario, Canada. He conducted these studies using a model proposed by Schumm et al. (1977) that qualitatively addresses stream morphology dynamics following reforestation. Buttle (1994) found that post-reforestation discharge decreased by approximately 50% of the original pre-reforestation flow. By analyzing a historical time series of air photos, he was able to identify changes in channel morphology including sinuosity and the entrenchment ratio (Buttle, 1995). Buttle concluded that the Ganaraska River responded similarly to the river studied by Schumm et al. (1977).

Justification

The fluvial system is an integral part of the biosphere, and is to earth what the circulatory system is to humans. Streams are the arteries that move water from land eventually to the ocean. A well functioning fluvial system efficiently delivers water and other nutrients to plant and animal species downstream, which grow and extend aquatic ecosystem diversity. This diversity then bolsters the overall health of the fluvial system by increasing its ability to combat pollution and distribute resources efficiently. When pollution, either natural or human-caused, is introduced to well-functioning aquatic and fluvial systems, they function as natural filters to reduce and breakdown toxins. In contrast, disturbances to fluvial systems, such as land use change, can disrupt the efficient flow of water, causing damage to these ecosystems. Just as a damaged artery can cause the necrosis of living tissue, disturbances on land disrupt the fluvial system and can cause a loss of aquatic biodiversity and a disruption in the natural equilibrium. Thus, disturbances in the fluvial system can impair the health of a broader ecosystem. Humans, then, are directly affected by alterations to the fluvial system because they rely on the direct and indirect benefits of healthy and diverse ecosystems, such as efficient water delivery for crop irrigation, pollution filtration, drinking water, recreation, and transportation.

The Copper Basin, in southeastern Tennessee, offers an extreme example of disturbance to the fluvial system. It is an erosional basin that has been manipulated by mining, acid rain and fog, deforestation, rural development, and a century-long period of land denudation. In the last 50 years, successful reforestation in most of the Copper Basin has fragmented the remaining bare land and decreased the sediment yield to the

fluvial system. Thus, the Copper Basin is an especially interesting location in which to study the relationship between a large magnitude watershed disturbance caused by land use change, and the fluvial system.

This study focuses on North Potato Creek, the largest and most central stream in the Copper Basin. I specifically chose North Potato Creek because of its location and accessibility. Its location upstream of the mining operations would enable me to address the effects of watershed land use change without the direct effects of contamination from mine tailings runoff. North Potato Creek is bordered almost entirely by private land. Private ownership gave me an opportunity to gain access and talk to residents living near the stream, and listen to their accounts of stream and land use changes, which often extended to past generations. Thus, I was able to acquire site-specific local knowledge about the headwaters of North Potato Creek concerning flooding, bankfull level, land use, past channel changes, and human-caused disturbances.

Little has been published about stream sediments in the Blue Ridge Mountains region. One initial habitat assessment by the Tennessee Division of Environment and Conservation (TDEC), at a reference station on North Potato Creek, found that the sediment load falls within the expectations for streams in the Southern Metasedimentary Mountains database, but suggested that more data would be required to properly classify the stream (Arnwine and Denton, 2001). Arnwine and Denton (2001) also stated that the Copper Basin, originally included in the Southern Metasedimentary Mountains ecoregion, a subregion of the Blue Ridge Mountains, might be better treated as a distinct subregion called Broad Basins due to its unique history of denudation. They advised caution in comparing streams in the Copper Basin to those of the Southern

Metasedimentary Mountains ecoregion until reference data in the Copper Basin area can be collected.

The body of literature examining watershed land use change, particularly reforestation, is very limited. Many of these studies are based on sediment modeling (e.g., Lukey et al., 2000), and are completed during and directly following reforestation. However, few long-term studies exist. I undertook this research to contribute to knowledge about the effects of reforestation on streams and to aid in the collection of site-specific data for North Potato Creek. The data collected in this study can be used by future researchers examining the long-term recovery of the Copper Basin. The key elements I address are land use change, sediment dynamics, channel morphology, and the management implications for land use change. Results of this study can help us to analyze the long-term effects of land use change on the dynamic responses of fluvial systems through the recovery phase.

Other published studies on the Copper Basin have examined a range of topics: land use and degradation (Foehner, 1980), soil erosion (Mathews, 1995), rainfall runoff (Harden and Mathews, 2000), tailings pond revegetation (Cook, 2000), and the development of hydric soils in mine tailings (Stevens, 2000). I have not found other published studies that address the dynamic fluvial system response to changing conditions in watersheds that have been exposed to similar circumstances as North Potato Creek: over 150 years of denudation, exposure to prolonged acid precipitation, and recent reforestation. It is important to study these complicated fluvial systems to further understand how such extreme changes in land use can affect fluvial system dynamics. The implication is that alterations in land use generate long-term changes in the

watershed (Harden and Mathews, 2000) and the fluvial system (Leopold, 1997), which eventually affect the health of these systems. These changes need to be monitored to help land managers make informed decisions on land use that work with nature to repair and restore the fluvial system so that it once again functions effectively.

To assess the current condition of North Potato Creek, I measured stream parameters that would permit me to compare various sites according to the protocol of a widely used classification system. Other stream classification systems are based on stream ordering and size (Strahler, 1956) and basic stream morphology (Montgomery and Buffington, 1993), but these systems do not address land use disturbance. I chose to use Rosgen's (1994) classification because it combines broad morphological characteristics and field measurements to interpret the stream's sensitivity to disturbance. Other studies have used the Rosgen Classification to distinguish stream types and identify management implications (Hansen, 2001), and to understand stream morphology to reconstruct a channel following a long-term disturbance (Thompson and Hoffman, 2001).

Objectives

I designed this study to address five questions that relate land use change over the last 50 years to the current state of North Potato Creek:

1. How has land use in the upper North Potato Creek watershed changed over the last 50 years?
2. Is the upper North Potato Creek actively transporting and/or storing sediment in a manner expected for streams in the same ecoregion?

3. Can the current morphology of upper North Potato Creek be attributed to land use change over the last 50 years?
4.
 - a) How do the study reaches on North Potato Creek classify according to the Rosgen Classification system?
 - b) According to their classified stream types, what are the management implications for the upper reaches of North Potato Creek?
5. What can the dynamics of upper North Potato Creek contribute to the broader understanding of fluvial adjustment to extreme disturbance and recovery?

I answer these questions by analyzing aerial photos from the last 50 years and by measuring stream parameters that can be used to conduct a Rosgen Stream Classification (Rosgen, 1994). I expected to find evidence indicating whether and how the fluvial system might be adjusting to the history of extended denudation and subsequent reforestation in the Copper Basin that will help managers make decisions on land use that benefit the health of this and similar systems, and their inhabitants. Furthermore, I provide the data acquired in this research as a database for use in the long-term evaluation of the dynamics in the fluvial system by future researchers. Finally, I hope to add to our understanding of fluvial system dynamics following a century-scale phase of extreme anthropogenic disturbance, and especially contribute to understanding the nature of the prolonged recovery from such disturbance.

Thesis organization

In the second chapter, I describe the study area and study sites, including geology, area history and land use. In the third chapter, I describe the data collection methods I used. The fourth chapter presents the data and calculations from field measurements of channel geometry, gradient, bankfull discharge, sediment particle size, stream profile, land use change, and water quality testing. Chapter five discusses results in the context of my study questions and considers the implications of these results for future land management. Furthermore, in chapter five I discuss errors and problems I faced with this study. The sixth chapter contains my final conclusions and possibilities for future research. Appendices contain additional data tables and information.

Chapter 2

Area Overview

Introduction

Copper Basin is an erosional depression in the Unaka Mountains in Southeastern Tennessee (Figure 2.1). This area includes the towns of Copperhill and Ducktown, and covers 130 km² in the Blue Ridge physiographic province. North Potato Creek drains the central to eastern portion of the basin (Figure 2.2). This area was fully denuded and underwent 100 years of exposure to direct rainfall that spawned massive gully formation and widespread erosion. Only in recent decades have forests of loblolly (*Pinus taeda* L.) and Virginia pine (*Pinus virginiana* Mill.) begun to protect the soil and decrease historically high sediment movement rates (Mathews and Harden, 1999).

Geology

The Blue Ridge Mountains were formed approximately 250 million years ago as a result of a collision between North America and Africa (Rodgers, 1970). These mountains have been highly metamorphosed, folded, and faulted through subsequent tectonic activity. During the Devonian period, this action produced highly mineralized zones of copper, giving the basin its name (Cook, 2000). The Copper Basin is underlain by formations of the Ocoee Supergroup, which contains Precambrian Great Smoky metasedimentary rocks and the Precambrian Copperhill formation (Fisher et al., 1970).

The Great Smoky Group contains massive layers of saprolite, schist, arkose, greywacke, shale, conglomerate, phyllite, quartzite, gneiss, and mica. Granite and gneiss

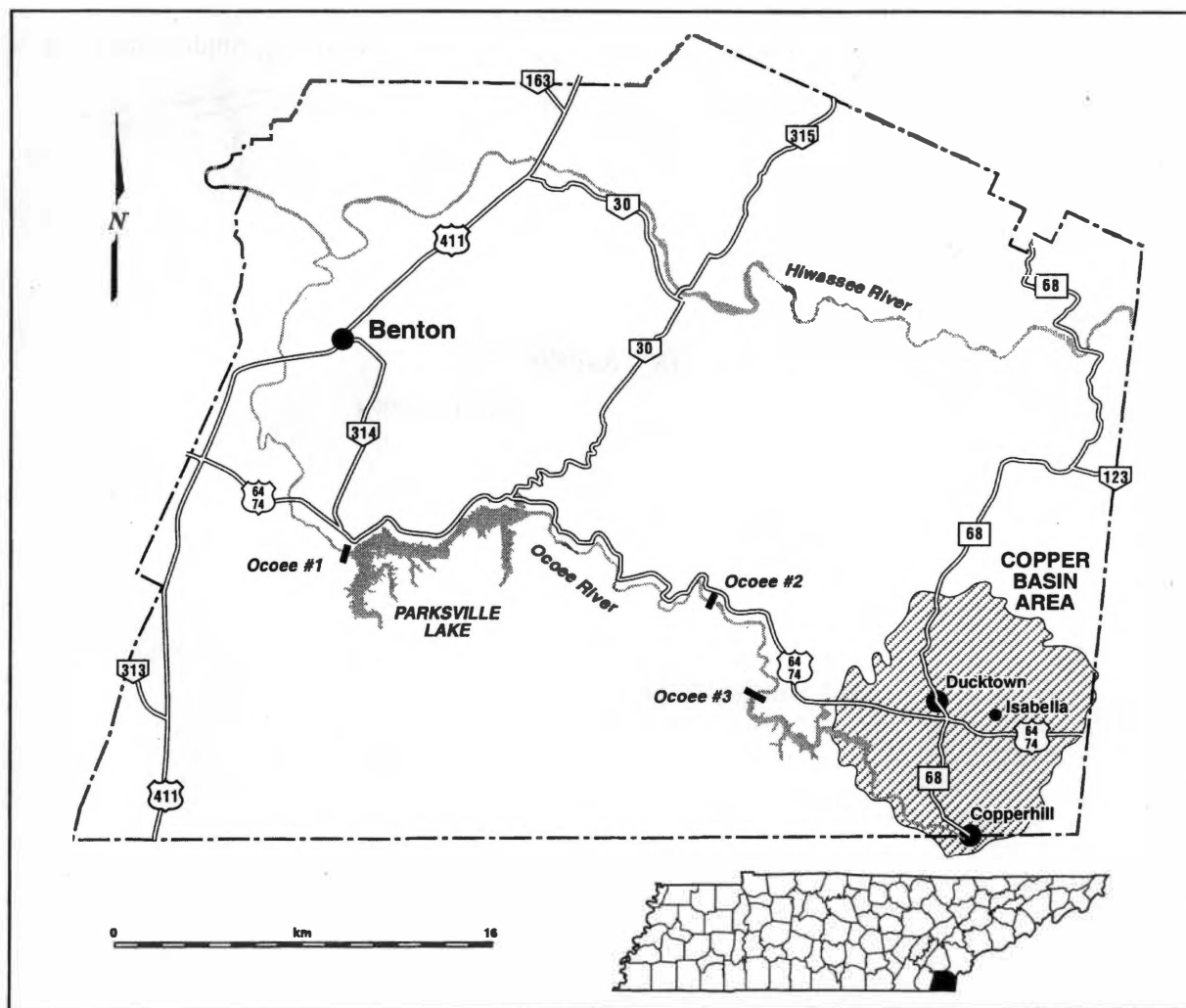


Figure 2.1 Map of Polk County, Tennessee, Showing the location of Copper Basin (Shaded Area)(Map courtesy of the University of Tennessee Cartographic Services Laboratory)

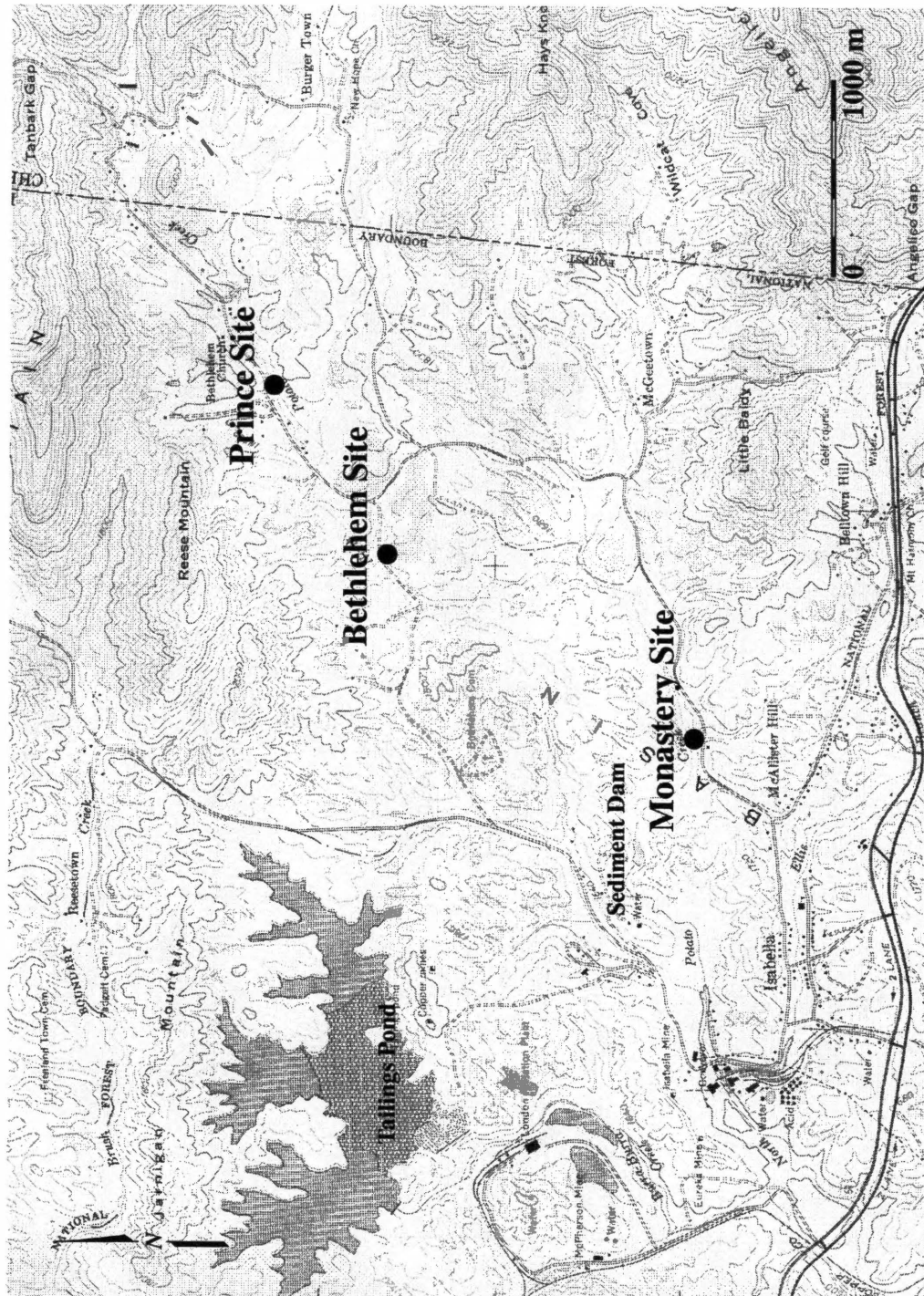


Figure 2.2 Topographic Map of Study Area (USGS Isabella Quad 1:24,000)

are located in the northern part of the Unaka Mountains, north of the Copper Basin. Phyllite, slate, schist, and quartzite are located in the southern portion of the mountains (Moore, 1994). This bedrock, which is largely schist, can now be found at the surface from over a hundred years of soil erosion (Cook, 2000).

The rocks of the Great Smoky Group include metamorphic, igneous and sedimentary rocks. The metamorphosed rocks produced highly mineralized zones. These mineralized zones were sulfide-rich and were mined to obtain small quantities of gold and pyrite (FeS_2). Other ore mineral deposits include pyrrholite, chalcopyrite, sphalerite, magnetite and trace amounts of silver (NRCS, 2001). Also contained in these deposits were iron oxides, magnetite, and silver (Cook, 2000).

The copper ore deposits mined included high-grade “black ores” or chalcocite, which contained the purest and most natural form of copper. Because they were high grade, they were the first ones mined (Cook, 2000). Black ores were located between 1-7 m below the surface. The gossan ores were mined next. They were located between 1-30 m below the surface in weathered, oxidized, and enriched zones. Once the gossan ores were depleted, the sulfide ores were mined. Sulfide ores contained the lowest grade of copper and pyrite but were in abundance. Some of these lower grade sulfide ores are still present today (Quinn, 1993).

History

Although this area has probably been continually inhabited for over 12,000 years, the earliest documented inhabitants of Copper Basin are the Cherokee Indians. Little is known concerning the length or extent of their occupancy. In 1836, Congress ratified the

Echota Treaty, which required the Cherokee to exchange their land east of the Mississippi River for a sum of five million dollars. A year later, surveyors noted the presence of iron hydroxide in the basin, and by 1838 the Cherokee Indians had been removed from lands east of the Mississippi to make room for settlers. Land began to be purchased by mining companies in Polk County, Tennessee, and the first large-scale operation, Hiwassee Mine, was erected in 1850 (Rush, 1993).

Once it was discovered that copper mining in the Copper Basin could be profitable, 54 other mines opened and closed between the years 1850 and 1987 (Rush, 1993). This influx of mining companies began to dramatically change the area with mines, processing plants, and associated infrastructure. Initially, ore was heap roasted in open-pit smelters, an inefficient process that required a large fuel source and produced large quantities of sulfur dioxide (SO₂) gas. In later years, raw ore was extracted and sent to the local London Flotation plant for initial processing. Here, the ore was crushed and then separated from other wastes in a process called flotation. The wastes were deposited in a large tailings pond located at the headwaters of Burra Burra Creek (Figure 2.2). The ore was then sent to local smelters in Isabella and Copperhill, and by train to processing plants in Georgia (Cochran, 2000).

The intense heat needed to process the ore required a large fuel source; thus, virtually all trees within hauling distance were harvested. Several photographs in the Burra Burra Mine Museum in Ducktown, Tennessee, show that every tree in the basin was removed. In addition, emissions from the smelters in Isabella and Copperhill fogged the basin with sulfur dioxide gas, which destroyed all the remaining vegetation in the low lying areas. The upper slopes of the watershed were allowed to recover and now are

covered by a hardwood forest, but the more accessible lower slopes and valley floor have never fully recovered.

In the years following the tree removal, large quantities of sediment were eroded from Copper Basin from direct exposure to rainfall (Mathews and Harden, 1999). As topsoil was stripped, massive gullies formed and sediment was very effectively delivered from the land to the stream channel. A study by Strahler (1956) documented the increase in drainage density required to accommodate the increased runoff and sediment yield. These gullies are still visible today beneath trees and in sparsely vegetated and bare land areas.

Sediment yields to North Potato Creek were extremely high for over a century (Muncy, 1991). North Potato Creek was able to move much of this sediment downstream to the Ocoee River, with excess stored in the channel and on the floodplain in sections of North Potato Creek. In the late 1930s, the Tennessee Valley Authority (TVA) observed its three reservoirs along the Ocoee River rapidly filling with sediment. This caused alarm and impelled TVA in 1941 to join the ongoing reclamation efforts in the basin. TVA set a goal to reforest the entire basin in hopes of slowing the sedimentation of its reservoirs (Cochran, 2000).

In the early 1940s, a Civilian Conservation Corps outpost was established to aid in the reforestation efforts. Testing began on experimental plots, looking for ideal vegetation and ground cover that would quickly reduce erosion (Mathews and Harden, 1999). Due to the nutrient-poor soils and the area's high SO₂ concentration, over 16 million trees were planted in the basin with varying but generally poor survival and growth success (Muncy, 1991). Sulfur dioxide gas came from nearby smelters, which

frequently emitted fumes so thick they reportedly fogged the basin and affected 32,000 acres of land (Muncy 1991). TVA briefly halted the sedimentation of its reservoirs by rerouting North Potato Creek into an abandoned mine in 1987 (Mathews and Harden, 1999). Aerial photos show that the stream has since resumed its previous course.

Widespread reforestation in the basin has only been successful since the mid-1980s (Mathews and Harden, 1999). A map drawn by Hursh (1948) describes the Copper Basin as having three distinct vegetation zones: a bare zone in the center, surrounding grassland, and peripheral forest (Figure 2.3). The watershed of North Potato Creek crosses all of these zones. Today, the previously bare areas of the North Potato Creek watershed are covered with pine forest, farms, and grazing lands. The dominant tree species planted were loblolly (*Pinus taeda* L.) and Virginia pine (*Pinus virginiana* Mill.) due to their ability to grow in acidic soils. Dense riparian corridors in most of North Potato Creek's watershed contain native hardwood tree species, shrubs, perennials and grasses.

