Abstract

LEMONDS, RODNEY WADE. Delineating River Bottom Substrate using Very High-Resolution Digital Imagery derived from Large Scale Aerial Photography. (Under the direction of Siamak Khorram.)

Progress Energy is currently relicensing the Tillery and Blewett Falls developments (i.e., Yadkin-Pee Dee River Hydroelectric Project No. 2206) with the Federal Regulatory Commission (FERC). As part of the relicensing process, Progress Energy established Resource Work Groups (RWG) during May 2003 to identify environmental issues associated with Project operations and develop study plans, if necessary, specific to Project lands and associated lakes and tailwater areas. The Water Resources Work Group identified the need to document existing gravel and cobble bars in the immediate tailwater areas below the Tillery and Blewett Falls Hydroelectric Plants and determine the stability or persistence of these substrate types through time (i.e., Progress Energy [2004] and Water RWG Issue No. 10, “Sediment Transport”).

Characterizing substrates is important for three reasons. First, many fish and other aquatic species require specific substrate types for spawning and inhabitation. Gravel and cobble, in particular, provide a substantial amount of surface area for deposition of eggs into redds or adhering to exposed surfaces. These substrate types also provide the micro-habitat conditions and interstitial spaces needed by many fish and aquatic invertebrate species. Second, the substrate composition determines the roughness of stream channel, and roughness has a large influence on the channel hydraulics (water depth, width, and current velocity) of stream habitat. Third, substrate composition, including the degree of embeddedness, can indicate localized and broader watershed anthropogenic influences on stream habitat quality. For

example, small particle composition may reflect land surface disturbances such as forestry and agriculture practices (Bain and Stevenson 1999).

The study objective was to assess the distribution and extent of the existing substrate types, including gravel and cobble bars, in the immediate tailwater areas below the Tillery and Blewett Falls Hydroelectric Plants. Each substrate type was classified and delineated from very high-resolution digital imagery derived from large scale aerial photography using Geographical Information System (GIS) software. The study also evaluated the spatial patterns of classified substrate types within each power plant tailwater study area.

Low altitude, large scale aerial photography was acquired with a fixed wing aircraft at each study area during February 2005. The aerial photographs were scanned, orthorectified with established ground elevation control data, and then composited to produce one georeferenced mosaic digital image for each study area. Substrates were delineated and classified in a digital environment using GIS software. A reference data accuracy assessment was conducted by comparing known field substrate classifications from GPS established transects to the classified GIS electronic image.

A total of 1,261 substrate type areas encompassing 296 acres were mapped within the Tillery and Blewett Falls Hydroelectric Plant tailwater study areas. Bedrock outcrops, or exposed bedrock, were the most frequently mapped habitat category numerically (1,106 areas) but only comprised 16 percent of total mapped acreage. Smaller particle substrates or mixtures of small and large particle substrates (e.g., cobble/gravel, bedrock/boulder/cobble, and cobble/gravel/boulder) were the most prevalent on an area basis within both study areas. Collectively, they comprised 76 percent of the total study area.

Based on these results, cobble and gravel substrates or mixtures of these substrates with larger substrates such as boulder and bedrock were prevalent in the immediate tailwater areas below the Tillery and Blewett Falls Hydroelectric Plants. There was no evidence of substantial scouring or armoring of the river channel given that areas with smaller substrate particles or mixtures of smaller and coarser particle substrates were frequently mapped within each power plant tailwater area.

Delineating River Bottom Substrate using Very High-Resolution Digital Imagery derived from Large Scale Aerial Photography

by
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BIOGRAPHY

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Background

Received a B.S. in Biology from Appalachian State University, Boone, North Carolina in 2001. Since 2001, he has been working and continuing his education in pursuit of a M.S. Forestry from North Carolina State University.

From 2001 to 2005 he served as an Environmental Specialist for Progress Energy, a Fortune 250 utility company, based in Raleigh, North Carolina. During his tenure with Progress Energy he worked on a number of fisheries / wildlife projects which included population assessments, 316b and Hydrorelicensing studies, as well as water quality / chemistry sampling in streams, rivers, and lakes associated with Progress Energy's fossil and nuclear powered generation facilities. In 2004 he was in charge interpreting and negotiating the NPDES permitting for 13 power plant facilities. In all of these projects he provided GPS mapping expertise as well as GIS mapping and analysis.

While at Progress Energy he established a GIS / GPS user group and trained over 20 employees on GPS data collection and GIS analysis. Many departments and several major projects were supported with this technology throughout the company.