Contemporary land use in North Potato Creek ranges from large-scale ranches to lower income rural neighborhoods. The upper slopes of the watershed are forested and are much less eroded than the lower slopes. They have typical hardwood forests for the region, containing species such as eastern hemlock (*Tsuga canadensis* (L.) Carr.), oak (*Quercus* spp.), maple (*Acer* spp.), and tulip-poplar (*Liriodendron tulipifera*). It appears that these slopes escaped the extremes of soil erosion and SO₂ fogging to which the lower slopes were exposed.

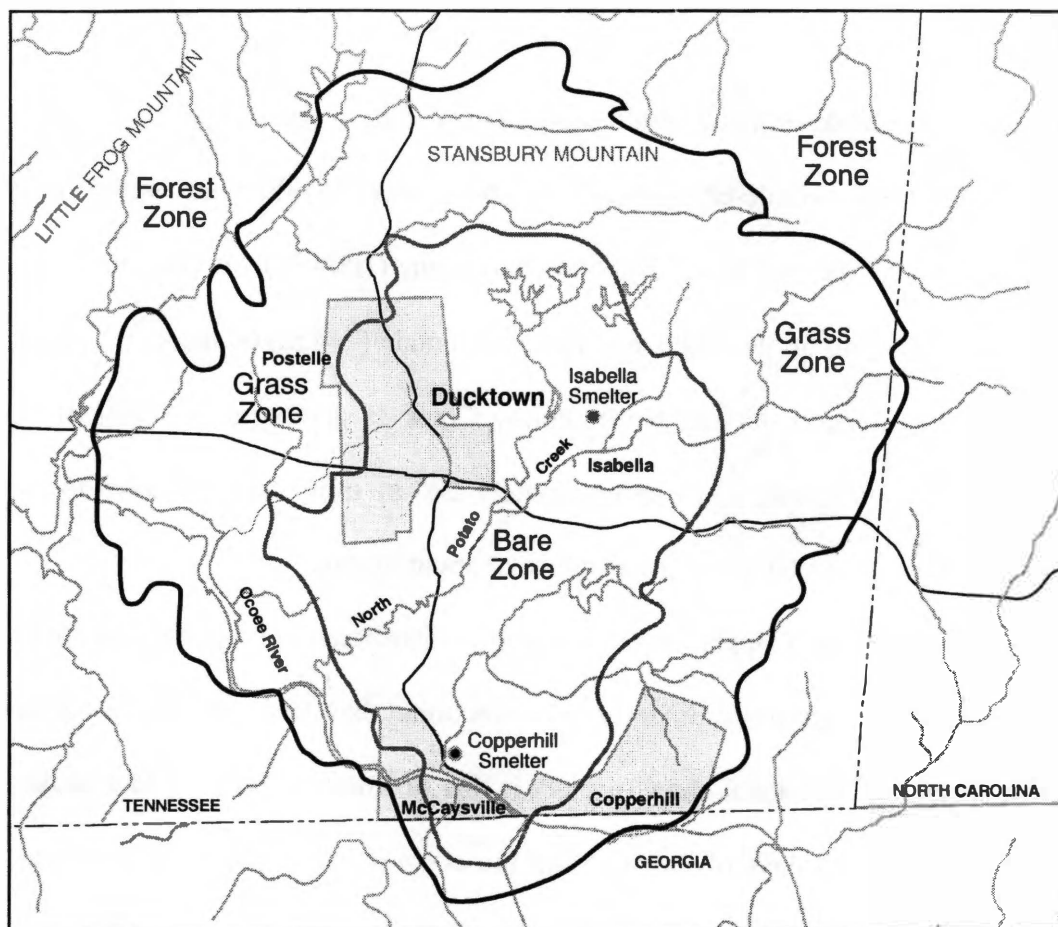


Figure 2.3 1948 Diagram of Basin Vegetation (adapted from Hursh 1948)

The study area

North Potato Creek drains a south-facing basin that is approximately 15 km² (Figure 2.2). The basin is bordered by Pack Top Mountain (732 m) on the north, Pack Mountain (1054 m) to the northeast, Angelico Mountain (1000 m) on the southeast, Amburn Mountain (658 m) on the south, and Reese Mountain (744 m) on the west. At its confluence with Burra Burra Creek, North Potato Creek is approximately 470 m in elevation. North Potato Creek drops approximately 200 m from its headwaters to its confluence with Burra Burra Creek over a distance of about 10 km.

Precipitation in the Copper Basin is evenly distributed throughout the year. Summer precipitation occurs predominantly as convectional thunderstorms, while winter precipitation, including occasional snow, usually is due to frontal systems. On average, thunderstorms occur on 56 days of the year and the average annual snowfall is 10 cm. The total annual precipitation is 73 cm, with the heaviest 1-day rainfall of 13 cm recorded at Copperhill on March 29, 1951 (NRCS, 1997). Winter mean temperature is 4° C, and the summer mean temperature is 23° C. Average relative humidity at dawn is 85% and in the afternoon is 55%. Prevailing winds are from the south, with spring having the highest average wind speeds of 13 km per hour (NRCS, 1997).

Residents informed me that the watershed contains numerous springs that ensure North Potato Creek has a constant base flow. Fish, crawfish, and other aquatic life benefit because of the constant flow and are present but scarcely found along its reaches. At any time of the year, heavy rains from prolonged storms are capable of turning the tranquil flow into a roaring river, causing flooding and property destruction.

North Potato Creek can be split into an upper and a lower section based on the influence of mining and water quality. The upper section extends from the headwaters to the confluence with Burra Burra Creek. Above this confluence, the stream has been indirectly affected by mining activities in the watershed and has relatively good water quality. Below this confluence and extending to the mouth at the Ocoee River, the lower section of North Potato Creek is directly influenced by mining activities in the watershed. The lower section carries a high sediment load and poor water quality. My research focuses on the upper section of North Potato Creek to look at the effects of land use change on the dynamics of the fluvial system.

In the upper section of North Potato Creek, the higher reaches of the stream channel flow predominantly over bedrock, while the lower reaches contain large amounts of fine sediment. Two residents of a monastery in the lower reaches of the basin have described the high volume of fluvial sediment movement, commenting that a concrete cinderblock will be completely buried by sand in a 24-hour period. My initial testing at this site revealed that sediment in the creek is extremely unconsolidated, such that a piece of rebar can be easily pushed down more than 50 cm into loose sand and gravel.

The Tennessee Department of Environment and Conservation (TDEC) is concerned about water quality in the lower section of North Potato Creek, particularly in the section from the mouth at the Ocoee River to McGheetown (waterbody ID# TN06020003014_0100) (Denton et al., 2000). This section once housed the Burra Burra Mine, London Flotation Plant, and several open pit smelters. It currently receives part of its flow from a large tailings pond at the headwaters of Burra Burra Creek. This lower section of North Potato Creek has been placed on the Tennessee 303(d) list of impaired

waters for its high sediment load, habitat alterations, heavy metal contamination, and low pH (Denton et al., 2000).

Site descriptions

I selected three sites along the upper section of North Potato Creek for analysis based on their locations in the drainage basin, gradient, and access. I first divided the watershed into three sections: an upper section characterized by the steepest gradient, a middle section with a moderate gradient, and a lower section with the least gradient. I then asked private landowners in each section for permission to study the stream on their property. Once access had been granted, I made observations of several channel criteria: stream gradient, channel material, and channel morphology. Based on these observations, I chose one site that appeared to be representative of each of the three gradient sections.

Site 1 (“Prince”), the highest of the three sites, is a 100 m reach located on the property of long-term resident Gene Prince (Figures 2.2, 2.4). The channel at this site is almost entirely in bedrock. The stream gradient increases as water cascades over tilted bedrock shelves. Loose sediment and small boulders are present in small quantities along pools in this section, but they are scarce. A thin wooded corridor borders the east side of the creek and a grass lawn borders the west. Based on my criteria, this reach appears to represent typical stream reaches in the upper watershed.

Site 2 (“Bethlehem”) is located along Bethlehem Rd. (Figures 2.2, 2.5). Here, North Potato Creek is filled with fine to coarse sand, cobbles, and small boulders. Bedrock is visible on the streambed throughout this 200 m reach. The creek is bordered



Figure 2.4 Photograph of the Prince Site Looking Downstream



Figure 2.5 Photograph of the Bethlehem Site Looking Upstream

on either side by a narrow floodplain with heavily vegetated terraces 1.5 meters above it. This reach appears to represent the stream in the middle portion of the watershed.

At Site 3 (“Monastery”), the lowest site, the stream flows through the grounds of a monastery 1 km above a sediment dam (Figures 2.2, 2.6) built to trap sediment. Upstream from the dam, water flows tranquilly over a bed surface covered with mostly sand and gravel deposits. Occasionally, boulders and bedrock can be found in the channel, but initial observations revealed a deep layer of sand and gravel-sized sediment on the channel bed. According to the residents, sediment moves at a rapid rate and the bed morphology will noticeably change following a high flow event, at times forming a new pool or riffle sequence. Indicators of present sediment movement are both bank erosion and depositional bars. This 200 m reach appears representative of North Potato Creek in this section of the watershed. Below this site, however, the stream is manipulated with holding ponds and mining operations and is too inaccessible and allegedly dangerous to study.

In addition to the three study sites on North Potato Creek, I chose two reference study sites outside of the Copper Basin on the upper Tellico River, near the Tennessee-North Carolina border (Figure 2.7). The Tellico River is located in the same Southern Metasedimentary ecoregion as North Potato Creek (Arnwine and Denton, 2001), thus, I am comparing North Potato Creek with a stream that flows across related geologic formations but was not subjected to the same history of mining and long-term degradation as streams in the Copper Basin. I collected data from the Tellico River to use to compare the two streams in terms of channel morphology, bankfull discharge, sediment movement, and streambed sediment sizes.



Figure 2.6 Photograph of the Monastery Site Looking Downstream

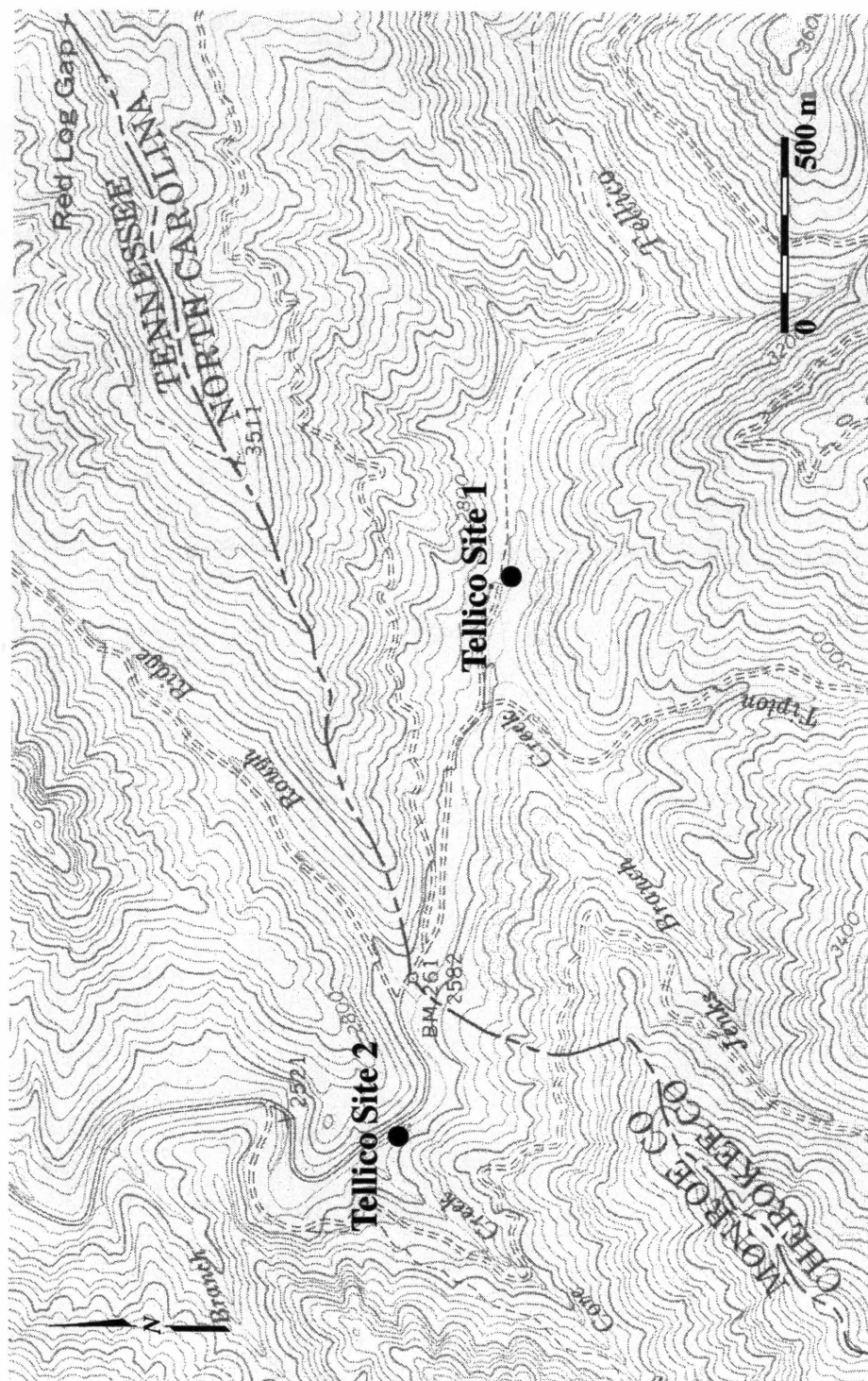


Figure 2.7 Topographic Map of the Tellico River Reference Sites (USGS Big Junction Quad 1:24,000)

Chapter 3

Methods

Chapter Overview

Methods are grouped into eight categories: interviews and observations, analysis of aerial photos and GIS images, water quality testing, bankfull discharge measurements, sinuosity, entrenchment ratio, sediment measurement, and site classification.

Interviews and Observations

The first phase of this study uses anecdotal stories and observations to find clues about possible changes in this drainage basin over the past century. I interviewed seven local residents and addressed questions to them about the past nature and history of land use in the basin. My questions were aimed at piecing together a history of North Potato Creek to understand how it has changed over time. Of particular interest was information pertaining to the development of changes in gully forms, the establishment of forest, and the identification of any known watershed disturbances or changes to the stream.

Aerial Photo and GIS Images

Aerial photographs gave a visual history of the basin extending to a time when the basin was vastly denuded of vegetation. I examined aerial photos taken in 1952, 1964, and 1994, paying special attention to the extent of different land use types. The scale of the photos ranges from 1:100,000 to 1:24,000. I scanned the photos and geo-referenced them using ESRI's (Environmental Systems Research Information, Inc.) ArcGIS

software to create digital raster images. I located six points on each photo, determined their UTM coordinates, and rectified each image so that the photos for each year were at the same map projection (UTM 1928) and scale (approximately 1:50,000). Next, I digitized and classified land use within the watershed as forested land, bare land, or sparsely vegetated land. I digitized points to locate the three study sites, and I digitized lines to locate roads, including highways, major roads, and unimproved roads at a 1:15,000 scale. I represented the major branch of North Potato Creek with a line following its course from its headwaters to its confluence with Burra Burra Creek.

To define the spatial extent of the three land use classes, I digitized using a minimum-size-polygon at the 1:15,000 scale. This allowed me to digitize land use based on the minimum areal extent of each land use type. For example, a 5 m² parcel of forested land fails to meet the minimum-size-polygon requirement and would be included in the land use class of the surrounding area. I defined forested land as all areas greater than the minimum-size that had continuous forest cover. I then defined polygons as bare land when they were either gullied, farmland, or not covered with visible vegetation. I classified the remaining land as sparsely vegetated land, which is land that contains a discontinuous tree cover or grass. Finally, I calculated the total area for each digitized land use, a process that enabled me to compare land use change in the watershed over the period from 1952 to 1994, an interval of 42 years.

Water Quality Testing

I tested water quality using a Green Water Monitoring Kit (Green, 2002). The purpose of testing the water quality was to determine if there were any indications of

human-caused disturbance. This monitoring kit is well-suited for testing water samples in the field and commonly used for reconnaissance-level testing. I collected three water samples at each site on different dates, and analyzed them for water temperature, turbidity, dissolved oxygen, percent oxygen saturation, nitrates, phosphates and pH. I tested water quality at low flow, approximately 1 to 1.5m³/sec, and usually took samples around noon to test the stream under similar circumstances. For each sample, I recorded weather information, ambient temperature, sampling time, exact sampling location and general stream observations, such as water level and color. A table showing the significance of testing values can be found in Appendix 1.

Turbidity, or the measure of the relative clarity of water, is primarily a measure of suspended matter, such as clay, silt, organic and inorganic matter, and microscopic organisms (Green, 2002). Lower turbidity levels reflect healthier aquatic ecosystems in which plants and animals have better access to sunlight and are less disturbed by suspended particles. High turbidity levels in a mountain stream may indicate erosion, runoff or stream sediment disturbances, whether natural or human-caused.

Dissolved oxygen (DO) is an important measure that helps gauge the general health of the mountain stream ecosystem. Because all animals need oxygen for life, streams that have higher DO levels are more likely to support healthy, stable, and diverse ecosystems (Green, 2002). Natural and human-induced changes to the watershed or stream can affect the amount of DO. For example, increased bacterial levels associated with pollution or large amounts of decaying organic matter will cause the oxygen saturation to decrease (Green, 2002). Temperature plays an important role, as cold water can hold more dissolved oxygen than warm water.

Nitrate is a naturally occurring nutrient that is needed by all plants and animals to build protein (Green, 2002). Decomposition and animal excrement release nitrate into the environment and increase plant growth, decay, and bacterial decomposition, which lowers the DO level in the water. Humans can raise nitrate levels by allowing fertilizers and sewage to come in contact with the stream.

Like nitrate, phosphate is also a nutrient needed for plant and animal growth and is a fundamental element in metabolic reactions (Green, 2002). Healthy aquatic ecosystems have a low level of phosphate, 1 ppm. Higher levels of phosphate can cause overgrowth, increased bacterial activity and decreased DO levels (Green, 2002).

Measurement of the stream's acidity, pH, can range from a value of 0 (acidic) to 14 (basic), with a value of 7 being neutral. The pH of natural streams is usually between 6.2 and 8.2 (Green, 2002). An extremely high or low pH can be caused by industrial waste, agricultural runoff, or drainage from improperly run mining operations. A pH at or below 4.0, is usually sufficient to kill fish, and most frogs or insects.

Bankfull Discharge

Bankfull discharge is useful because it expresses the stream's capacity to move larger sizes and quantities of sediment at a channel-forming or -maintaining flow (Leopold, 1997). Leopold (1997) describes bankfull as the condition that is reached when water exceeds channel capacity and begins to flow over the floodplain. This condition occurs only a few days per year on average. Five measurable criteria – area, wetted perimeter, gradient, Manning's roughness coefficient and hydraulic radius – are

used for determining bankfull velocity with Manning's Equation, and bankfull discharge with the continuity equation.

Manning's Equation (Reid and Dunne, 1996) [3.1]

$$V = \frac{R^{2/3} S^{1/2}}{n}$$

Continuity Equation (Naden, 1988) [3.2]

$$Q = VA$$

Where A = cross-sectional area (expressed as m²)
S = gradient (expressed in degrees)
n = Manning's roughness coefficient
R = hydraulic radius (expressed as m)
V = bankfull velocity (expressed as m/sec)
Q = bankfull discharge (expressed as m³/sec)

I followed the methods outlined in Harrelson et al. (1994) and Cooney (1991) to measure channel geometry. I chose six cross-sections at each study reach that were 5-20 m apart depending on their accessibility. First, I extended a level measuring tape across the stream at bankfull height and measured the depth to the bed using a measuring rod. Measurement intervals across the channel were based on the micro-topography of the stream channel so that I could accurately graph the channel geometry. I then made observations across each cross-section to note the location of water level and bed forms. The measure of bankfull width and depth is used in Rosgen's (1994) classification to determine the width to depth ratio. Schumm et al. (1977), proposed that following reforestation, this ratio should decrease as the depth increases but the width does not change.

I measured velocity using the float method over a known distance (Harrelson et al., 1994). This method involves timing a floating object as it moves over a known distance down the stream and dividing the distance by the time (seconds), to give the flow rate in meters per second. I multiplied each value by 0.85 to account for friction along the bed and banks (Harrelson et al., 1994). I then averaged six trials along different flow paths to compute an average velocity for each reach at low flow.

Sinuosity

I calculated sinuosity for the entire North Potato Creek (“stream sinuosity”) and also for each reach (“reach sinuosity”)(Buttle, 1995). To calculate sinuosity, I measured stream distance between two known points and divided that by the length of the valley between the same points. I based my calculations of stream sinuosity on topographic maps from 1927, 1957, and 1978. Reach sinuosity was calculated aerial photographs from 1952, 1964, and 1994.

Entrenchment Ratio

The entrenchment ratio (ER) is important because it shows the relationship of the width of the river to its valley. Rosgen (1994) defines entrenchment as the vertical containment of the river and the degree to which it is incised in the valley floor. The ER is measured by dividing the stream’s width at two times bankfull depth (also called the flood-prone area) by bankfull width. Rosgen claims that the flood-prone area is flooded at 50-year return intervals.

Sediment Measurement

During trips to the study area, I observed that the higher gradient upper reaches (site 1) of the stream are dominated by bedrock, but the streambeds of the lower reaches (sites 2 and 3) are covered with cobbles, gravel, and sand. The Tellico sites have a higher gradient than North Potato Creek sites 2 and 3, and contain bed materials ranging from silt to large boulders. I tailored my methods to the reach being addressed. For example, at the North Potato Creek sites 1 and 2, I sampled the available sediment in the small pools below cascades and in eddies, while at the lower site, I extracted samples from riffles and channel bars along stream cross-sections.

Sediment Sampling

Along each cross-section for which I measured stream channel geometry, I also measured the b-axis (intermediate axis) of the five largest cobbles or boulders. I also sampled the fine sediment fraction. The streambed at the upper two sites consists mainly of bedrock, boulders, and large cobbles, so I collected sand- and gravel-sized sediment from pools, eddies, and bars. At site 3, the streambed is covered with finer alluvium, so I collected sand- and gravel-sized sediment along each cross-section. Using a 1000 ml Nalgene cylinder, I was able to retrieve sediments to depths of 0.3 m, but usually had to push the sand and gravel by hand into the cylinder. I collected nine 1000 ml samples at each site and transferred each into a labeled plastic bag. I did not sample fine sediments at the Tellico River sites.

Sediment Quantity Estimation (Site 3 only)

At site 3, bed sediment was dominated by sand- to cobble-sized material, and was much finer than the bed sediment of the other two North Potato Creek sites. At site 3, I undertook the task of estimating the amount of loose sediment along a 100 m section of the streambed and describing the packing and depth of the sediment as a step in understanding the processes affecting this reach. I considered the depth of bed sediment to be to the depth to which I could push a rebar rod into the sediment by hand. Based on my observations of sediment movement and interviews with local residents, I assumed the loose sediment to be the presently active layer of bed sediment.

I chose a relatively straight section of the stream and extended a 100 m measuring tape along the channel. I then measured channel width every 20 m and found an average width of 5 m over the length of this section. Next, beginning at 0 m and ending at 100 m, I measured the depth of channel sediments by taking three equally spaced measurements across the channel every 5 m. These three measurements were then averaged and multiplied by the stream width and section length. Then, the totals for each section were summed to approximate the quantity of active sediment in this section.

Dry Sieving in the Laboratory

In the laboratory, I labeled and placed each 1000 ml sediment sample onto an aluminum pan. I then air-dried the samples and ran them through a series of pre-weighed sieves. Sieving followed the Wentworth scale, with sieve openings of 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.126 mm, and 0.064 mm. The Wentworth scale is a standard scale used in many studies analyzing the distribution of fine sediment. According to this scale, 2 mm is the boundary separating gravel from sand, and 0.064 is the boundary separating

fine sand from silt. After sieving, I weighed each sieve and calculated the respective sediment weight. The weight of sediment on each sieve divided by the weight of the entire original sample gave the percentage of each sediment size per total sample weight.

Sediment Movement Observations

After I had sieved the dry samples, I painted them with a fluorescent pink spray paint. I returned each sample to its prior location and placed it on the stream bottom during a time of low flow, paying careful attention not to allow the sediment to go directly into suspension. I made note of the water level, velocity, and starting time. Additionally, at each site, I choose three cobbles up to 15 cm diameter to paint, and also placed them in the stream. I observed the samples for two hours and measured particle movement over the distance that I could locate the painted particles.

Site Classification and Comparison

Stream classification systems allow the comparison of stream channels based on a consistent and reproducible set of parameters. The most commonly used classification system by USDA Forest Service hydrologists is the one developed by D.L. Rosgen (Harrelson et al., 1994). Harrelson and her co-authors state that the Rosgen system is intended to predict a river's behavior from its appearance and allow the comparison of site-specific data from a given reach to data from other reaches.

In his presentation of the stream classification system, Rosgen (1994) stated that stream pattern morphology is influenced by a series of integrated variables: channel width, depth, velocity, discharge, channel gradient, roughness of channel materials, sediment load, and sediment size. Rosgen's stream classification provides four levels of

assessment. The first level is a broad morphological characterization that requires general information about the watershed. The second level is a morphological description of the stream with verified field measurements. The third level describes the stream condition with the objective to further interpret and predict stream morphology. The fourth level involves measurements of biological, fluvial, and geomorphic processes to evaluate for mitigation and impact assessment.

Rosgen describes his stream assessment as a “hierarchy of river detail.” He begins with a broad morphological characterization and zooms in to field level testing and verification. Users choose the level of detail they need and tailor the information required to fit their objectives. The level of detail needed for my study is primarily that of Levels 1 and 2. In addition, I use information from the third and fourth levels, such as channel geometry and sediment analysis, to describe the current stream condition and verify observations of physical processes. Information required for Level 1 characterizes landforms, lithology, soils, climate, depositional history, basin relief, valley morphology, river profile morphology, and the general river pattern. The objective is to describe generalized fluvial features using remote sensing and existing information of landform composition and evolution. In my study, information for Level 1 comes from NRCS Soil Surveys, TVA aerial photographs, and topographic maps.

Level 2, a morphological description of the stream, requires measurements to characterize channel pattern, entrenchment ratio, width to depth ratio, sinuosity, channel material, and gradient. The objective of this level of classification is to provide a more detailed level of interpretation and description of specific channel properties. In my

study, information for Level 2 comes from field measurement of channel geometry, topographic maps, and lab sieving.

After compiling the required parameters for each study reach, I classified each reach according to Rosgen's classification criteria to allow a comparison between the study reaches. With the Rosgen criteria, an alphanumeric value is assigned to each study site based on the number of channels, entrenchment, width-depth ratio, sinuosity, and channel material. Additionally, Rosgen allows for some adjustment of the criteria by allowing some values to be slightly modified, a technique called the "continuum concept" (Rosgen, 1994). With this, sinuosity and entrenchment may vary by a value of ± 0.2 , and the width-depth ratio may vary by a value of ± 2 , so that these values fit within the stream type designated by the majority of other parameters.

Chapter 4

Results

Aerial Photo and GIS Interpretation

Aerial photos show snapshots of the North Potato Creek watershed over the 42-year period from 1952 to 1994. Due to the scale of the photos, it was difficult to measure changes in stream size and location, but in some instances these were observable. For example, the stream changed channel locations in the Monastery section several times, but the changes were too small to accurately measure from these photos.

In all photos, North Potato Creek in its headwaters is confined to a single channel with a narrow wooded corridor extending to 1.5 km below the Bethlehem site. The stream then changes abruptly in each photo year. The 1952 photo shows the valley floor filled with sediment for about 2 km above the sediment dam (Figure 2.2). In the 1952 photo, the Monastery section has a braided pattern with floodplain in excess of 50 m wide. By 1964, the stream had become entrenched and made a single-thread channel through the alluvium in this reach. By 1994, along the same reach the stream had changed its meander pattern in a few locations but was still a single channel and visibly looked the same. In the 1994 photo, a wooded corridor had established along the Monastery section. The digitized air photos (Figures 4.1, 4.2 and 4.3) display the distribution of vegetation cover as it changed over the 42-year period from 1952 to 1994.

The distribution of vegetation cover has changed dramatically over the 42-year period from 1952 to 1994. Forested land, which in 1952 existed primarily along the northeastern ridges, has slowly extended down into the rest of the watershed. By 1994,

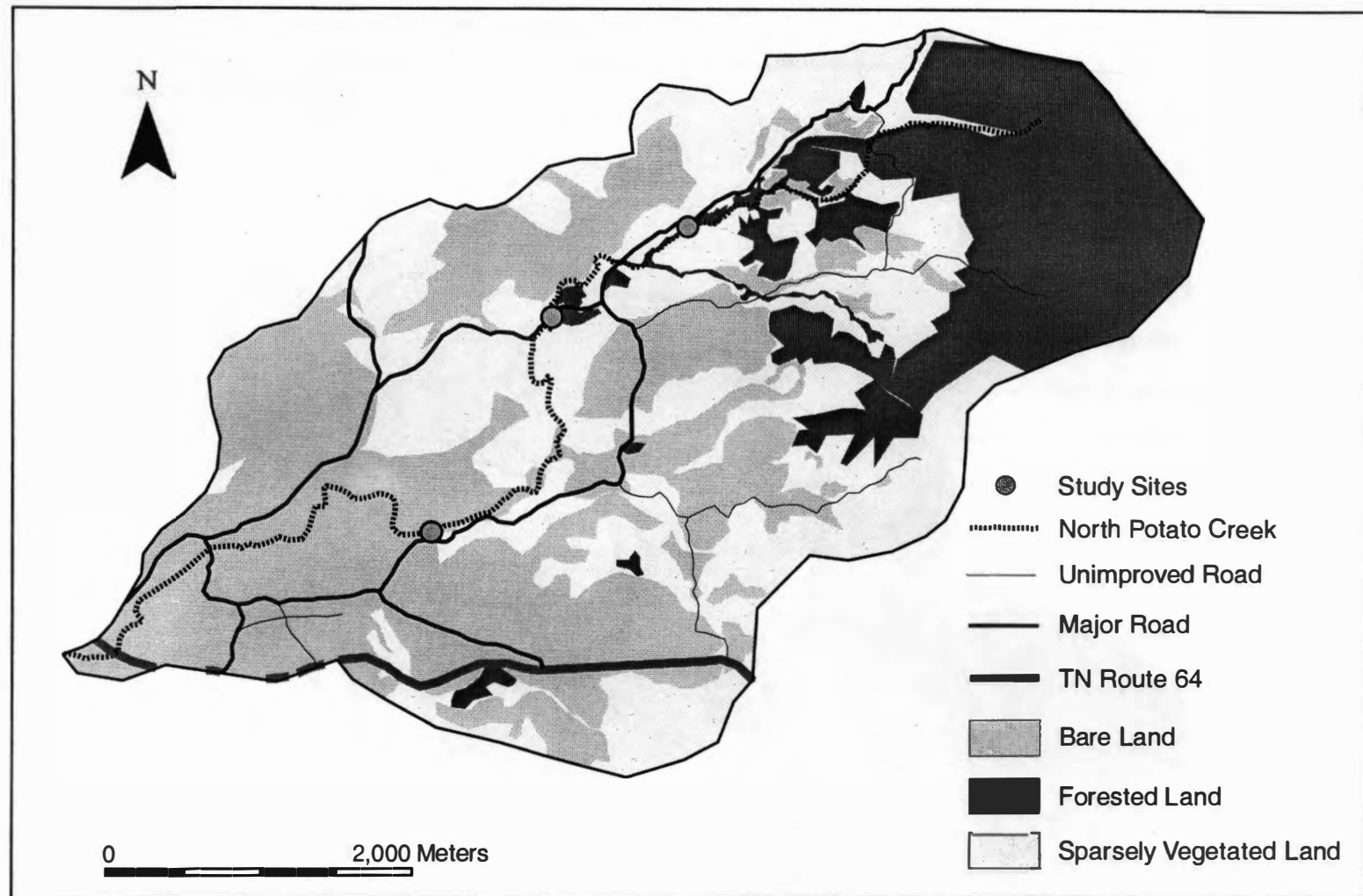


Figure 4.1 GIS Image Showing Land Use Classes, 1952

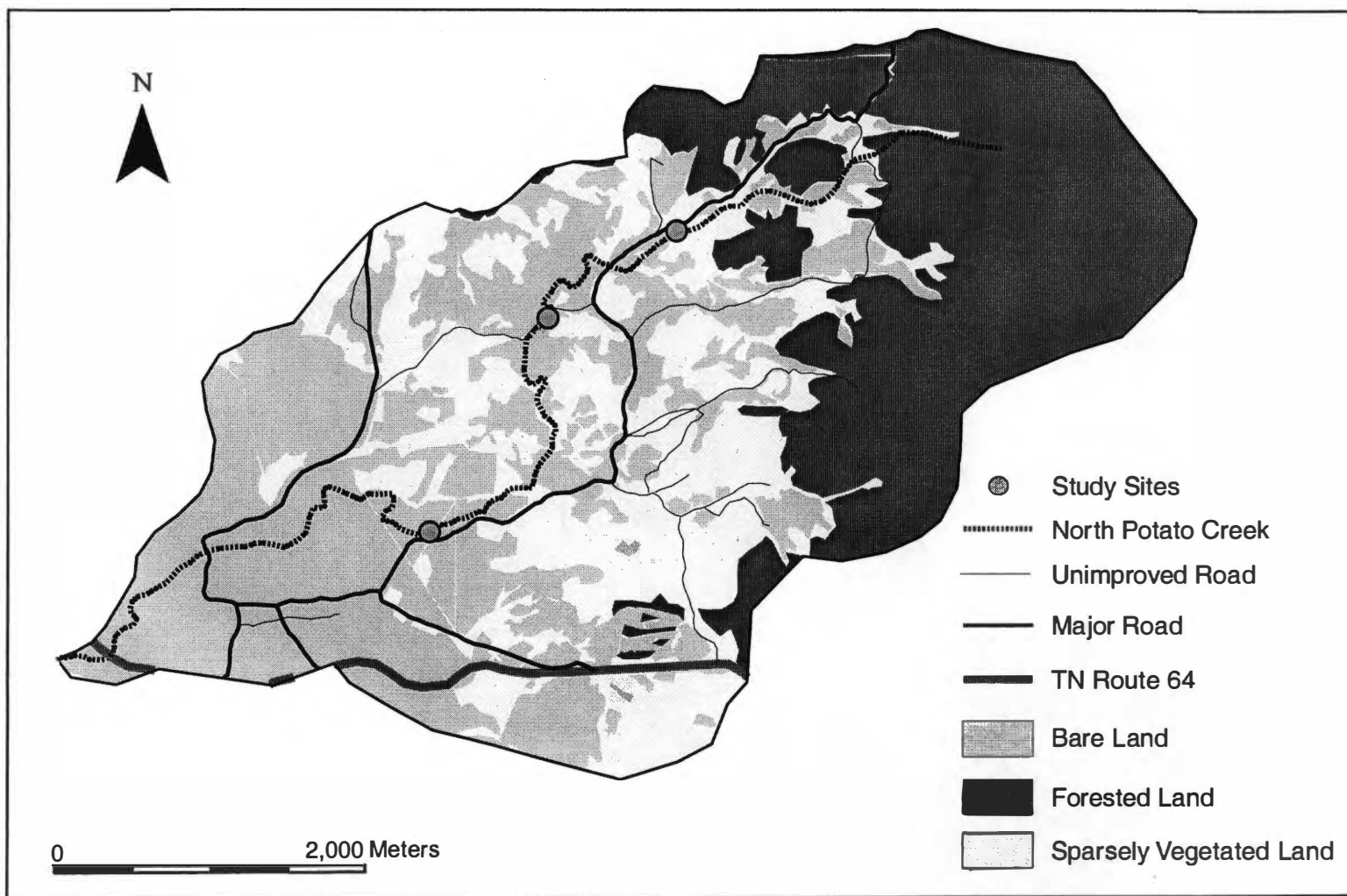


Figure 4.2 GIS Image Showing Land Use Classes, 1964

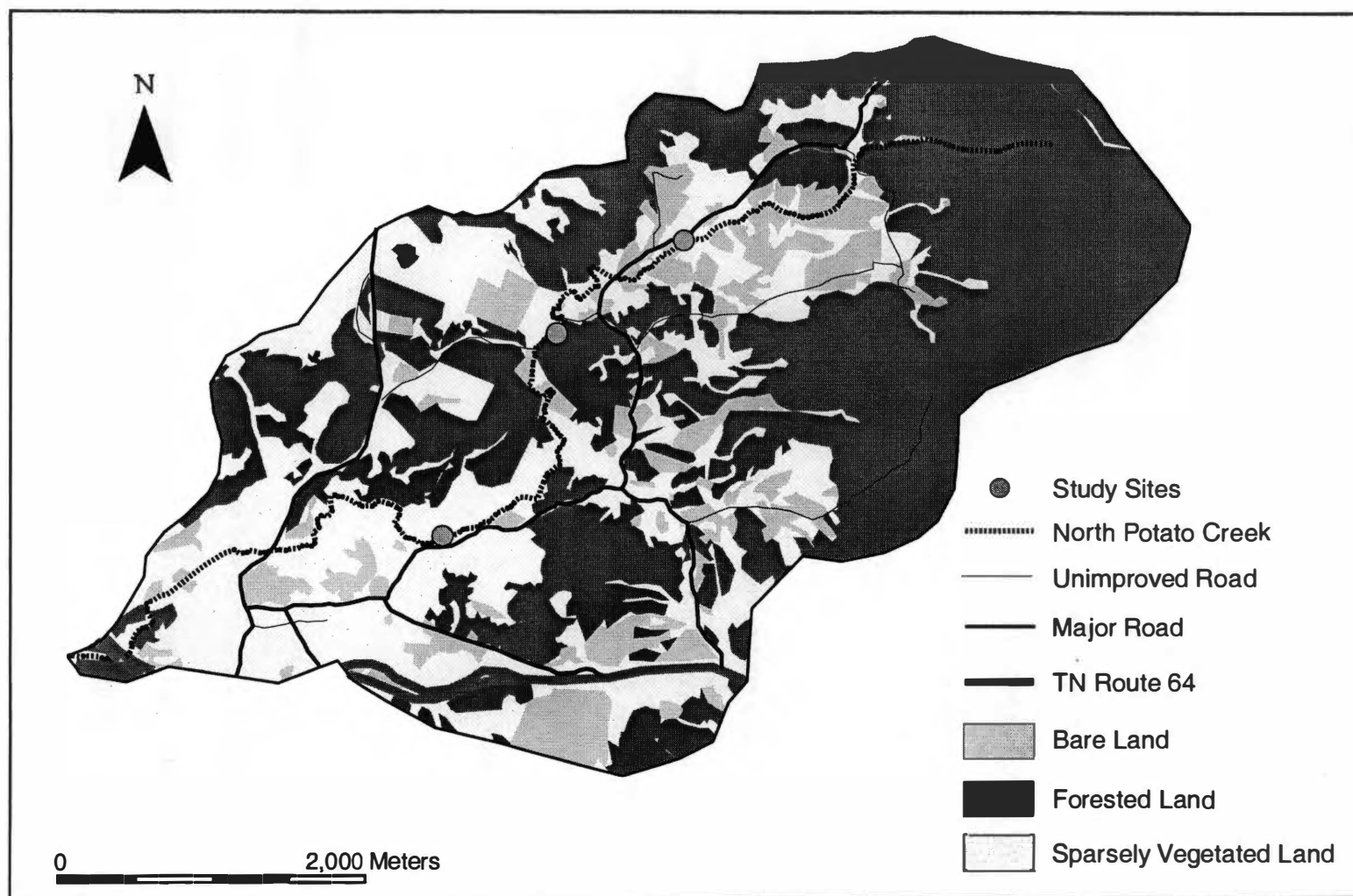


Figure 4.3 GIS Image Showing Land Use Classes, 1994

more than half (54%) of the watershed was forested. Another obvious change is the gradual disappearance of large areas of bare land. In 1952, continuous bare land covered much of the lower portion of the watershed, but by 1994 this had been broken up into numerous smaller tracts and mostly replaced by forest and sparsely vegetated land. The distribution of sparsely vegetated land also changed, though not as noticeably as the other land covers. The location of sparsely vegetated land moved from the center of the watershed in 1952 to the lower part of the watershed in 1994.

I was able to quantify the area for each land use type per each year by using the GIS program (Table 4.1). Forested land expanded from 21% in 1952 to 54% in 1994. Bare land changed slightly more, decreasing from 51% in 1952 to 12% in 1994, a change of 39%. Sparsely vegetated land cover had little change in area from 29% in 1952 to 34% in 1994, but the location of sparsely vegetated land did change. Also, the length of roads in the watershed nearly doubled from 1952 to 1964, as many temporary roads were built while the watershed was broadly denuded. By 1994, these temporary roads were no longer visible in the photos.

Water Quality Data

Results of the water quality tests show apparently healthy conditions in upper North Potato Creek (Table 4.2). I observed some fish, insects, and small crawfish in the stream, but residents claim that they are not very common. Algae, though, was abundant on the rocks at the Bethlehem site. The changes in stream temperature throughout the testing period follow an expected seasonal temperature cooling from summer to winter.

Table 4.1 Changes in Land Use in Upper North Potato Creek Watershed Between 1952 and 1994

	1952	%	1964	%	1994	%	Change (%)
Watershed Area (Ha)	2,510	100	2,510	100	2,510	100	0
Forested Land (Ha)	520	21	790	31	1,350	54	+33
Bare Land (Ha)	1,270	51	990	39	300	12	-39
Sparcely Vegetated Land (Ha)	720	29	720	29	860	34	+5
River Length (m)	11,000	na	11,000	na	11,000	na	na
Road Length (m)	12,633	na	22,877	na	13,350	na	na

Table 4.2 Water Quality Testing

	Sample Temp. (°C)	Stream Temp. (°C)	Turbidity (JTU)	Disolved Oxygen (ppm)	DO (% Saturation)	Nitrate (ppm)	Phosphate (ppm)	pH
6/25/01								
Prince	18	19	40	7	70	<1	<1	8
Bethlehem	17	17	40	7	70	<1	1	8
Monastery	17	17	60	8	81	1	3	8
11/17/01								
Prince	12	10	40	6	55	<1	<1	7 to 8
Bethlehem	11	10	40	6	60	<1	2	8
Monastery	9	9	10	5	45	<1	<1	8
1/20/02								
Prince	7	7	50	4	40	<1	<1	7 to 8
Bethlehem	8	7	50	4	34	<1	<1	7 to 8
Monastery	8	7	50	4	34	<1	<1	7 to 8

Turbidity was typically 40-50 JTU, with single readings of 60 JTU and 10 JTU. The reading of 10 JTU is an outlier and possibly an error. Dissolved oxygen (DO) levels dropped from 7-8 ppm to 4 ppm from summer to winter. Oxygen saturation dropped from 70-81% in summer to 34-40% in winter. Nitrate levels in North Potato Creek were less than 1 ppm, with one measurement of 1 ppm. These values are very low. The phosphate levels in North Potato Creek were low, ranging from less than 1 ppm, to one measurement of 2 ppm and another of 3 ppm. PH values ranged from 7 (neutral) to 8 (slightly basic).

Bankfull Discharge

I calculated bankfull discharge for each reach on North Potato Creek (Table 4.3) and for two reaches on the Tellico River (Table 4.4), and then averaged the six calculations of bankfull discharge for North Potato Creek sites (Table 4.5). Bankfull discharge ranged from 2.8 m³/s at the Prince study reach to 1.7 m³/s at the Bethlehem reach. The Tellico can carry more discharge at bankfull, with calculated values of 5.9 m³/s to 7.3 m³/s. At each site, the cross-sections are numbered in order with “1” as the most upstream.

Longitudinal Profile

Using a topographic map (USGS, 1990), I graphed the longitudinal profile of North Potato Creek (Figure 4.4). The 0 km location represents the stream’s confluence with Burra Burra Creek. According to the topographic map, North Potato Creek extends approximately 10 km above Burra Burra Creek, at an elevation of 648 m.