Current Activities

-GIS consulting to Progress Energy, other utilities, and Environmental / Engineering firms

-Working for InVision Inc. (Executive Staffing Firm) Raleigh, NC

TABLE OF CONTENTS

Section	Title	Page No.

LIST OF FIGURES

LIST OF TABLES

Acronym List

Federal/State Agencies

Advisory Council on Historic Preservation (ACHP)
Federal Aviation Administration (FAA)
Federal Energy Regulatory Commission (FERC)
National Park Service (NPS)
National Marine Fisheries Service (NMFS)
National Oceanic and Atmospheric Administration (NOAA)
National Resource Conservation Service (NRCS) formerly known as Soil Conservation Service
National Weather Service (NWS)
North Carolina Department of Environment and Natural Resources (NCDENR)
North Carolina Environmental Management Commission (NCEMC)
North Carolina Department of Natural and Economic Resources, Division of Environmental Management (NCDEM)
North Carolina Division of Parks and Recreation (NCDPR)
North Carolina Division of Water Resources (NCDWR)
North Carolina Division of Water Quality (NCDWQ)
North Carolina Natural Heritage Program (NCNHP)
North Carolina State Historic Preservation Officer (NCSHPO)
North Carolina Wildlife Resources Commission (NCWRC)
South Carolina Department of Natural Resources (SCDNR)
South Carolina Department of Health and Environmental Control (SCDHEC)
State Historic Preservation Office (SHPO)
U.S. Army Corps of Engineers (ACOE)
U.S. Department of Interior (DOI)
U.S. Environmental Protection Agency (USEPA)
U.S. Fish and Wildlife Service (USFWS)
U.S. Geological Survey (USGS)
U.S. Department of Agriculture (USDA)
U.S. Forest Service (USFS)

Other Entities

Alcoa Power Generating, Inc., Yadkin Division (APGI)
Appalachian State University (ASU)
Progress Energy (Progress)
University of North Carolina at Chapel Hill (UNCCH)

Facilities/Places

Yadkin - Pee Dee River Project (entire two-development project including both powerhouses, dams and impoundments)
Blewett Falls Development (when referring to dam, powerhouse and impoundment)
Blewett Falls Dam (when referring to the structure)
Blewett Falls Hydroelectric Plant (when referring to the powerhouse)
Blewett Falls Lake (when referring to the impoundment)
Tillery Development (when referring to dam, powerhouse and impoundment)
Tillery Dam (when referring to the structure)
Tillery Hydroelectric Plant (when referring to the powerhouse)
Lake Tillery (when referring to the impoundment)

Documents

401 Water Quality Certification (401 WQC)
Draft Environmental Assessment (DEA)
Environmental Assessment (EA)
Environmental Impact Statement (EIS)
Final Environmental Assessment (FEA)
Initial Consultation Document (ICD)
Memorandum of Agreement (MOA)
National Wetland Inventory (NWI)
Notice of Intent (NOI)
Notice of Proposed Rulemaking (NOPR)
Preliminary Draft Environmental Assessment (PDEA)
Programmatic Agreement (PA)
Scoping Document (SD)
Shoreline Management Plan (SMP)

Laws/Regulations

Clean Water Act (CWA)
Code of Federal Regulations (CFR)
Electric Consumers Protection Act (ECPA)
Endangered Species Act (ESA)
Federal Power Act (FPA)
Fish and Wildlife Coordination Act (FWCA)
National Environmental Policy Act (NEPA)
National Historic Preservation Act (NHPA)

Terminology

Alternative Relicensing Process (ALP)

Cubic feet per second (cfs)
Degrees Celsius (C)
Degrees Fahrenheit (F)
Dissolved oxygen (DO)
Feet (ft)
Gallons per day (gpd)
Geographic Information Systems (GIS)
Gigawatt Hour (GWh)
Global Positioning System (GPS)
Grams (g)
Horsepower (hp)
Kilogram (kg)
Kilowatts (kW)
Kilowatt-hours (kWh)
Mean Sea Level (msl)
Megawatt (MW)
Megawatt-hours (MWh)
Micrograms per liter (μg/L)
Milligrams per liter (mg/L)
Millimeter (mm)
Million gallons per day (mgd)
National Geodetic Vertical Datum (NGVD)
National Wetlands Inventory (NWI)
Non-governmental Organizations (NGOs)
Ounces (oz.)
Outstanding Remarkable Value (ORV)
Parts per billion (ppb)
Parts per million (ppm)
Pounds (lbs.)
Power Factor (p.f.)
Probable Maximum Flood (PMF)
Project Inflow Design Flood (IDF)
Rare, Threatened, and Endangered Species (RTE)
Ready for Environmental Assessment (REA)
Resource Work Groups (RWG)
Revolutions per Minute (rpm)
Rights-of-way (ROW)
Stakeholders (federal and state resource agencies, NGOs, and other interested parties)