Table 4.3 Cross-Sectional Measurements From Three Sites on Upper North Potato Creek

		8/9/01			11/17/01		
		Cross-Section			Cross-Section		
		1	2	3	1	2	3
Prince	Area (A) m ²	1.4	2.1	1.3	1.4	1.9	2.3
	Wetted Perimeter (P) m	6.02	7.52	4.68	6.4	5.82	6
	Gradient (s)	0.03	0.035	0.056	0.056	0.044	0.03
	Mannings n	0.055	0.055	0.055	0.055	0.055	0.055
	Hydraulic Radius (R) m	0.23	0.28	0.28	0.21	0.33	0.38
	Velocity (V) m/s	1.2	1.5	1.8	1.5	1.8	1.7
	Discharge (Q) m ³ /s	1.7	3.2	2.3	2.1	3.4	3.9
Bethlehem	Area (A) m ²	3.8	3.9	4.1	4.1	4.5	4.4
	Wetted Perimeter (P) m	6.1	8.2	8	8.56	9.16	8.6
	Gradient (s)	0.00093	0.00093	0.00093	0.00093	0.00093	0.00093
	Mannings n	0.045	0.045	0.045	0.045	0.045	0.045
	Hydraulic Radius (R) m	0.62	0.48	0.51	0.48	0.49	0.51
	Velocity (V) m/s	0.49	0.42	0.43	0.42	0.42	0.43
	Discharge (Q) m ³ /s	1.9	1.6	1.6	1.7	1.9	1.9
Monastery	Area (A) m ²	5.1	4.9	4.9	4.7	4.9	4.7
	Wetted Perimeter (P) m	7.9	11.7	8.76	11	9.4	7.98
	Gradient (s)	0.00093	0.00093	0.00093	0.00093	0.00093	0.00093
	Mannings n	0.036	0.036	0.036	0.036	0.036	0.036
	Hydraulic Radius (R) m	0.65	0.42	0.56	0.43	0.52	0.59
	Velocity (V) m/s	0.64	0.48	0.58	0.48	0.55	0.60
	Discharge (Q) m ³ /s	3.2	2.3	2.8	2.3	2.7	2.8

Table 4.4 Cross-Sectional Measurements From Two Sites on Upper Tellico River

		4/20/02	
		Cross-Section	
		1	2
Tellico Sites	Area (A) m ²	9.6	11.4
	Wetted Perimeter (P) m	14.3	16
	Gradient (s)	0.0013*	0.0013*
	Mannings n	0.045	0.045
	Hydraulic Radius (R) m	0.67	0.71
	Velocity (V) m/s	0.61	0.64
	Discharge (Q) m ³ /s	5.9	7.3
* Values estimated based on field observations			

Table 4.5 Average Bankfull Velocity and Discharge on North Potato Creek

Averages		
Prince	Velocity	1.6 (m/sec)
	Discharge	2.8 (m ³ /sec)
Bethlehem	Velocity	0.44 (m/sec)
	Discharge	1.6 (m ³ /sec)
Monastery	Velocity	0.56 (m/sec)
	Discharge	2.7 (m ³ /sec)

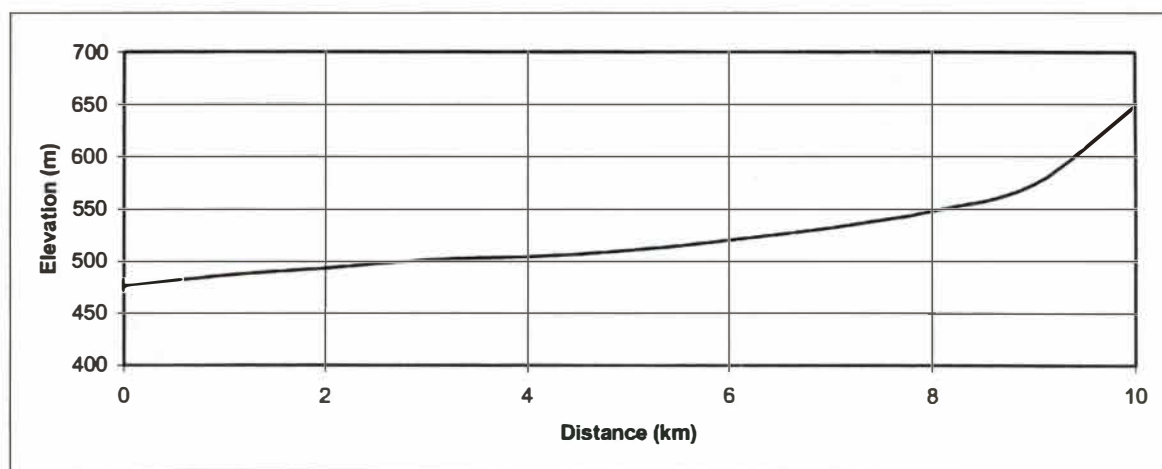


Figure 4.4 Stream Elevation Profile for North Potato Creek Above Burra Burra Creek

The overall stream slope is 0.0172, which was calculated by dividing the elevation change by the stream's overall distance. Measured gradients at the three North Potato Creek study sites range from 0.00093-0.056 (Table 4.3), and the two Tellico Sites have gradients of approximately 0.013 (Table 4.4).

Cross-Section Morphology

The following channel cross-sections were created from my cross-section measurements (Appendix 3). I measured a total of 18 cross sections, three cross-sections at each of the three Copper Basin study reaches on two different dates, 8/9/01 and 11/17/01. I measured multiple cross-sections to have enough data to be able to describe the average channel shape for each site. The three cross-sections in Figures 4.5-4.7 represent the three study reaches. On each graph, the right side of the graph refers to the west (right) stream bank. Additionally, I measured cross-sections of two reference sites on the upper Tellico River on 4/20/02.

The Prince site is a bedrock site, consisting of a pool-cascade sequence. Bedrock extends across the stream, dipping towards the southeast and disappearing under the left bank. The east side consists of a raised sandy alluvial bank with a 3 m wide wooded corridor. The alluvial bank has many indications of active erosion processes including root exposure, trees that lean towards the stream, and evidence of bank cutting. Beyond the alluvial bank is a well-established floodplain. According to an interview with a local resident, the floodplain has been inundated by floodwater once in the past 30 years. The bedrock on the west bank and channel bottom confines the channel laterally and

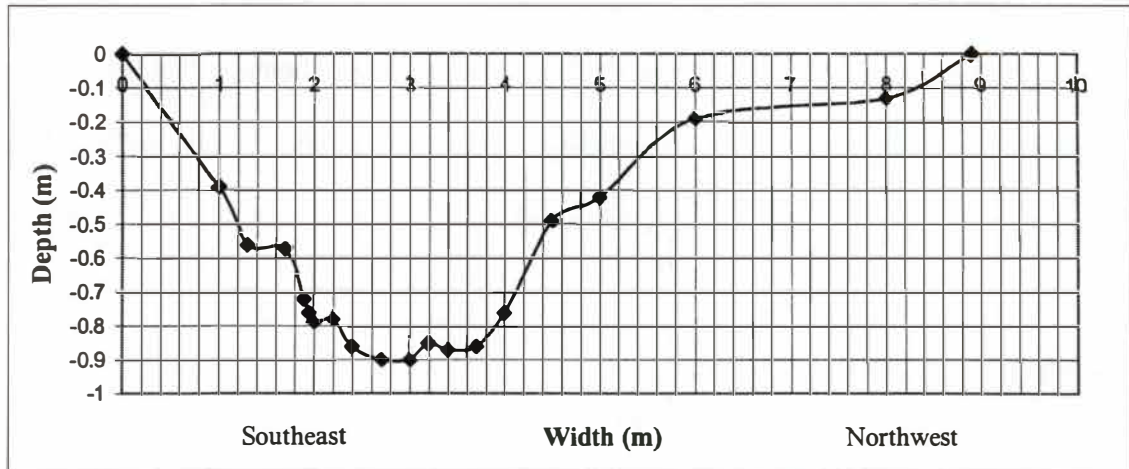


Figure 4.5 Cross-Section Profile: Prince 3, 8/9/01

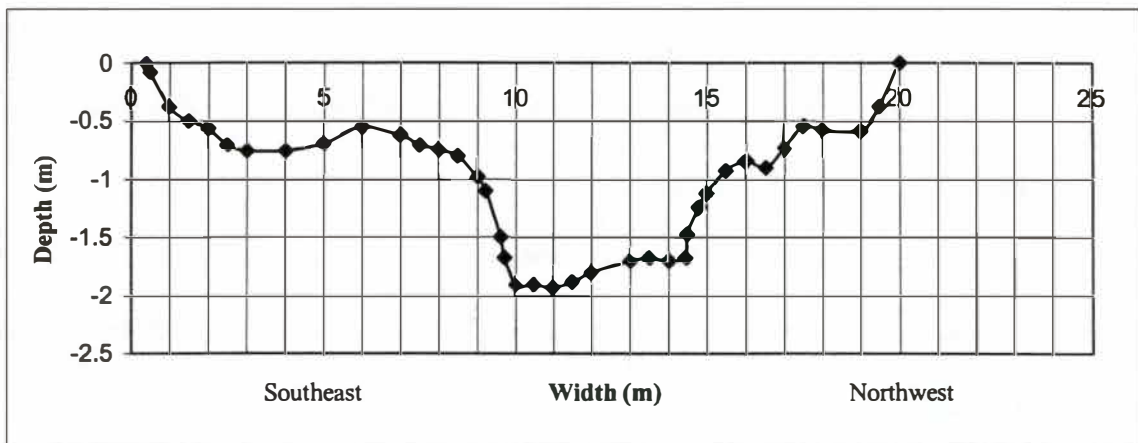


Figure 4.6 Cross-Section Profile: Bethlehem 3, 8/9/01

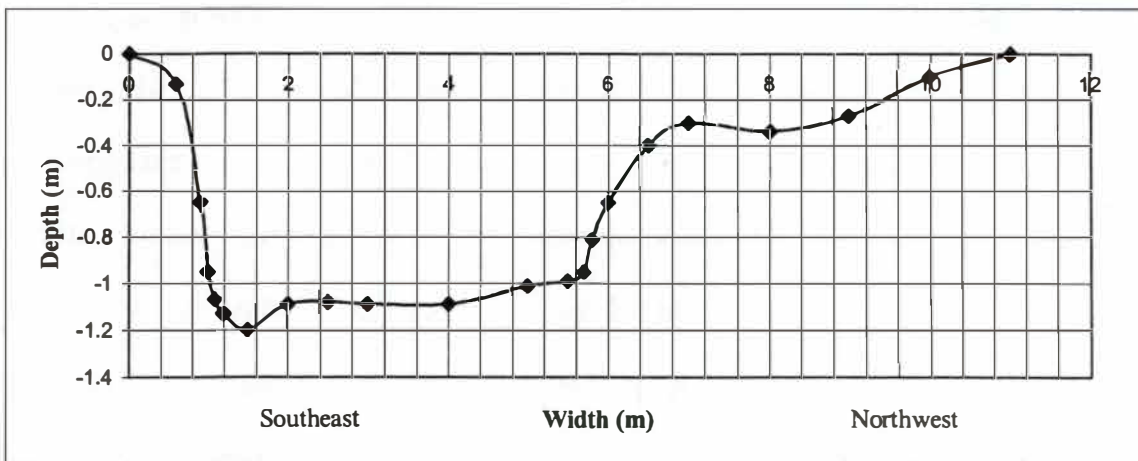


Figure 4.7 Cross-Section Profile: Monastery 2, 8/9/01

vertically, effectively preventing the west side of the channel and channel bottom from being further entrenched.

At the Bethlehem site, the bedrock channel bottom is primarily covered with rocks and cobbles up to 45 cm (b-axis measurement). The banks are similarly composed of various sized rocks and sandy alluvium with a well-established riparian ecosystem extending across the floodplain. There appears to be an abandoned channel approximately 20 m west of the current channel that contains similar cobbles and rocks but no visible bedrock. This channel is slightly higher in elevation than the current channel. The current channel bottom appears to be armored by the cobbles, and sand is not found in abundance anywhere between the banks. There is a terrace-like deposit above both banks, but no visible floodplain.

At the Monastery study reach of North Potato Creek, the stream and surrounding land surface are composed of alluvial deposits of an unknown depth. From an interview with two of the Monastery residents, I learned that the channel has changed drastically over the last 20 years such that the current channel lies approximately 20 m west of its previous location. Residents believe that the channel changed by avulsion during a large storm event. During the time of my research, I measured channel migration using a white drainpipe that enters the stream on the east side for reference. Over a period of 6 months, I measured 0.9 m of erosion on the east bank. Other signs of active erosion are bank undercutting and collapse, exposed roots, and trees falling into the stream. Channel and bank sediments consist mainly of unconsolidated sand and gravel.

The upper Tellico (Figure 4.8) looks very similar to the Prince and Bethlehem sites. The Tellico streambed consists of mainly cobbles and large boulders with some

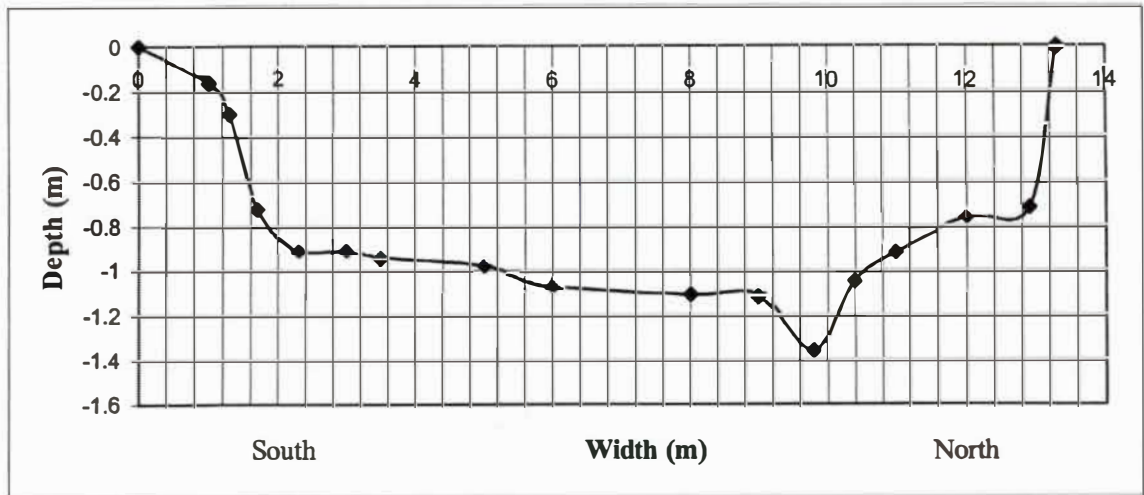


Figure 4.8 Cross-section Profile: Tellico River 1, 4/20/02

bedrock sticking up in fins perpendicular to flow. The channel banks are very similar to the Bethlehem site, dominated by alluvium and stabilized by vegetation. I observed some evidence of bank erosion was observed in the form of exposed roots, but this was not very widespread.

Planview Morphology: Stream and Reach sinuosity

North Potato Creek has an average sinuosity of 1.17 (Table 4.6). Topographic map analyses show that this value has increased from 1.14 in 1927 to 1.18 in 1978. Reach sinuosity data also show a change from 1952 to 1994 (Table 4.7).

At the present time, the entire length of North Potato Creek consists of a single thread channel. The 1952 and 1964 aerial photos, however, show sections of the stream with multiple thread channels; of note is the Monastery site in 1952. A change in the sinuosity for the Monastery section (Table 4.7) accompanies the change from a braided channel in 1952 to a meandering channel in 1994. Neither the Prince nor Bethlehem reach showed a change in sinuosity in the period 1952 to 1994.

Entrenchment Ratio

Dimensionless entrenchment ratios (ER) were calculated for the three Copper Basin sites (Table 4.8). The width of the flood-prone area at the Monastery site used to calculate the ER was too wide to measure and not fully accessible. When this is the case, the ER is assumed to be much greater than 2.2 (Rosgen, 1994). According to the average ER values for the Prince and Bethlehem sites (Table 4.8), these sites are moderately to slightly entrenched.

Table 4.6 Stream Sinuosity Values from Topographic Maps of North Potato Creek Measured Above Burra Burra Creek

	1927	1957	1978
Stream Length (m)	10,150	10,150	10,150
Valley Length (m)	8,920	8,610	8,610
Sinuosity	1.14	1.18	1.18

Table 4.7 Reach sinuosity Values from Aerial Photos

	1952	1964	1994
Prince	1.2	1.2	1.2
Bethlehem	1.3	1.3	1.3
Monastery	1.3	1.6	1.8

Table 4.8 Entrenchment Ratios for Three Cross-Sections at Each Study Site

8/9/01			Average
Prince	1	2.6	
	2	2.2	
	3	2.4	
			2.2
Bethlehem	1	2.1	
	2	1.9	
	3	3	
			2.3
Monastery	1	na*	
	2	na*	
	3	na*	
			na*
*Flood-prone area is very large (ER >> 2.2)			

Width to Depth Ratio

Measurements of width to depth (“width-depth”) from my study reaches on North Potato Creek and the Tellico River were approximately the same (Table 4.9). The dimensionless width to depth ratio is considered low when it is less than 12, and is considered moderate to high when it is over 12 (Rosgen, 1994). The Prince site had width-depth values that ranged from 7.3-11.6. The Bethlehem site had width-depth values that ranged from 8.3-12.7. The Monastery site had values that ranged from 6.7-11.3. The two Tellico sites had values of 9.9 and 10.3.

Width-depth values changed over time at each site. At the Prince site, the average width-depth values changed by 1.7. The average width-depth measurements at the Bethlehem site are fairly consistent, with a variation of 0.8. The average values at the Monastery changed 1.7. At the Tellico River, the width-depth values are similar to those measured in North Potato Creek.

Sediment Measurement

When I measured the b-axis of the five largest particles on two different dates, I found that each site had a different range of sizes (Figure 4.9). The Prince site had the widest range, from 14.4-62 cm, of the three North Potato Creek sites. The Bethlehem site had an abundance of cobbles and boulders, ranging from 15.4-31.6 cm. The Monastery site had few cobbles and no boulders, with b-axes ranging from 5.2-9.5 cm. The Tellico site had a broad range of sediment sizes, from 20-75 cm.

Table 4.9 Width-Depth Ratios for Three Study Sites on North Potato Creek and Two Study Sites on the Tellico River

8/8/01				
Prince	Width (m)		Depth (m)	W/D
	1	4.5	0.4	11.3
	2	6	0.6	10.0
	3	3.8	0.35	10.9
	Average			10.7
Bethlehem				
	1	5	0.5	10.0
	2	7	0.55	12.7
	3	6	0.6	10.0
Average				10.9
Monastery				
	1	6	0.9	6.7
	2	9.5	0.9	10.6
	3	7	0.8	8.8
Average				8.7
Tellico (4/20/02)				
	1	12	1.16	10.3
	2	13.3	1.35	9.9
Average				10.1

11/18/01					
		Width (m)		Depth (m)	W/D
	1	5.2	0.45	11.6	
	2	4.5	0.55	8.2	
	3	4.4	0.6	7.3	
Average				9.0	
	1	6.6	0.8	8.3	
	2	7.3	0.8	9.1	
	3	6.8	0.8	8.5	
Average				8.6	
	1	9	0.8	11.3	
	2	7.7	0.7	11.0	
	3	6.3	0.7	9.0	
Average				10.4	

There is a clear distinction between the range of measured particle sizes at each site (Table 4.10, Figure 4.9). Larger cobbles and boulders can be found in the pools at the Prince site but are not common. Due to their scarcity, no cobbles or boulders were available for measurement along cross-section 2. Particles on the streambed at the Bethlehem site are sub-angular and rounded. These particles are dominantly shale in origin and form a porous layer over the bedrock channel. Particles on the streambed at the Monastery site are much smaller than those at the other sites. These materials are mostly rounded cobbles and small boulders. The Tellico cross-section 1 is the furthest upstream, followed by 2 and 3 respectively. Materials in the Tellico River are very rounded and much larger than those in the study sites on North Potato Creek.

The graph in Figure 4.9 demonstrates that the materials at the Prince site are highly variable in size in the range of cobbles, while the materials at the Monastery site are relatively homogenous. Large particles at North Potato Creek decrease in size downstream.

Comparing the dry-sieved sand fractions of bed sediment (Figure 4.10) shows the three study sites to have the same sand size distribution. In a second sample taken at a later date (Figure 4.11), only the distributions from the lower sites (Bethlehem and Monastery) were similar. Sand from the December Prince sample had a dominant sediment size around 0.5 mm and similar percentages of fines 0.125 mm and smaller. Particles smaller than 0.063 mm were virtually absent from all samples.

It was not my aim to calculate the median sediment sizes (D_{50}) for each site, but with my data and observations I am able to provide an estimate. Sediments at the Prince site contained very few cobbles and larger particles; thus, I estimate the D_{50} from sieving

Table 4.10 Averaged B-Axis Values

	Cross-Section	Measurement Day 1 (cm)	Measurement Day 2 (cm)
Prince	1	62	47
	2	na	na
	3	14.4	14.4
Bethlehem	1	21.4	20.6
	2	30.6	31.6
	3	17.6	15.4
Monastery	1	9.5	6.6
	2	8.4	7.6
	3	5.2	6.5
Tellico	1	75	52.5
	2	50.5	25
	3	37.5	20

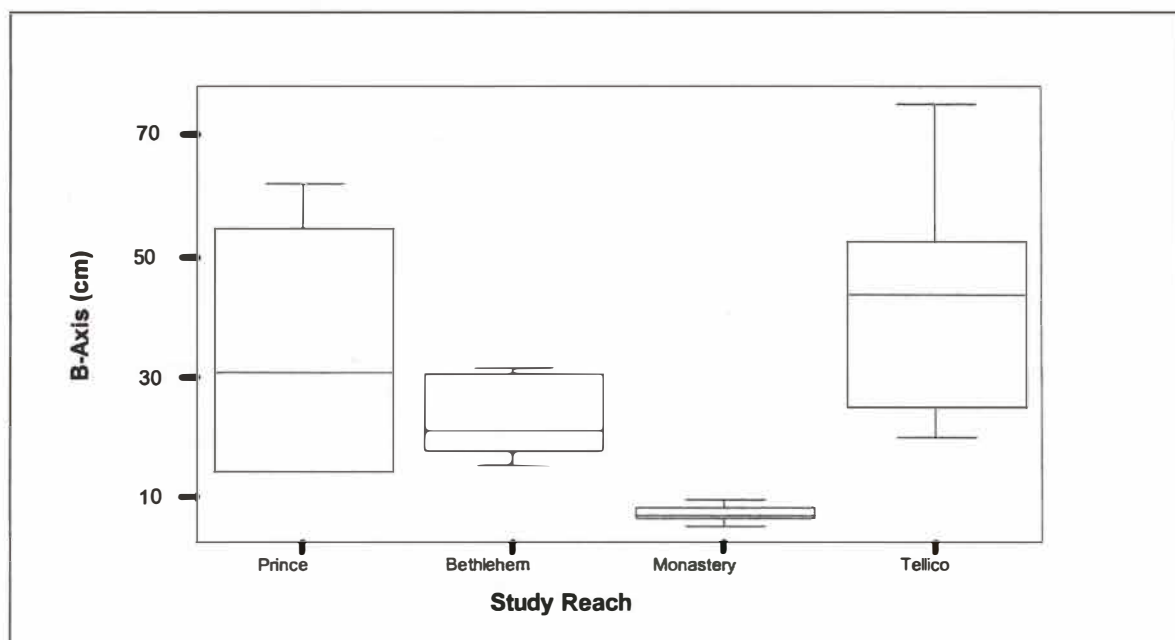


Figure 4.9 Average B-Axis Measurements of Large Particles for Each Study Site. Each box shows the median and upper and lower quartile; the “whiskers” show maximum and minimum values.

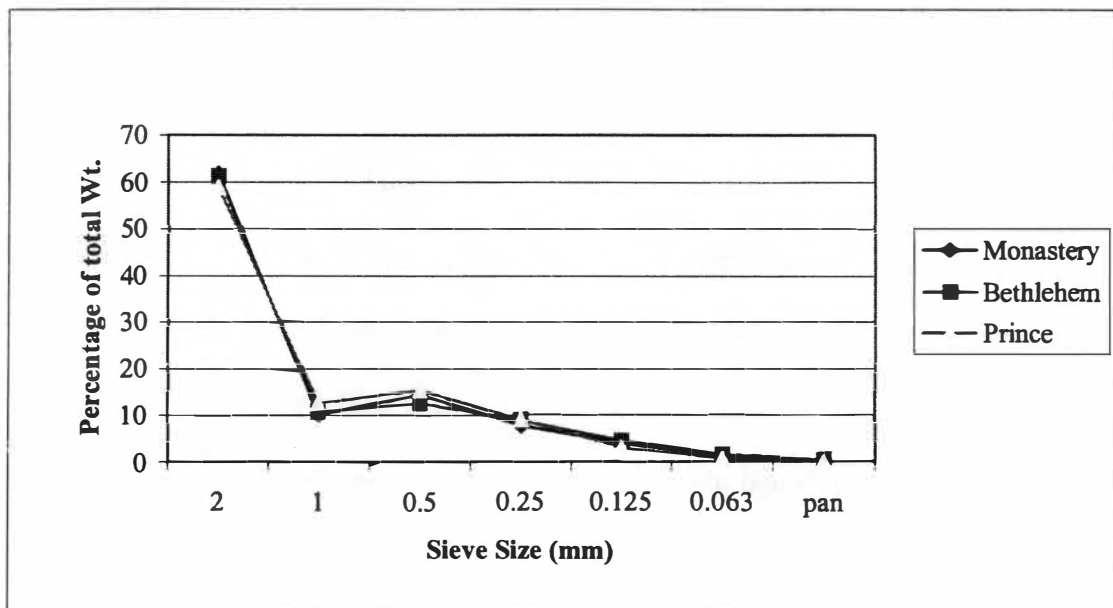


Figure 4.10 Sand Fraction Distribution of Bed Sediment at Three Sites, 10/28/01

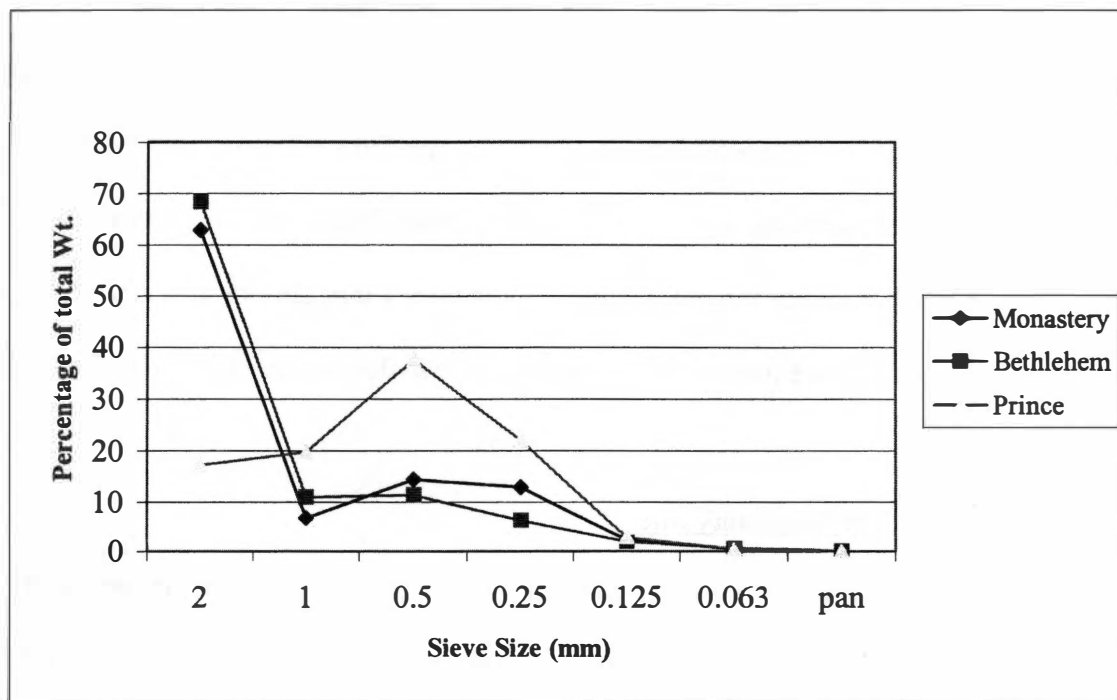


Figure 4.11 Sand Fraction Distribution of Bed Sediment at Three Sites, 12/3/01

data at 0.5 mm. The Bethlehem site contained primarily cobbles and boulders on a bedrock channel, with small patches of sand and gravel. The D_{50} for this site was in the range of cobbles 20 to 25 cm in size. At the Monastery, the D_{50} gravel, in the range of 2-50 mm. The Tellico sites had larger particles than the sites on North Potato Creek, with an approximate D_{50} of large cobbles to boulders, approximately 20-100 cm in size. Additionally, each of the Tellico River sites contained a wide range of sediment sizes, from fine sediments distributed along the banks to larger boulders in the middle of the stream.

Sediment Movement Observations

When I placed painted sediment (following dry sieving) in the stream at baseflow to observe and measure sediment transport over a two-hour period, I found that sediment was quickly and actively transported at all sites, with the fines (<0.063 mm) transported in suspension, never reaching the bed. The sand-sized sediment was transported as bedload, and a small quantity moved beyond the distance I was able to measure. Gravel and larger materials did not move during the initial, low-flow observation period (Table 4.11).

Sediment Volume at the Monastery Site

At the Monastery site, I measured sediment depth by probing sediments with a one-meter long rebar rod to estimate the quantity of sediment stored along a 100 m section of the stream. The average sediment depth was 0.24 m, and I estimated the total quantity of loose bed sediment in this 100 m section to be 117 m^3 .

Table 4.11 Summary of Painted Sediment Observations

Study site	Observations after 1 hour	Observations after 2 hours
Prince: Placed in the stream 2 m above a cascade sequence and saw sand and finer material immediately transport, disappearing in a pool 8 m directly below the cascade. Silt just washed away in suspension.	Gravel rolled over the cascade and also stopped in the pool. Small cobbles (b-axis < 7 cm) did the same.	Larger cobbles (> 7 cm) did not move unless prompted by a push. The smaller particles were caught in the pool and stopped.
Bethlehem: Placed in the stream in middle of the reach. Sand and silt were immediately transported.	Small gravel (< 8 mm) moved up to 1 m. Sand moved up to 8 m and was filling in behind cobbles.	I noticed painted sediment that faded at 12 m. Cobbles fell out first, around 30 cm, as they lodged into place behind rocks, followed by gravel at 1.2 m. Sand moved the furthest, beyond 12 m.
Monastery: Placed in the stream 7 m above the top of a riffle sequence, near the middle of the reach. Silt and fine sand transported in suspension.	The sand had been carried away, with some visible 7 m downstream. At 7 m, the sediment entered a riffle sequence and was no longer visible.	Sediments 3 cm and larger did not move. Movement for 5 mm sized particles was measured at 1.5 m. Sand moved readily. I observed sand filling behind cobbles and forming small bed forms.
Tellico River: Placed in the stream in homogenous sections containing boulders and large cobbles. The gradient was similar to the Bethlehem site. Silt and fine sand transported in suspension.	The sand had been carried away, leaving a small trail and fragments visible behind cobbles up to 10 m downstream.	Sediments larger than 8 cm did not move. Gravel and sand moved readily and could be traced to 15 m downstream before they were no longer visible.

Site Comparison and Classification

This section is organized into two parts according to the two parts of Rosgen's (1994) stream classification technique. Level 1 is a broad morphological characterization of the stream. Level 2 is a morphological description of the stream using site-specific measurements and observations

Rosgen, Level 1

I classified each site according to the data required for Rosgen's Level 1 (Table 4.12). At this broad level, the Prince site classifies as a type A stream, and the Bethlehem and Monastery sites classify as type C streams.

Rosgen's (1994) description of the Level 1 stream classification for type A and C streams is provided below:

Type A: Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock or boulder dominated channel. High relief valleys. Erosional or depositional, containing bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step-pool bed morphology.

Type C: Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well defined floodplains. Broad valleys with terraces, in association with floodplains, alluvial soils. Slightly entrenched with well-defined meandering channel. Riffle-pool bed morphology.

Rosgen Level 2

In Level 2, each site is classified with an alphanumeric value associated with a specific morphology and dominant bed material. The letter corresponds to the stream type and the number corresponds to the dominant bed material. I summarized the observed values from Level 1 and 2 to label each site with an alphanumeric Rosgen stream value (Table 4.13).

Table 4.12 Summary of Rosgen Level 1 Values

	Prince	Bethlehem	Monastery
Valley Gradient (from topographic maps)	0.0172	0.0172	0.0172
Channel Gradient	.042	0.00093	0.00093
Cross-section Morphology	see Figure 4.5	See Figure 4.6	see Figure 4.7
Sinuosity (from the 1978 topographic map)	1.2	1.3	1.8
Rosgen Stream Type	A	C	C

Table 4.13 Summary of Rosgen Level 2 Values

	Prince	Bethlehem	Monastery
Channel Material	Bedrock channel with one alluvial bank	Bedrock channel with cobbles and small boulders	Alluvial sediment, sand and gravel
General description	Stable channel except for erosion on alluvial bank	Stable flat channel with floodplain and terrace-like deposits	Meandering alluvial channel with relatively high bank erosion rates
Entrenchment Ratio	2.2 +/- 0.2*	2.3 +/- 0.2*	na
Width/Depth Ratio	9.9 +/- 2*	8.2 +/- 2*	9.6 +/- 2*
Sinuosity	1.2 +/- 0.2*	1.3 +/- 0.2*	1.8 +/- 0.2*
Channel Gradient	0.042	0.00093	0.00093
Rosgen Stream Value	A ₁	B ₁	C ₄
* The (+/-) value reflects the Rosgen "continuum concept"			

According to the Rosgen Classification, the Prince site is a type A₁ stream. The Prince site is a bedrock site, consisting of a pool-cascade sequence. Bedrock extends from the northwest side, across the stream, dipping under the southeast bank (Figure 4.5). The southeast bank (Figure 4.5) consists of sandy alluvium with a 3 m wooded corridor. This bank has many indications of active erosion processes including root exposure, trees that lean towards the stream, and evidence of bank undercutting. Beyond the alluvial bank is a well-established floodplain. According to the general description, channel morphology, and dominant bed material, this reach was a good match with an A₁ stream type. The width-depth ratio fits within the expected range of values for an A₁ stream and so does sinuosity when the continuum concept (0.2% flexibility) is applied. However, the measured entrenchment ratio at the Prince site corresponds to that of a type B stream.

According to the Rosgen Classification, the Bethlehem site is a type B₁ stream. This site has visible bedrock on the channel bottom, which is primarily covered with rocks and cobbles up to 45 cm (b-axis measurement). The banks are composed of various sized rocks and sandy alluvium with well-established riparian ecosystems extending well into the floodplain on both sides. An abandoned channel, approximately 20 m west of the current channel, appears to act as an overflow channel based on the large cobbles and boulders present and the slightly higher elevation of the abandoned channel compared to the current channel. Additionally, the site contains terrace-like deposits above the bank on both sides of the current channel and a 5 m wide floodplain. The sinuosity of this reach fits well with Rosgen's range of values for type B streams and the entrenchment ratio fit when the continuum concept was applied. On the other hand,

the width-depth ratio value indicates a type A, DA or E stream. None of the measured criteria at this site was associated with a type C stream, as Level 1 had inferred.

According to the Rosgen Classification, North Potato Creek at the Monastery site is a type C₄ stream. A type C₄ stream has dominantly gravel bed material. The measured values for entrenchment and sinuosity at this site match well with type C streams. However, the width-depth ratio indicates a type A, DA or E stream.

Measurements of channel sediments and my observations of channel morphology of the two sites on the Tellico River classify these sites as B₂ or B₃. These sites have visible bedrock on the channel bottom, which is primarily covered with large cobbles and boulders up to 75 cm (b-axis measurement). The banks are composed of various-sized rocks and sandy alluvium with well-established riparian ecosystems on both sides. Additionally, there is a broad floodplain on the north side of the river at both sites but no floodplain exists above the south bank because it is approximately 2 m higher than the other bank. These sites look similar to the Bethlehem site on North Potato Creek except they contain a much broader range of sediment sizes.

Chapter 5

Discussion

A Conceptual Model of North Potato Creek

Based on my observations of the watershed and analysis of aerial photos, I propose the following conceptual model for North Potato Creek. Prior to mining in the early 1800s, North Potato Creek was a bedrock stream that likely supported a biologically diverse ecosystem, similar to other streams in the Southern Blue Ridge Province, such as the Tellico River. Around the time that settlers began to move into the area and mine copper, this situation changed. Copper mining required a fuel source and the Copper Basin's trees were removed to support it. Tree removal has directly exposed soil in the watershed to rainfall and rainfall runoff. Additionally, into the early 1900s, the release of sulfuric gas from local smelters increased the denudation of the Copper Basin. This left the North Potato Creek watershed's slopes vulnerable to soil erosion. Thus, a massive quantity of acidified sediment would have been eroded from the slopes to the stream system, altering the morphology and ecosystem of North Potato Creek by forming a wide floodplain across the valley floor. Decreases in the sediment load contributed to reincision and the formation of fluvial terraces at the Bethlehem site, and to channel migration at the Monastery site farther downstream.

Before the mining era, sediment in North Potato Creek would have encompassed a full range of grain sizes from small boulders to clay particles, as the Tellico River sites do today. At low flow, North Potato Creek was able to move a large quantity of clay to gravel-sized sediment, resulting in a cobble and boulder channel. During periods of high

flow, the stream was capable of moving larger materials downstream and depositing finer sediments on the floodplain. Prior to 1952, a sediment dam was built 1 km below the Monastery site to reduce the stream's sediment yield. Over time, eroded sediment from the denuded watershed began to collect behind the sediment dam. As the sediment accumulated, it filled the stream channel and overflowed into the valley, eventually developing a broad valley floor with an alluvial braided stream that extended 2 km upstream of the dam. Sometime between 1952 and 1964, the dam filled and was topped by North Potato Creek. At this point, the stream began to flow over materials previously deposited on the valley floor because its base level was higher, allowing it to move sediment downstream and over the dam during high flows.

In the late 1970s and early 1980s, reforestation of denuded slopes in the watershed was beginning to occur, which would have reduced the sediment yield to the stream. Areas that were reforested would have had lower sediment yields compared to areas bare of vegetation. This reduction in the sediment yield caused the stream to readily scour sediments that had been deposited prior to reforestation. At the Prince site, erosion of floodplain sediment is visible as bank erosion. At the Bethlehem site, terraces 1.5 m high line both banks, suggesting that the stream incised into the alluvial deposits. Downstream, the Monastery site lies on loose alluvial fill and has obvious changes in channel location, evident from extensive bank erosion and deposition on point bars.

As the forest expanded and increasingly protected the watershed's slopes, the sediment yield to the stream decreased. As sediment moved downstream, surface erosion processes did not equally replenish it. Thus, the channel is increasingly showing a bedrock channel as the driving forces, shear stress and gravity, are in excess of the

resisting forces, sediment and bed friction. The only section that remains alluvial is the reach containing the Monastery site, above the sediment dam. Here, the dam effectively raises the stream's base level and forces the stream to flow over the sediment backfill and past the dam.

Study Questions

1. *How has land use in the upper North Potato Creek watershed changed over the last 50 years?*

Humans have affected the watershed and stream in many ways. Starting with mining and the massive deforestation that followed soon after, the basin was denuded of vegetation for over 100 years. Removal of the watershed's forest allowed the erosion of massive quantities of soil and its transport downstream. A dam was built in the stream, which captured large amounts of eroded sediment and stored them in the channel. Subsequently, rural development, farming, and reforestation have increased the extent of forested and sparsely vegetated land, drastically reducing the area of bare land.

The North Potato Creek watershed was composed of 51% bare land in 1952 but only 12% by 1994. Bare land included extensive gully fields that have been reduced in size by reforestation efforts, rural development and ranching or farming. The increase of forested land, from 20% forested land in 1952 and 54% by 1994, can be attributed to the end of mining activities in the basin during the 1960s and the success of reforestation in the 1980s.

Reforestation efforts were increasingly successful following the end of mining and acid processing related disturbances, and in the 1970s as fertilizer pellets and fungi

(*Pisolithus Ectomycorrhizae*) were provided for each tree seedling (Berry and Marx, 1978). Based on my measurements of stream pH, now neutral to slightly basic at baseflow, it also seems possible that the once highly acidic soils have returned to pH levels capable of supporting forest growth.

Water quality testing reveals that sewage and fertilizer contamination were not affecting the stream's health at the time of testing, though the stream does have a relatively high turbidity. Roads, construction projects, and ranches all have contributed to this high level of turbidity by exposing sediment at the surface and therefore increasing the yield of fine sediment to the stream. In many areas of the North Potato Creek watershed, I observed construction and farming activities. As these activities continue, I expect the erosion from these sites to continue to put sediment into the stream.

The Bethlehem site has little evidence of direct human maintenance except for the road acting as a possible levee to floodwaters, and a culvert just upstream. This site also has very angular large cobble and boulder-sized materials covered with algae. The abundance of algae on these large stream materials suggests that they have been in the creek for some time, and the fact that they are angular demonstrates that the materials have entered the stream from local sources. Additionally, this suggests that they have not been abraided recently by a wash-load of moving sand. These materials exceed the stream's ability to transport at normal flows and thus remain in the channel.

Aerial photos also show how the channel of North Potato Creek changed over the 42-year photo record. Photos show that the stream changed little along its entire span except along the section of the Monastery. This reach changed radically between the years 1952 and 1994, from a broad valley with a multi-threaded braided channel to a

single-threaded meandering channel with a wooded corridor. The channel in this reach is actively migrating and continues to reflect the fluvial system's dynamic response to past human-caused disturbance, showing that changes in the watershed and stream channel take a long time for the surface and fluvial systems to recover.

2. *Is upper North Potato Creek actively transporting and/or storing sediment in a manner expected for streams in the same ecoregion?*

Alterations to the land use in the watershed have changed the sediment dynamics in North Potato Creek. Historical erosion of bare slopes in the Copper Basin is known to have introduced large quantities of sediment into the stream. The current rate of soil erosion in the watershed has been shown to decrease as the forest increases in size and density (Harden and Mathews, 2000). In many locations around the watershed, I observed gullies with pine needles on top but exposed soils along the bottom and sides. This suggests that the gullies are active and contribute a relatively high sediment yield given the young forest cover and abundance of gullies in currently bare and sparsely vegetated areas. Thus, erosion processes are still active, but sediment loading has decreased relative to 50 years ago, when the watershed had a larger percentage of bare land.

The Tellico River was used as a reference stream, but it is believed to have an increased load of fine particles from off-road vehicles, which loosen surface particles and increase the yield of fine particles to the stream. Finding an undisturbed reference stream is difficult because most watersheds of the Southern Metasedimentary ecoregion have been historically disturbed by logging or other human activity.

North Potato Creek has a very different range of sediment sizes in its channel as compared to the Tellico River. Observations from the two sites on the Tellico River show that each site contains a full range of sediment in its channel, from silt (mud) to large woody debris and boulders with a b-axis measurement greater than 75 cm. Large materials create eddies and low energy places where smaller particles can accumulate. North Potato Creek does not contain large woody debris or boulders in its channel, nor does the watershed currently have well used off-road trails, which helps explain the low percentage of fine particles (0.063 mm) in the stream. The particle size characteristics for each study reach on North Potato Creek were bimodal, either predominantly cobbles and sand (Prince and Monastery) or gravel and sand (Monastery). Boulders are not found in the channel of North Potato Creek because of the smaller size of the watershed as compared to the Tellico River's watershed.