Section 1 – Introduction

Progress Energy Carolinas, Inc. (Progress Energy) also known as Carolina Power & Light, a subsidiary of Progress Energy, owns and operates the Yadkin-Pee Dee River Project (Project), located on the Yadkin-Pee Dee River in North Carolina. The project consists of the Tillery Development and the Blewett Falls development, which have licensed capacities of 84 and 24.6 megawatts (MW) respectively. The Yadkin - Pee Dee River Project (Project No. 2206) is operated under a license issued by the Federal Energy Regulatory Commission (FERC) which expires on April 30, 2008. FERC regulations require Progress Energy to file an application to relicense the Project by April 30, 2006. As part of the relicensing process, Progress Energy established Resource Work Groups (RWG) during May 2003 to identify environmental issues associated with Project operations and develop study plans, if necessary, specific to Project lands and associated lakes and tailwater areas. The Water RWG identified the need for a sediment transport study to be conducted in the Project tailwater areas (i.e., Progress Energy [2004] and Water RWG Issue No. 10 “Sediment Transport”).

Dams and the operation of such hydroelectric facilities are believed to inhibit the natural migration of smaller substrates (gravel and cobble) downstream. Gravel and cobble recruitment downstream of each hydroelectric dam was mentioned by RWG members as a potential issue due to its potential impact on aquatic resources. This substrate is vital habitat for inhabitation and spawning of aquatic organisms (Collier et al. 1996). Aquatic resources include resident fish species, migratory fish species, and benthic macroinvertebrates, including mussel fauna. Terrestrial wildlife also utilize the tailwaters / river for habitat, feeding, and wetland habitats.

An abundance of native and non-native resident fish species (both game and non-game), mussels, and macroinvertebrates, inhabit waters of the Project area. A number of state- or federal-listed rare, threatened and endangered fish and mussel species inhabit the waters of the Pee Dee River. These species include Shortnose sturgeon (*Acipenser brevirostrum*), Atlantic sturgeon (*Acipenser oxyrhincus*), Robust redhorse (*Moxostoma robustum*), Carolina redhorse (undescribed *Moxostoma* species), Highfin carpsucker (*Carpiodes velifer*), Carolina heel splitter (*Lasmigona decorata*), Roanoke slabshell (*Elliptio roanokensis*), Eastern pondmussel (*Ligumia nasuta*), Eastern lampmussel (*Lampsilis radiata radiata*), Creeper (*Strophitus undulatus*), Alewife floater (*Anodonta implicata*), and Yellow lampmussel (*Lampsilis cariosa*) (Progress Energy 2003).

There are seven species of migratory fish found in the lower Pee Dee River. These species include American eel (*Anguilla rostrata*), American shad (*Alosa sapidissima*), Atlantic sturgeon (*Acipenser oxyrhincus*), Shortnose sturgeon (*Acipenser brevirostrum*), Hickory shad (*Alosa mediocris*), Blueback herring (*Alosa aestivalis*), and Striped bass (*Morone saxatilis*) (Progress Energy 2003). Migratory fish are of special concern because the Blewett Falls Hydroelectric Dam is the last dam on the Yadkin-Pee Dee River and the first obstruction these fish encounter when migrating upstream from the Atlantic Ocean.

Based on visual observations, Progress Energy contended that the amount of gravel/cobble (i.e., smaller particle substrates) present below each dam did not appear to be a limiting factor for inhabitation or spawning by fish or other aquatic organisms, such as mussels or other macroinvertebrate species. However, after further discussions at Water RWG meetings, Progress Energy agreed to conduct an empirical-based study to determine the distribution and extent of all substrate types, including gravel and cobble, in the immediate tailwater areas below the Tillery and Blewett Falls Hydroelectric Plants.

Several methods were evaluated while planning this study. A visual survey was conducted initially to get an idea of what type of substrates were present. This was a quick way to determine if smaller substrates existed but quantification of such a survey was difficult and not comprehensive. Different types of conventional field surveys such as random sample and cross-section transects were considered. These methods would provide a quantifiable approach but to achieve the detail needed the number of sample points or transects required would be too costly. The method selected would need to completely map the study area, provide a resolution / minimum mapping unit of less than one foot, and be in a digital format compatible with Geographic Information System (GIS) software.