The percentage by weight of sand in the <2 mm sediment fractions is generally the same for every reach of North Potato Creek. On the second sieving date, I found that the Prince site had a different sand-fraction percent breakdown, which implies that a local disturbance introduced different sand-sized sediment into the stream. My observations and experiments with reintroducing sand particles indicate that even at times of low flow, critical shear stress in the three study reaches of North Potato Creek is high enough to initiate the motion of sand-sized bed material. Thus, the sand fraction is actively and constantly transported downstream by North Potato Creek. Sand-sized sediment moves through the system with only small amounts remaining in the pools and eddies at the upper sites. At the Monastery site, the dam has decreased the gradient, allowing some

sediment to be deposited. The rest is transported over the dam, especially during high flows.

The Bethlehem site had the least amount of sand of the three North Potato Creek sites. Sand was only in trace amounts in eddies and behind larger cobbles. This suggests either that sand moved through the reach more efficiently or that recently there has not been a large sand load. The latter hypothesis is supported by the fact that this site had an abundance of algae-covered cobble and boulder-sized material, which would show signs of abrasion if a large sand load had passed through.

By using the Tellico River as a reference site, I found that sediment dynamics in North Potato Creek differ from what is expected for streams in the same ecoregion. Erosion rates from the watershed are decreasing but they are still likely higher than other watersheds in the same ecoregion (Harden and Mathews, 2000). The lack of variety of sediment sizes in the stream is likely due to the history of exposed soils, extensive erosion and increased runoff. Erosion from the slopes would have washed sediment into the stream from the denuded slopes, creating the vast gully network that can be seen to this day. The higher gradient at the Prince site enabled the stream to move the available sediment downstream. At the Bethlehem site, where the gradient decreases, the stream easily moves sand; thus, the bedrock channel is covered with mostly cobble-sized particles. Sediment currently comes from active gullies, farming, and construction practices. Because these sediment sources remain active, I hypothesize that the amount of sediment entering the stream will not decrease in the near future, maintaining the unique sediment storage and transport dynamics of the North Potato Creek.

3. Can the current morphology of upper North Potato Creek be attributed to land use change over the last 50 years?

My research on North Potato Creek shows that differences in channel morphology at the Monastery reach can be attributed to land use change over the last 50 years. Changes include adjustment from a braided channel to a single-threaded channel, an increase in sinuosity, and observed channel migration. The upper sites, Prince and Bethlehem, have a stable channel due to bedrock, a higher gradient, and heavily wooded banks. These sites do not have major changes that can be measured or observed from aerial photos.

With the exception of the Monastery site, North Potato Creek is now a bedrock stream. The Prince site is almost entirely bedrock and the Bethlehem site is bedrock littered with a layer of cobbles and boulders. Based on sediment probing, the channel bed at the Monastery site is composed of at least 0.24 m of unconsolidated alluvium as a result of the deposition of massive quantities of sediment behind a dam 1 km downstream. The dam acts as a sediment trap, effectively backing up sediment in the channel. This also has the effect of decreasing the stream gradient along this reach, which allows sediment to be deposited as the stream loses energy. The loose alluvial sediment and low gradient along this reach enable the stream to migrate across the valley fill. Below the dam, I identified numerous sections that flow on bedrock, including one, approximately 4 km downstream from the Monastery site, that crosses under Highway 64.

Aerial photos show that the stream channel has remained in the same location over the last 42 years in the upper reaches of North Potato Creek. The characteristic

bedrock channel and wooded banks maintain the channel's location and minimize erosion. The section of North Potato Creek flowing through the Monastery is the most active of the three sites, where loose sediment and a high bankfull discharge enable the stream to constantly move alluvium. The landscape here is composed of alluvial deposits with an unknown depth. Because there is only alluvium and no bedrock to confine the channel, there is little to no structural control.

From my initial interview with residents at the Monastery site, I learned that the stream has been actively migrating, with the current channel approximately 20 m removed from its location 30 years ago. My observations of the streambed support this claim, as this reach changed significantly each time I visited the site. Observed changes include the migration of riffle sequences, bank erosion, and development of new sand bars and gravel riffles. Based on measurements of channel migration at a stationary white drainpipe, the stream is currently migrating approximately 2 m per year towards the channel's previous location. I expect that this will continue as long as the sediment dam maintains the current stream base-level and forces the stream to migrate laterally. A lowering of base-level is frequently cited as a cause for stream incision in sand and gravel bedded streams (Reid and Dunne, 1996; Thorne et al., 1997). Therefore, if the dam were to be removed or to fail, I hypothesize that the base-level would drop and the stream would incise into the loose sediment.

The overall sinuosity for North Potato Creek is very low, with an average value of 1.17. The slight increase in sinuosity from 1.14 in 1927 to 1.18 in 1978 could be due to map error or to the sediment dam, which began storing sediment along the Monastery reach prior to 1952. Sinuosity is affected by many variables. Bedrock plays a major role

in laterally confining the stream and decreasing sinuosity, as noted in the Prince channel profile. Alternatively, fine alluvium allows the stream to migrate and can increase sinuosity. Sections of North Potato Creek, such as the Bethlehem site, appear to be laterally confined by roads that act as levees. Humans also decrease the sinuosity of streams by building culverts and by physically maintaining or “cleaning” the stream channel of debris.

A 0.5 increase in the sinuosity for the Monastery section (Table 4.7) reflects the change from a braided channel in 1952 to a single-thread meandering channel in 1994. A similar condition noted by Buttle (1995) was that reforestation increased the sinuosity of the alluvial channel in the Ganaraska River, Canada. Alluvial channel banks are easily eroded and allow the stream channel to migrate across the valley floor in response to a decrease in the sediment supply from the watershed. This interpretation is supported by information learned from residents, who stated that the stream has drastically changed channel locations following episodes of bankfull and higher flows. They also added that large quantities of sediment were eroded and moved downstream after each event. Thus, over the past half-century in this reach, avulsion and bankfull discharges have not maintained the channel as Leopold (1997) suggests, but have created major changes in channel sinuosity by eroding the loose alluvial bank material. At the Prince and Bethlehem sites, there was not a significant change in sinuosity because the channel was constrained by bedrock.

According to a local resident, the floodplain at the Prince site has been inundated by floodwater once in the past 30 years. Bedrock on the right bank and channel bottom confines the channel laterally and vertically, effectively preventing the right side of the

channel and channel bottom from being entrenched. This indicates that, at high water flows, the stream is attempting to erode sediment from its channel but is being constrained by the bedrock and forced to erode the alluvial bank. Eventually, it may cut into the floodplain at the Prince site, but the wooded corridor appears to have stabilized much of this bank.

Width-depth ratios in North Potato Creek are similar to those at Tellico River sites. The Monastery width-depth ratios changed by approximately 1.7, from 8/8/01 to 11/17/01, a relatively large change that cannot be explained by topographic variation because this is a very flat and consistent reach. Here, the average width-depth change is a result of bed aggradation, the deposition of sand and gravel along the channel bottom. Cross-section data show that the bankfull depth decreased by approximately 0.3 m, from 8/8/01 to 11/17/01. Generally, as a bed surface aggrades, the depth will decrease and the ratio of width to depth will increase, assuming that the width does not change. Schumm et al. (1977) suggest that the width-depth ratio should decrease following reforestation. Future researchers should measure these values again in the future to draw a better link between width-depth ratio and reforestation.

As forested areas continue to increase in extent, sediment input and rainfall runoff from the watershed should decrease. Because the stream can readily move fine sediment, it will erode alluvial bank material and continue to alter the channel morphology. My observations of North Potato Creek suggest that this will expose underlying bedrock and increase the occurrence of bedrock in the stream channel. If the sediment dam were removed, I expect that North Potato Creek along the Monastery reach would begin to incise and move the alluvial fill until it encountered bedrock. I hypothesize that removal

of the sediment dam would move large quantities of sand downstream to the Ocoee River, form terraces at the level of the current floodplain, and restore the entire length of North Potato Creek to a bedrock channel.

4. *a) How do the study reaches on North Potato Creek classify according to the Rosgen Classification system?*

Stream types can imply much more than what is initially described in their alphanumeric titles (Rosgen, 1994). This was the case for each of my three study sites. The set of stream criteria I measured at each site did not absolutely fit in a specific stream type according to the Rosgen (1994) classification, so I used the majority of matching criteria, the general description, and the cross-sectional morphology to determine the best fit classification. An example of this is the Bethlehem site, where values for gradient and sinuosity classified the reach as a type C stream, but most other criteria classified the reach as a type B stream. This suggests that the unique disturbance history of the North Potato Creek has altered the current channel morphology, and that it will continue to adjust until its parameters match its stream type.

The Rosgen description of type A streams corresponds well with North Potato Creek at the Prince site. This section has relatively low bank erosion, a cascading step/pool profile, high relief, and a bedrock channel. According to the general description, channel morphology and dominant bed material, this reach was a match with an A₁ stream type. For example, the width-depth ratio fits within the expected range of values and so does sinuosity when the continuum concept is applied. However, the

measured entrenchment ratio corresponds to a type B stream. Human interaction and the presence of tilted bedrock perpendicular to stream flow helps explain these values.

The Bethlehem site is best classified as a type B stream, specifically as a B₁ stream because the streambed is composed of bedrock with cobbles. The sinuosity of this reach fits well with Rosgen's range of values and the entrenchment ratio fits with the continuum concept applied. Alternatively, the width-depth ratio value indicates a type A, DA or E stream. None of the measured criteria at this site was associated with a type C stream, as the Level 1 classification had predicted. This is probably a result of the difficulty of accurately measuring stream gradient, a problem with such broad classification criteria at Level 1. It is also possible that the Rosgen classification, which was developed in the U.S. southwest, New Zealand, and Canada, is not fully applicable to headwater streams of the Southern Appalachians.

I classified the Monastery reach as a type C₄ stream. It has a low gradient in a broad valley with terraces, an alluvial channel, a dominantly gravel bed, and riffle-pool bed morphology. The measured values for entrenchment and sinuosity match well with type C streams. The width-depth ratio, however, indicates a type A, DA or E stream. According to Rosgen (1994), type C streams are morphologically active as they meander through alluvial deposits, constantly eroding and depositing sediment.

4. *b) According to their classified stream types, what are the management implications for the upper reaches of North Potato Creek?*

Disturbances in the North Potato Creek watershed over the last 150 years have modified the sediment dynamics and changed the morphology of the stream channel.

These alterations have caused the stream to adapt to a new equilibrium state following a period of dynamic change. Thus, managers must take this unique situation into account and develop their management practices to work with the current fluvial system dynamics as the stream responds to the long-term recovery of the watershed. I suggest that managers develop a long-term recovery plan to first address the watershed and then the fluvial system.

A full natural recovery of this stream and associated aquatic ecosystem is not likely because of the magnitude of the disturbance to the watershed and fluvial system. For the purpose of this study, I define a “full natural recovery” as the ability of the stream to return to a pre-impact equilibrium state without human influence. Alterations of the land have caused long-term changes in the watershed hydrology, fluvial system dynamics, and aquatic habitat. Alterations include deforestation, rural development, dam building and acidification. Deforestation and development removed trees and caused soil erosion, which decreased the watershed’s ability to filter and safely release water. The placement of a dam in North Potato Creek once stopped the downstream flow of sediment and stored it in the channel, but now at high flows the stream is able to move this sediment over the barrier because the basin is full. This dam holds an unknown quantity of sediment, which decreases the channel gradient and increases the base level. The stream now meanders across the alluvial fill, a characteristic that is remarkably unusual for streams in the Southern Metasedimentary ecoregion. Like many dams around the world, the one in North Potato Creek also functions to biologically isolate the aquatic plant and animal populations upstream, further decreasing the likelihood of a full natural recovery. Finally, the acidification of the basin by environmentally destructive ore processing

practices contributed to the massive loss of watershed plant and animal species, reducing the health of the aquatic ecosystem and further altering the dynamics of the fluvial system.

Managers need to assist in the recovery of the North Potato Creek watershed to restore its ability to adequately capture, store, and safely release water. A natural approach to watershed restoration is one that works with nature to make long-term changes that will eventually assist in the natural recovery of the watershed and fluvial system (Petersen, 1999). The first part in this natural approach is to identify landforms and structures that do not adequately capture, store, or safely release water. Once these areas are identified, managers need to make changes to increase their ability to function. This includes fostering the expansion of the reforested areas with the continued planting of native species that increase the diversity and health of the forest. This will enable the expansion of the hardwood forests down into the lower reaches of the watershed that are now continuous stands of loblolly and Virginia pine.

The most common factor that decreases the health of aquatic ecosystems in Tennessee is siltation (Arnwine et al., 2001). Because gullies in the North Potato Creek watershed appear to still actively contribute sediment to the stream, they inhibit the establishment of aquatic ecosystems. Petersen (1999) recommends filling gullies with rocks and trees to reduce siltation, and recommends importing native aquatic species to help support the aquatic and riparian ecosystems. Aquatic ecosystems function to filter pollution and capture sediment, and also to slow and absorb the energy from floodwater. The importation of aquatic species is critical to upper North Potato Creek because of its isolation from downstream aquatic ecosystems by the sediment dam and by acid drainage

from mine tailings in Burra Burra Creek. This has reduced the water quality of lower North Potato Creek and the Ocoee River further downstream, and made it unsuitable to support aquatic life (Arnwine et al., 2001). Thus, managers must first address gully erosion to help reduce sediment yield and channel siltation, then address the replacement of native aquatic species and habitat.

After that, an evaluation of the sediment dam will be critical to restoration because it harbors potentially contaminated sediment and raises the stream base level. Researchers need to test the buried sediment for contamination to determine whether dredging or dam removal is necessary or possible. If it were possible, the removal of the dam would allow the stream in the Monastery reach to return to a bedrock channel. This is crucial to restoring this section and allowing aquatic species to reestablish.

It is highly improbable that the fluvial system will completely recover the dynamics that existed prior to impact because of the extent of disturbance. The fluvial system will continue to adjust towards a new equilibrium state that brings the system closer to a full natural recovery. Natural recovery will last as long as it takes for soils to form so that they can function properly to filter and release water. This could take thousands of years. To aid managers in developing a long-term plan, I have collected a variety of site-specific data from North Potato Creek that managers can use for baseline analyses, such as:

- Aerial photo interpretation: Use a GIS program to continue monitoring land use change and make conclusions about the fluvial system response.
- Water quality monitoring: Test water quality to identify problem areas and sources of pollution to aid in the restoration of aquatic ecosystems. It

would be useful to monitor during variable flows and seasons to add to our understanding of the fluvial system response to climate and seasonality.

- **Bankfull discharge:** Monitor the role of land use change in altering discharge, adding to our understanding of the relationship between infiltration and dynamic fluvial response.
- **Stream and reach sinuosity:** Monitor the fluvial response to land use change and restoration practices, adding to our understanding of the fluvial response to extreme disturbance in a humid temperate region.
- **Sediment Measurement:** Sampling bed sediment to monitor the current load of fine particles moving through the system as it adjusts to land use change and restoration practices. This is useful to determine if land use change is reducing or changing the composition of this sediment along different reaches, adding to our understanding about the effects of reforestation and restoration management on the fluvial system.

Therefore, as forested land in the North Potato Creek watershed continues to expand and link up with riparian communities, I hypothesize that the overall diversity and long-term health of these communities should increase. Managers can use data I have collected to continue monitoring this system while working with nature to apply restoration practices. Ultimately, this study and the collected data will add to the understanding of how fluvial systems recover from extreme denudation and extended land use change.

5. *What can the dynamics of upper North Potato Creek contribute to the broader understanding of fluvial adjustment to extreme disturbance?*

Fluvial systems and aquatic ecosystems are of interest to land managers because they can be used as a proxy for the general health of the watershed (Denton et al., 2000). Healthy ecosystems represent less disturbed watersheds (Rosgen, 1994), and healthy watersheds adequately filter, store, and release water downstream. These systems respond to changing land use by altering their behavior to compensate for changes in the driving and resisting forces, a process called dynamic equilibrium (Leopold, 1997). In disturbed watersheds, small changes can upset the equilibrium of the fluvial system and trigger a prolonged period of dynamic change, ultimately causing the stream to adapt to a new equilibrium.

This type of research is of value to scientists interested in defining the relationship between land management and the dynamics of a natural system response. Understanding these dynamics is useful to aid in watershed and stream restoration, because human-related changes often cause an irreversible response and variation from pre-impact fluvial dynamics. This research aids hydrologists and land managers in making informed decisions on watershed restoration and land use practices, and increases the awareness of the implications of land use disturbance for fluvial systems. The goal is for managers to produce a set of reproducible parameters to govern a long-term natural watershed recovery, and to control and predict the dynamic fluvial system response to watershed disturbance.

Errors and Problems

Watershed systems are extremely complex with numerous processes affecting their form and function. Errors and problems exist in a study of this type because controlling for all these processes is impossible, but identifying possible errors and problems is useful for improving future research.

Water quality was measured using the Green Water Monitoring Kit, a low cost and very basic kit designed for testing at the reconnaissance level. Errors can exist in matching the sample to the correct color on the card, and having a possible range of values makes the data less precise. Also, I controlled for temporal and discharge differences between the sites by testing all the sites within a 1 to 2 hour period but I did not control for discharge variations between the testing dates or sample over a full range of discharge conditions. Thus, the water quality data provide a first glimpse, but not a rigorous assessment, of water quality in upper North Potato Creek.

Measurements, including water quality and sediment movement, were made while the stream was at low flow. I assumed that low flow was baseflow because it occurred frequently throughout the period of observation. Baseflow was assumed to be the consistent over time.

A fairly common problem cited in many studies (Harrelson et al., 1994; Reid and Dunne, 1996; Leopold, 1997) is the accuracy in determining bankfull stage. Measurements of bankfull velocity and discharge, entrenchment, width-depth ratio, and flood-prone area all rely on accurate assessment of bankfull stage. Because of the accuracy problem in identifying bankfull stage, any value associated with bankfull

conditions is expected to be slightly variable. This helps to explain why the calculated discharge did not increase downstream on North Potato Creek as I would expect.

The Rosgen (1994) stream classification uses broad morphological observations and measurements of specific stream criteria to assign a generalized value to a particular stream or reach. Streams do not always fit neatly into a stream type, as was the problem with my study reaches. At every site, a particular measured stream value did not fit within the expected Rosgen (1994) set of values. I had to classify each reach according to the majority of stream characteristics that fit within a general stream type.

Channel gradient measurements were crude and may have created inaccurate results. Gradient was measured using an Abney level, a device that relies heavily on the operator's precision. Gradient was measured by pointing the device upstream to an object with a known elevation above the channel bed. The scale allows readings to the hundredth of a degree, but errors in focusing and lining up the viewfinder with the object generate slight deviations in repeated measurements. The Rosgen Classification system is very sensitive to changes in these measurements and so is the Manning Equation. Values for bankfull discharge could be off by a few meters.

Rosgen's classification method was developed for use in streams of the southwestern United States and New Zealand, and I was unable to find a publication that tested it in humid temperate environments. Thus, the classification method may not account for differences in climate or its associated flow regimes. In wetter areas, like southeastern Tennessee, discharge is dependent on local precipitation and subject to short peaks following storm events. In the drier areas of the Southwest, discharge is usually dependent on snowmelt in mountainous areas or on infrequent precipitation events.

Snowmelt creates a long period of higher flows, and the infrequent storms often cause flash flooding. Thus, differences in the flow regime and seasonal discharge could explain some of the differences in my measured values from the values associated with a particular Rosgen stream type.

In this study, I used two sampling methods to analyze stream sediment. One method looked at the b-axis of larger sediments and the other at dry-sieved gravel and finer sediment. These sampling methods were used to determine the distribution of sand-sized and larger sediment. I assumed that the fine sediments were being transported and that larger sediment was not. Observations of painted sediment revealed this to be true except at high flows where large sediments that I had tagged either were buried or moved beyond view. These sampling methods, though, were not well suited for measuring the D_{50} sediment size. For this, I had to initially make observations of the D_{50} at each site and choose the appropriate sampling method to capture the observed D_{50} . This resulted in a fairly subjective method.

Another problem that introduced unknown factors to my study is the effect of storms on the stream flow and sediment yield. I was not able to visit the stream to collect data during periods of high flow. Thus, documenting storms and their ability to generate a higher sediment yield and stream discharge remains for future research. For the purposes of this study, I hypothesize that precipitation associated with storms has the ability to erode higher quantities of sediment from the watershed and generate periods of higher flow and sediment yield than I observed.

Finally, seasonality, like storms, may have a strong effect on the stream system. Seasonality was not controlled for in this study. In winter, because native trees in the

upper slopes and wooded corridor along the stream channel lose their foliage, a lack of forest canopy effectively decreases the interception of precipitation. In winter, deciduous trees do not transpire and conifers transpire far less, which results in increased runoff and a higher peak discharge. Also, in areas where soils are not well established, erosion rates and rainfall runoff rates are still relatively high. This has the effect of increasing the sediment yield during late fall, winter, and early spring. A higher sediment yield from the slopes to the stream would increase sediment movement by the stream and could cause aggradation along the streambed.

Chapter 6

Conclusion

Conclusions

The extensive removal of vegetation, beginning in the 1850s with the introduction of mining, allowed massive quantities of sediment to erode from the Copper Basin into the stream system. The vast gully systems visible in aerial photos provide a proxy measure of the surface erosion that occurred. Thus, for an extended time, the stream system has responded by increasing sediment transport and by storing sediment along its channel and on the floodplain.

In the last 50 years, land use in the basin has changed considerably. Forests in the higher parts of the watershed have re-colonized areas that were previously bare of vegetation. Forest growth will eventually help stabilize the watershed's soils and decrease erosion by developing a protective canopy and active soil. Rural development has also helped stabilize soils and decrease erosion with the development of grass rangelands and revegetation of bare land. Thus, a continuation of land uses that promote vegetation should further reduce erosion rates and, in turn, decrease the watershed's sediment yield to the stream.

Stream pattern morphology is influenced by a series of integrated measurable and observable parameters. Using Rosgen's (1994) classification system, I found that the bedrock portions of North Potato Creek, at and above the Bethlehem site, have a very low sensitivity to disturbance and an excellent morphologic recovery potential. Sections of the stream that have been highly disturbed by damming sediment in the channel

(Monastery) now have a very high sensitivity to disturbance and a very high potential to erode stream materials. The Monastery reach of upper North Potato Creek has high rates of bank erosion and channel migration associated with Rosgen type C streams.

Streams are dynamic systems that can provide information on the activities of the watershed and hint at the complexity of the geomorphological processes at work. Upper North Potato Creek is basically a bedrock stream. Large quantities of sediment exist in its channel only in the reach above the sediment dam. This sediment, which was once soil on the slopes of the watershed, has been transported through the fluvial system and is now trapped behind the dam. The Monastery site lies in this section, where sediment extending kilometers up the valley changed this reach from a predominantly bedrock channel to an alluvial channel. Active sediment transport and deposition, erosion, and channel migration provide evidence that North Potato Creek is not in a steady state, and that it will continue to adjust until the driving and resisting forces are in equilibrium. Just as erosion rates take years to return to pre-reforestation levels (Harden and Mathews, 2000), stream processes will continue to adjust over a long period of time. If the dam were removed, I hypothesize that the stream would erode and transport sediment downstream, incising its channel and eventually restoring a bedrock channel to the entire length of North Potato Creek.

The merit in studying these environments is in the development of a better understanding of how watershed disturbances affect fluvial system dynamics. It is important to understand the current geomorphological processes at work in reforested watersheds to link morphological change in the stream system to land use change. In the case of North Potato Creek, this understanding can shape legislative decisions and land

use management that will promote the restoration and conservation of watershed and fluvial systems. Ultimately, it is important to study these areas so that land use managers can make well-informed decisions on stream restoration, land use practices, and be able to control or predict morphological change in the fluvial system based on changing land use.

Future Research

The North Potato Creek watershed is in a period of transition, with forests expanding over previously denuded slopes. Watershed processes have been affected by widespread anthropogenic changes that created a dynamic response and alteration of stream system morphology. Future research topics aimed at further understanding the implications of land use change and watershed restoration include:

- Mapping the extent of gullies and evaluating current geomorphic processes that are acting to either erode or stabilize them.
- Conducting a sediment budget for North Potato Creek to determine the current sediment yield of the watershed and to predict future sediment dynamics.
- Studying the effects of a pure pine forest in this dominantly hardwood environment, in terms of soil development, understory biological composition, seasonal erosion rates, and its effects on general erosion processes.
- Studying the effects of the southern pine beetle on the destruction of the basin's pure pine forests and evaluating the future of these forests, and consequences of their removal.

- Studying the composition and historical extent of riparian vegetation as a controlling mechanism affecting channel stability and sediment storage.
- Taking core samples of floodplain and stream sediment to determine if acid or heavy metal contamination persists from a history of mining-related disturbances.
- Conducting an environmental assessment of the sediment dam and estimating the quantity of sediment stored upstream of it.
- Measuring bank erosion at the Monastery site to determine stream migration rates across the floodplain.
- Measuring the rates of soil formation and erosion in different land use areas of Copper Basin, such as bare land, forested land, and sparsely vegetated land.

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- USGS Isabella quadrangle, Tennessee-Polk County, 7.5 minute series topographic map. Photorevised 1978.

Appendices

Appendix 1

Table A1.1 Ranking of Water Testing Parameters

Test factor	Result	Rank
Dissolved Oxygen	91-110% Sat.	4 (excellent)
	71-90% Sat.	3 (good)
	51-70% Sat.	2 (fair)
	<50% Sat.	1 (poor)
PH	4	1 (poor)
	5	1 (poor)
	6	3 (good)
	7	4 (excellent)
	8	3 (good)
	9	1 (poor)
	10	1 (poor)
Nitrate	5 ppm	2 (fair)
	20 ppm	1 (poor)
	40 ppm	1 (poor)
Phosphate	1 ppm	4 (excellent)
	2 ppm	3 (good)
	4 ppm	2 (fair)
Turbidity	0 JTU	4 (excellent)
	>0 to 40 JTU	3 (good)
	>40 to 100 JTU	2 (fair)
	>100 JTU	1 (poor)

Appendix 2

Cross-Section Data

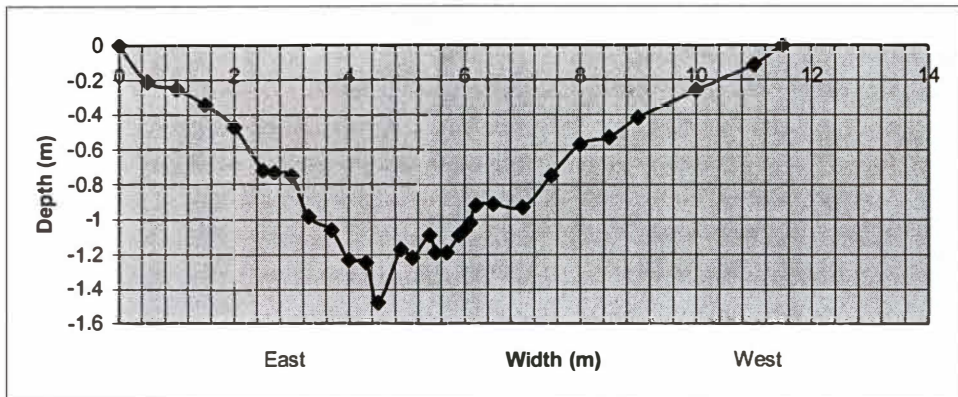


Figure A2.1 Cross-Section Profile, Prince 1 on 8/9/01

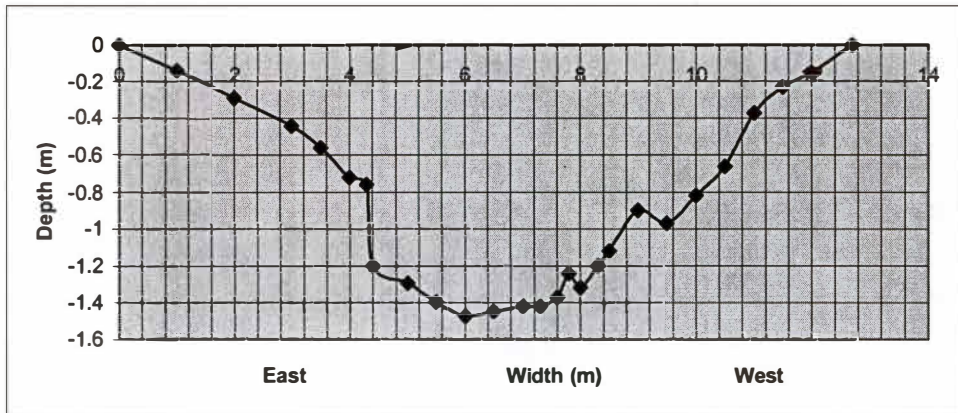


Figure A2.2 Cross-Section Profile, Prince 2 on 8/9/01

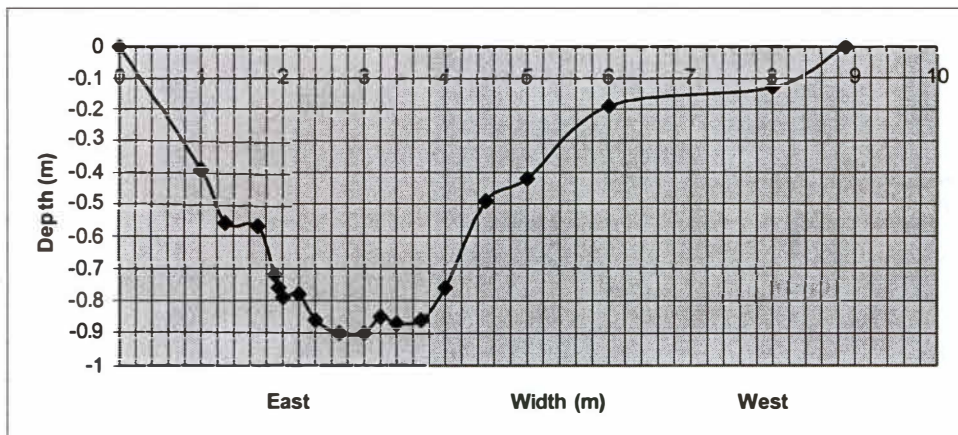


Figure A2.3 Cross-Section Profile, Prince 3 on 8/9/01

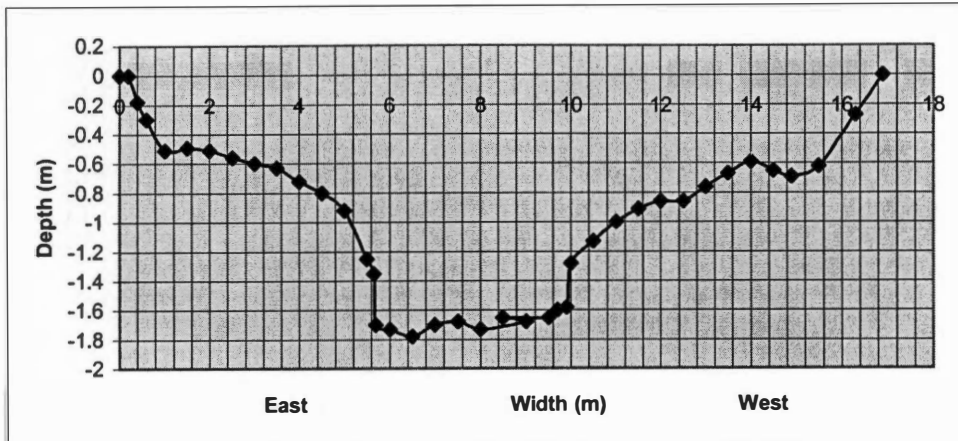


Figure A2.4 Cross-Section Profile, Bethlehem 1 on 8/9/01

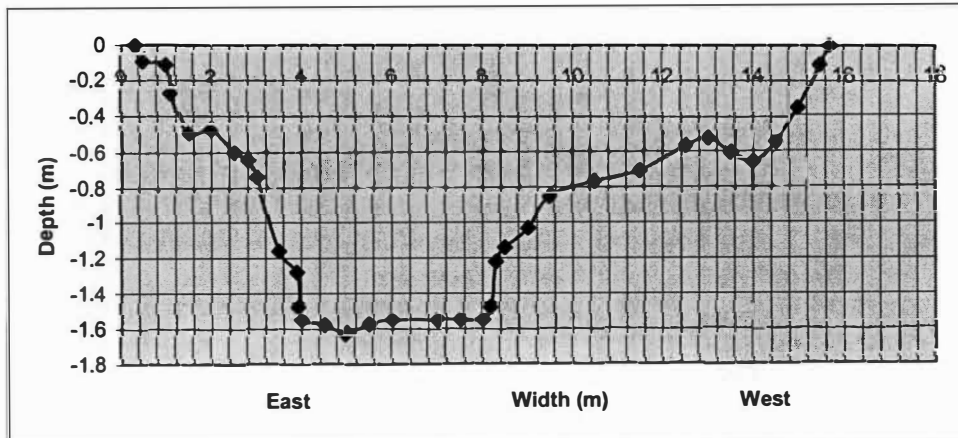


Figure A2.5 Cross-Section Profile, Bethlehem 2 on 8/9/01

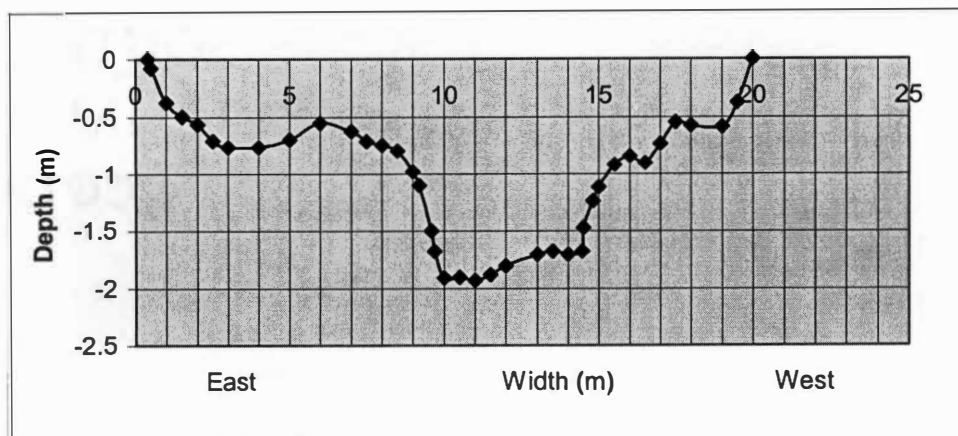


Figure A2.6 Cross-Section Profile, Bethlehem 3 on 8/9/01

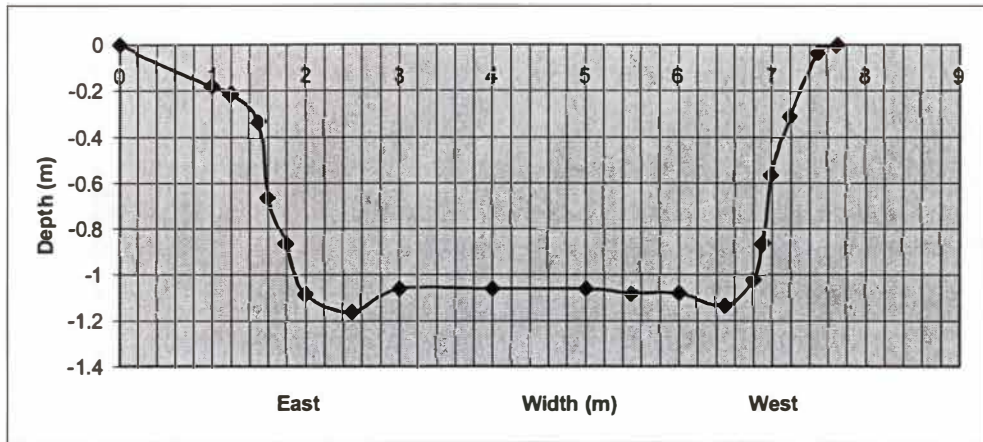


Figure A2.7 Cross-Section Profile, Monastery 1 on 8/9/01

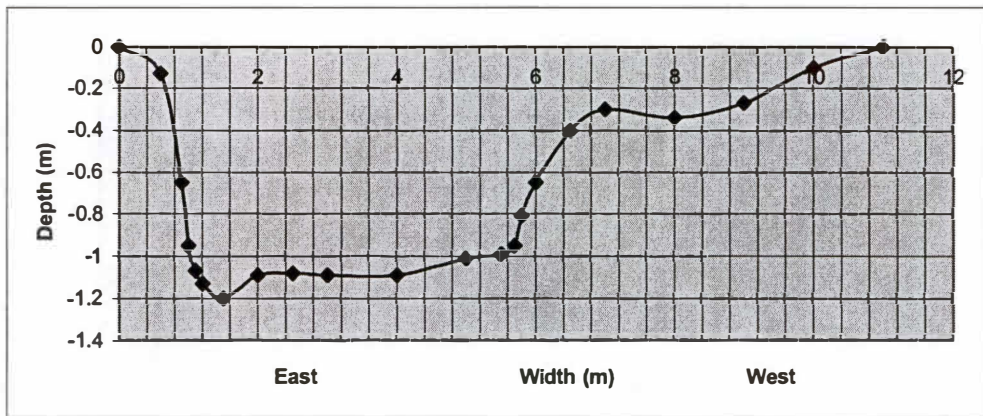


Figure A2.8 Cross-Section Profile, Monastery 2 on 8/9/01

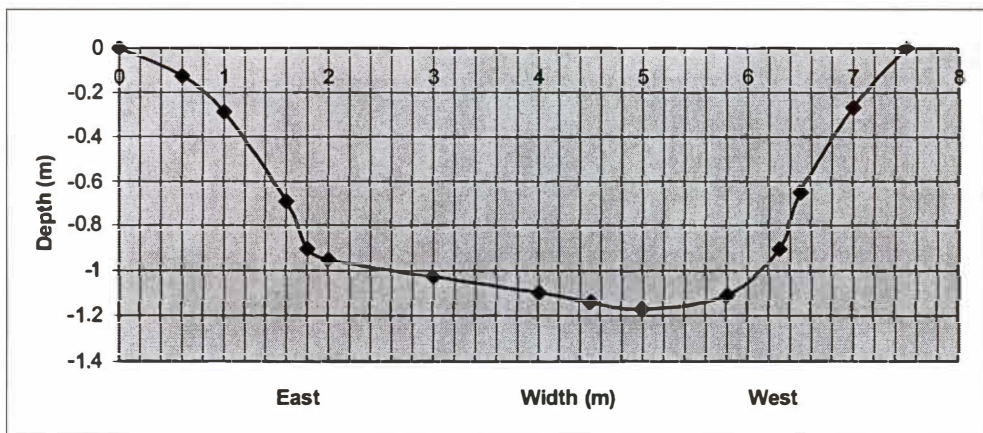


Figure A2.9 Cross-Section Profile, Monastery 3 on 8/9/01

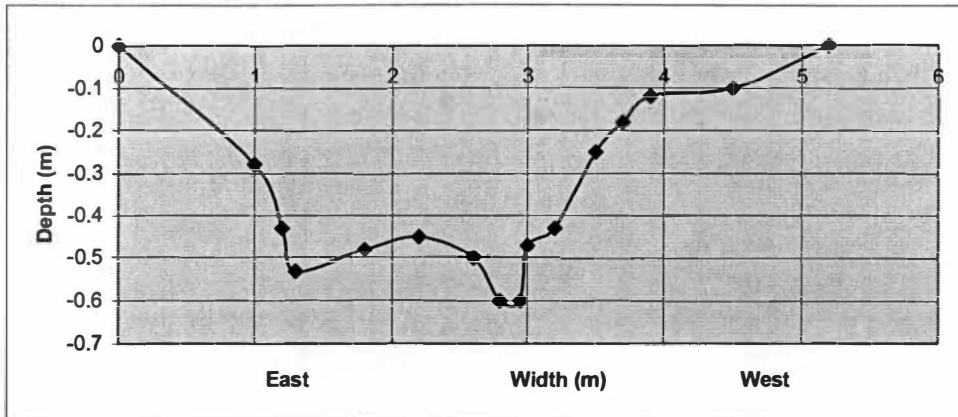


Figure A2.10 Cross-Section Profile, Prince 1 on 11/17/01

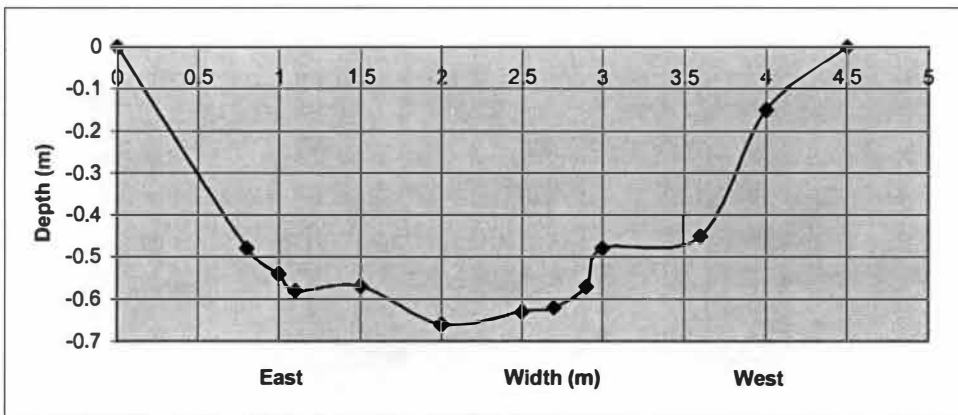


Figure A2.11 Cross-Section Profile, Prince 2 on 11/17/01

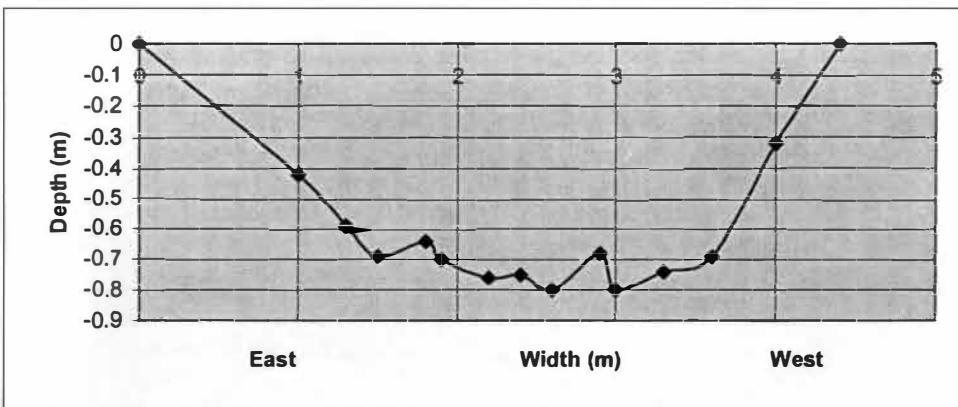


Figure A2.12 Cross-Section Profile, Prince 3 on 11/17/01

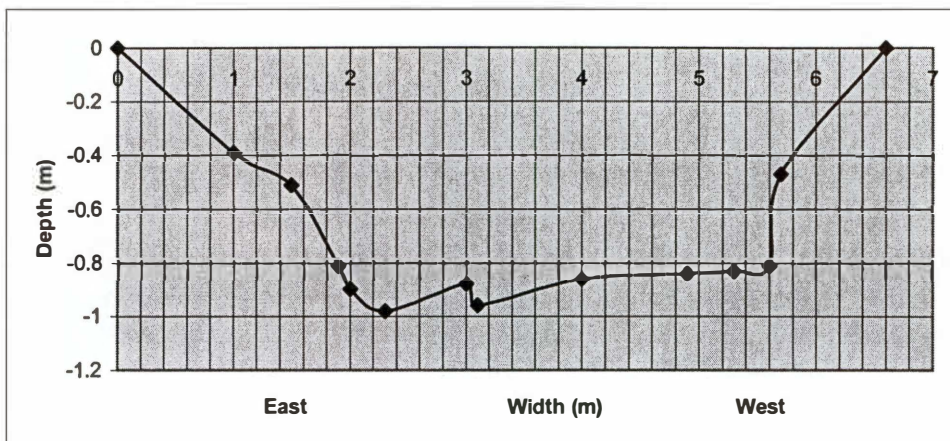


Figure A2.13 Cross-Section Profile, Bethlehem 1 on 11/17/01

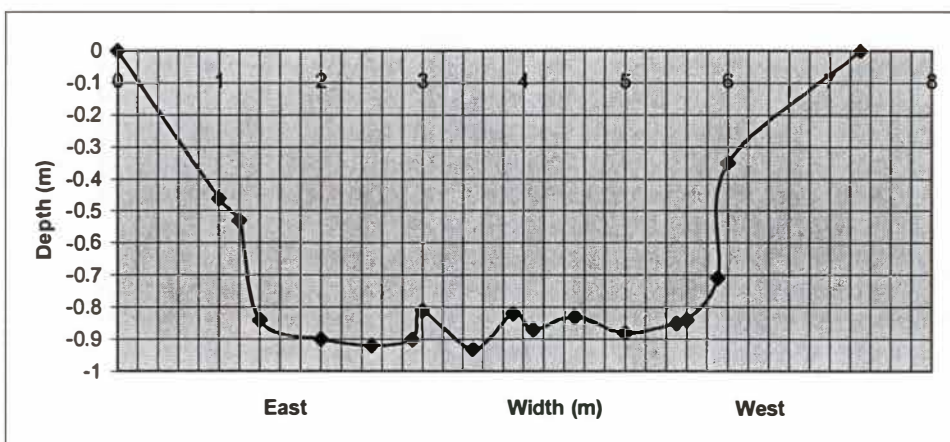


Figure A2.14 Cross-Section Profile, Bethlehem 2 on 11/17/01

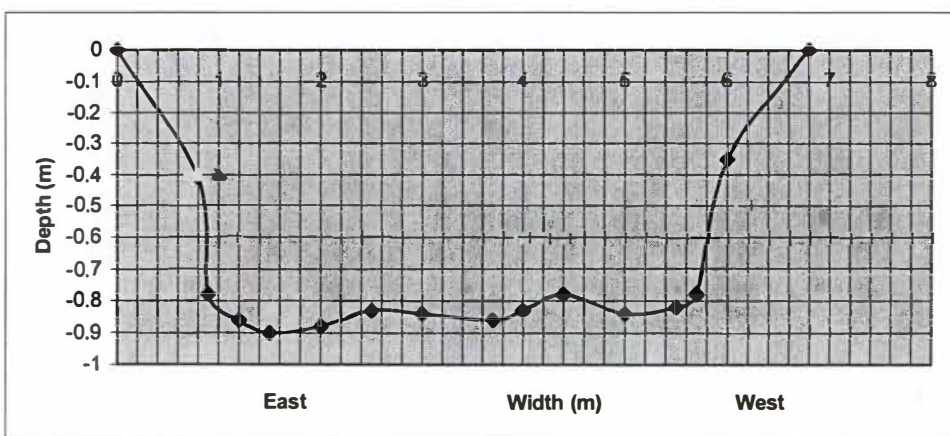


Figure A2.15 Cross-Section Profile, Bethlehem 3 on 11/17/01

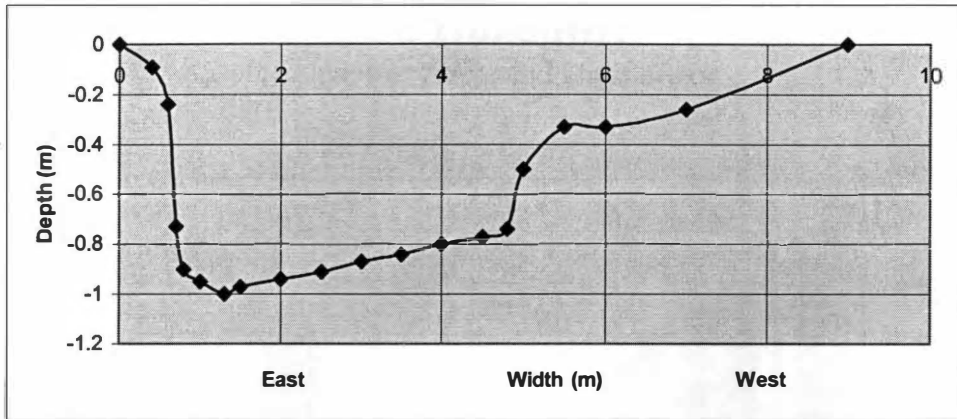


Figure A2.16 Cross-Section Profile, Monastery 1 on 11/17/01

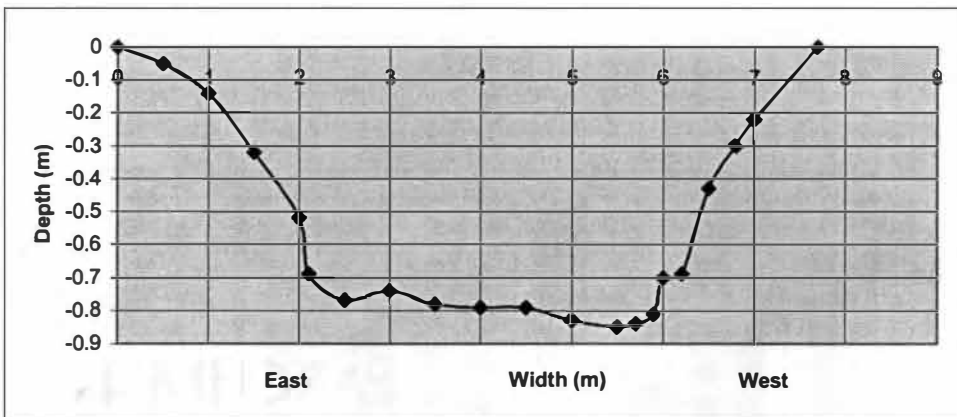


Figure A2.17 Cross-Section Profile, Monastery 2 on 11/17/01

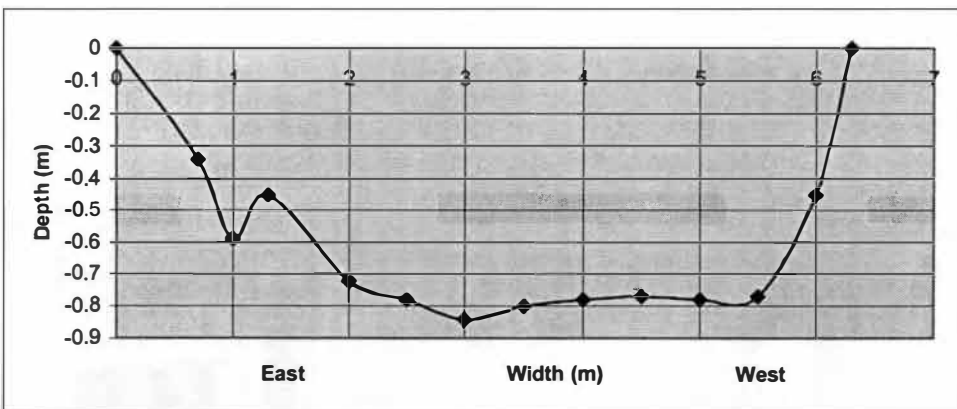


Figure A2.18 Cross-Section Profile, Monastery 3 on 11/17/01

Appendix 3

B-Axis and Laboratory Sieving

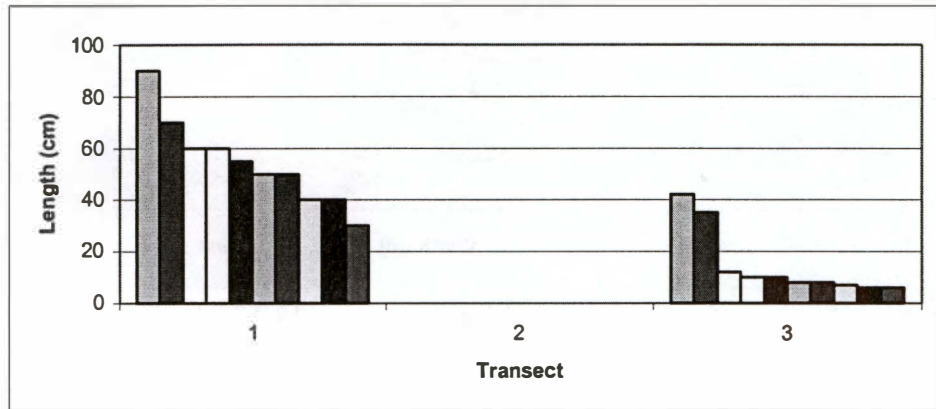


Figure A3.1 B-Axis at Prince on 11/17/01

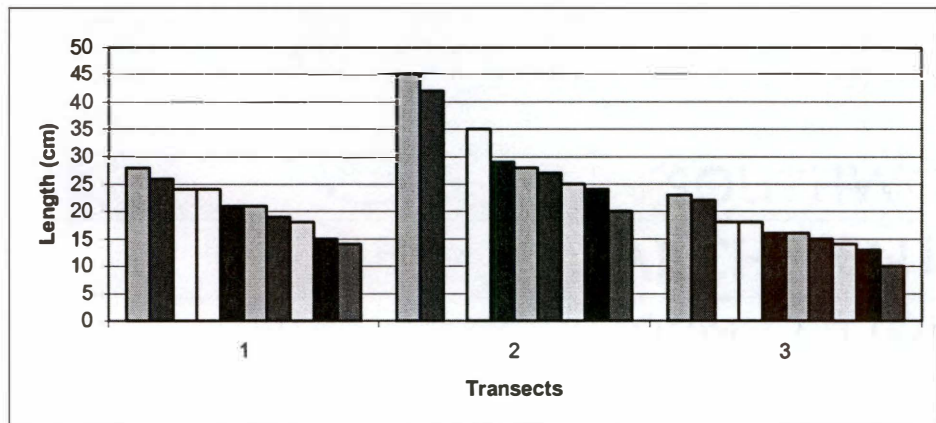


Figure A3.2 B-Axis at Bethlehem on 11/17/01

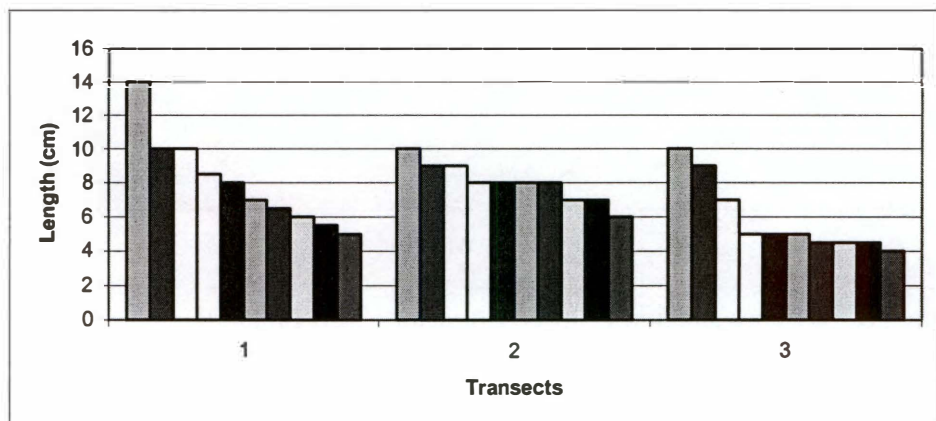


Figure A3.3 B-Axis at Monastery on 11/17/01

Table A3.1 Sand Fraction Sieving on 10/28/01, Prince

Sample	Sieve (mm)	Tot. wt. (g)	Sieve wt. (g)	Sample wt. (g)	% of tot. sample
P1	2	1045.5	486.5	559.0	63.78
	1	521.0	422.5	98.5	11.24
	0.5	511.5	391.0	120.5	13.75
	0.25	434.5	367.0	67.5	7.70
	0.125	378.5	353.5	25.0	2.85
	0.063	338.5	333.0	5.5	0.63
	Pan	368.5	368.0	0.5	0.06
	Total wt.=				876.5 100.00
P2	2	586.0	487.0	99.0	14.04
	1	587.0	422.0	165.0	23.40
	0.5	629.0	391.0	238.0	33.76
	0.25	509.5	367.0	142.5	20.21
	0.125	400.0	353.5	46.5	6.60
	0.063	344.5	333.0	11.5	1.63
	Pan	370.5	368.0	2.5	0.35
	Total wt.=				705.0 100.00
P3	2	1397.0	487.0	910.0	84.22
	1	496.5	422.0	74.5	6.89
	0.5	444.5	391.0	53.5	4.95
	0.25	396.0	367.0	29.0	2.68
	0.125	363.5	353.5	10.0	0.93
	0.063	336.0	333.5	2.5	0.23
	pan	368.5	367.5	1.0	0.09
	Total wt.=				1080.5 100.00
Tot Ave.	Sieve (mm)	total weight	total %		
	2	1568.0	58.90		
	1	338.0	12.70		
	0.5	412.0	15.48		
	0.25	239.0	8.98		
	0.125	81.5	3.06		
	0.063	19.5	0.73		
	pan	4.0	0.15		
	total wt	2662.0	100.00		

Table A3.2 Sand Fraction Sieving on 10/28/01, Bethlehem

Sample	Sieve (mm)	Tot. wt. (g)	Sieve wt. (g)	Sample wt. (g)	% of tot. sample
B1	2	1210.0	487.0	723.0	78.97
	1	463.5	422.0	41.5	4.53
	0.5	444.0	390.5	53.5	5.84
	0.25	431.0	367.0	64.0	6.99
	0.125	378.5	353.5	25.0	2.73
	0.063	339.0	333.0	6.0	0.66
	pan	370.0	367.5	2.5	0.27
Total wt.=				915.5	100.00
B2	2	654.0	487.0	167.0	23.49
	1	573.5	422.0	151.5	21.31
	0.5	583.0	391.0	192.0	27.00
	0.25	473.5	367.0	106.5	14.98
	0.125	418.5	353.5	65.0	9.14
	0.063	357.0	332.5	24.5	3.45
	pan	372.0	367.5	4.5	0.63
Total wt.=				711.0	100.00
B3	2	1137.0	487.0	650.0	73.36
	1	496.0	421.5	74.5	8.41
	0.5	463.0	391.0	72.0	8.13
	0.25	420.0	367.0	53.0	5.98
	0.125	380.0	353.0	27.0	3.05
	0.063	340.0	332.5	7.5	0.85
	pan	369.5	367.5	2.0	0.23
Total wt.=				886.0	100
Tot Ave. Sieve (mm) total weight total %					
	2	1540.0	61.29		
	1	267.5	10.65		
	0.5	317.5	12.64		
	0.25	223.5	8.90		
	0.125	117.0	4.66		
	0.063	38.0	1.51		
	pan	9.0	0.36		
total wt		2512.5	100.00		

Table A3.3 Sand Fraction Sieving on 10/28/01, Monastery

Sample	Sieve (mm)	Tot. wt. (g)	Sieve wt.	Sample wt.	% of tot. sample
M1	2	986.0	487.0	499.0	67.75
	1	488.5	420.5	68.0	9.23
	0.5	444.5	390.5	54.0	7.33
	0.25	412.5	366.5	46.0	6.25
	0.125	398.5	353.0	45.5	6.18
	0.063	351.0	333.0	18.0	2.44
	pan	373.0	367.0	6.0	0.81
	Total wt.=		736.5	100.00	
M2	2	839.0	487.0	352.0	48.35
	1	532.5	422.0	110.5	15.18
	0.5	599.0	391.0	208.0	28.57
	0.25	407.0	367.0	40.0	5.49
	0.125	365.0	353.5	11.5	1.58
	0.063	337.0	333.0	4.0	0.55
	pan	369.5	367.5	2.0	0.27
	Total wt.=		728.0	100.00	
M3	2	1069.0	487.0	582.0	68.23
	1	479.5	422.0	57.5	6.74
	0.5	464.0	391.0	73.0	8.56
	0.25	460.5	367.0	93.5	10.96
	0.125	391.0	353.5	37.5	4.40
	0.063	340.0	333.0	7.0	0.82
	pan	370.0	367.5	2.5	0.29
	Total wt.=		853.0	100.00	
Tot Ave.	Sieve (mm) total weight total %				
	2	1433.0	61.83		
	1	236.0	10.18		
	0.5	335.0	14.46		
	0.25	179.5	7.75		
	0.125	94.5	4.08		
	0.063	29.0	1.25		
	pan	10.5	0.45		
	total wt	2317.5	100.00		

Table A3.4 Sand Fraction Sieving on 12/3/01, Prince

Sample	Sieve (mm)	Tot. wt. (g)	Sieve wt.	Sample wt.	% of tot. sample
P1	2	581.0	487.0	94.0	11.76
	1	643.5	422.0	221.5	27.70
	0.5	728.0	391.0	337.0	42.15
	0.25	485.5	367.0	118.5	14.82
	0.125	374.5	353.5	21.0	2.63
	0.063	339.5	333.0	6.5	0.81
	pan	369.0	368.0	1.0	0.13
Total wt.=				799.5	100.00
P2	2	803.5	487.0	316.5	38.48
	1	607.5	422.0	185.5	22.55
	0.5	601.0	391.0	210.0	25.53
	0.25	462.5	367.0	95.5	11.61
	0.125	365.5	353.5	12.0	1.46
	0.063	336.0	333.0	3.0	0.36
	pan	368.0	368.0	0.0	0.00
Total wt.=				822.5	100.00
P3	2	494.0	487.0	7.0	0.87
	1	493.0	422.0	71.0	8.78
	0.5	758.0	391.0	367.0	45.36
	0.25	686.0	367.0	319.0	39.43
	0.125	394.0	353.5	40.5	5.01
	0.063	337.5	333.5	4.0	0.49
	pan	368.0	367.5	0.5	0.06
Total wt.=				809.0	100.00
Tot Ave.	Sieve (mm)	total weight	total %		
	2	417.5	17.17		
	1	478.0	19.66		
	0.5	914.0	37.60		
	0.25	533.0	21.93		
	0.125	73.5	3.02		
	0.063	13.5	0.56		
	pan	1.5	0.06		
total wt		2431.0	100.00		

Table A3.5 Sand Fraction Sieving on 12/3/01, Bethlehem

Sample	Sieve (mm)	Tot. wt. (g)	Sieve wt.	Sample wt.	% of tot. sample
B1	2	1179.0	487.0	692.0	84.75
	1	462.0	422.0	40.0	4.90
	0.5	432.0	390.5	41.5	5.08
	0.25	397.0	367.0	30.0	3.67
	0.125	362.5	353.5	9.0	1.10
	0.063	336.0	333.0	3.0	0.37
	pan	368.5	367.5	1.0	0.12
	Total wt.=		816.5	100.00	
B2	2	966.5	487.0	479.5	49.18
	1	624.5	422.0	202.5	20.77
	0.5	579.5	391.0	188.5	19.33
	0.25	441.5	367.0	74.5	7.64
	0.125	376.0	353.5	22.5	2.31
	0.063	338.5	332.5	6.0	0.62
	pan	369.0	367.5	1.5	0.15
	Total wt.=		975.0	100.00	
B3	2	1159.0	487.0	672.0	74.01
	1	477.0	421.5	55.5	6.11
	0.5	470.5	391.0	79.5	8.76
	0.25	436.0	367.0	69.0	7.60
	0.125	377.0	353.0	24.0	2.64
	0.063	339.0	332.5	6.5	0.72
	pan	369.0	367.5	1.5	0.17
	Total wt.=		908.0	100	
Tot Ave.	Sieve (mm) total weight total %				
	2	1843.5	68.29		
	1	298.0	11.04		
	0.5	309.5	11.47		
	0.25	173.5	6.43		
	0.125	55.5	2.06		
	0.063	15.5	0.57		
	pan	4.0	0.15		
	total wt	2699.5	100.00		

Table A3.6 Sand Fraction Sieving on 12/3/01, Monastery

Sample	Sieve (mm)	Tot. wt. (g)	Sieve wt.	Sample wt.	% of tot. sample
M1	2	1176.0	487.0	689.0	81.30
	1	470.0	422.0	48.0	5.66
	0.5	429.5	391.0	38.5	4.54
	0.25	409.5	366.5	43.0	5.07
	0.125	375.5	353.0	22.5	2.65
	0.063	337.5	333.0	4.5	0.53
	pan	369.0	367.0	2.0	0.24
Total wt.=				847.5	100.00
M2	2	544.5	487.0	57.5	6.93
	1	533.0	422.0	111.0	13.38
	0.5	725.5	391.0	334.5	40.33
	0.25	656.5	367.0	289.5	34.90
	0.125	385.0	353.5	31.5	3.80
	0.063	337.0	333.0	4.0	0.48
	pan	369.0	367.5	1.5	0.18
Total wt.=				829.5	100.00
M3	2	1515.5	487.0	1028.5	89.43
	1	456.5	422.0	34.5	3.00
	0.5	425.5	391.0	34.5	3.00
	0.25	399.0	367.0	32.0	2.78
	0.125	368.5	353.5	15.0	1.30
	0.063	337.5	333.0	4.5	0.39
	pan	368.5	367.5	1.0	0.09
Total wt.=				1150.0	100.00
Tot Ave.	Sieve (mm) total weight total %				
	2	1775.0	62.79		
	1	193.5	6.84		
	0.5	407.5	14.41		
	0.25	364.5	12.89		
	0.125	69.0	2.44		
	0.063	13.0	0.46		
	pan	4.5	0.16		
total wt		2827.0	100.00		

Vita

Donald J. Kemp, Jr. was born in La Jolla, CA on November 23, 1976. He was raised in Leucadia, CA and went to grade school at Capri Elementary. He attended Diegueno Jr. High and graduated from San Dieguito High School in 1995. From there, he went to the University of California, Los Angeles and received his BA in Environmental Studies from the department of Geography in 1999. He received his MS from the department of Geography, at the University of Tennessee, Knoxville in 2002.

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