Based on these requirements, a remote sensing technique was believed to be the method of choice. Satellite images would provide a cost-effective approach in digital format but current technology did not provide the resolution needed. The best satellite resolution available at the time of this survey was 1 meter. Aerial photography could meet the resolution requirements and comprehensively capture the study area. Acquisition of the photography was cost-effective but only hard copy photographs were available. Current digital camera technology was limited to a resolution of 2 meters so it was not an option.

Among these options, it was decided to acquire low altitude aerial photography and scan them into digital format. This was a cost effective approach that provided complete coverage of the study area and control of the acquisition time and scale (i.e. altitude). To get the data into a GIS usable format, the photographs were scanned. The result was very high-resolution digital imagery derived from large scale photography. For the purpose of this study, these images will be referred to from here on as very high-resolution digital imagery.

Section 2 - Study Objectives

The objective of this research was to determine if very high-resolution digital imagery could provide a detailed characterization of the aquatic habitat substrates found in the immediate tailwater areas below the Tillery and Blewett Falls Hydroelectric Plants. The immediate tailwater area encompassed the entire river channel from the hydroelectric power plant and dam extending at least one linear mile downstream. River bottom substrates are vital for inhabitation and spawning by fish or other aquatic organisms, such as mussels or other macroinvertebrate species (Collier, Webb, and Schmidt 1996).

The specific objectives of this study were to determine if very high-resolution digital imagery could: (1) provide a detailed characterization of the aquatic habitat substrate types (i.e., substrate types and frequency of occurrence) below the Tillery and Blewett Falls Hydroelectric Plants, with emphasis on smaller substrate types such as sand, gravel, and cobble; (2) quantify each substrate type on an area basis; and (3) provide a repeatable GIS-based methodology for substrate mapping and classification.

This particular study was needed to determine if the Tillery and Blewett Falls Hydroelectric Plants were preventing the recruitment of smaller substrates downstream. No historical documentation of the substrate composition existed for these study areas. The results of this study will be compared to future studies to detect change of substrate composition and distribution. The results of this study can also be used in conjunction with water quality and aquatic organism data to assess any possible correlations.

Section 3 - Site Description

3.1 General Locale Description

The Yadkin-Pee Dee River Project is located in south-central North Carolina (Figure 3-1). The Yadkin-Pee River basin is the second largest in North Carolina covering 7,213 mi2 as measured at the North Carolina-South Carolina state line (North Carolina Division of Water Quality [NCDWQ] 2002). The Yadkin-Pee Dee River originates near the town of Blowing Rock and flows northeasterly for approximately 100 miles from the Blue Ridge Mountains into the Piedmont physiographical region. As the river turns southeast, it enters an area in Central North Carolina that has experienced considerable urban growth. This growing urban area is known as the Piedmont Crescent (Appalachian State University [ASU] 1999). Just to the south of the Piedmont Crescent, the region enters an area known as the Uwharrie Lakes Region. This region is named for the chain of six reservoirs located along this reach of the Yadkin-Pee Dee River, two of which are Lake Tillery and Blewett Falls Lake. It is in this region that the Uwharrie River joins the Yadkin River at the upper end of Lake Tillery to form the Pee Dee River.

The flow of the Yadkin-Pee Dee River is regulated by a federal flood control development and six hydroelectric developments on the main stem of the river (Figure 3-1). The first development, traveling downstream from the headwaters, is the W. Scott Kerr Dam, a federal flood control project. The next four developments make up the Yadkin Project. These four hydroelectric developments, High Rock, Tuckertown, Narrows, and Falls (FERC No. 2197), are owned and operated by Alcoa Power Generating, Inc., Yadkin Division (APGI), and are located along a 38-mile stretch of the river (River Mile [RM] 272 to 234). High Rock Reservoir is operated as a storage reservoir and serves as the principal storage and water regulation facility for the lower Yadkin-Pee Dee River (APGI 2002).

The next two hydroelectric developments on the river, located at RMs 218 and 188 are the Tillery and Blewett Falls developments, which constitute Progress Energy's Yadkin-Pee Dee River Project (FERC No. 2206). The primary purpose of this Project is to provide peaking and load-following generation. Its ability to provide such benefits and meet other flow-related needs is largely dependent on the schedule of flows being released from upstream reservoirs. Currently, an agreement between APGI and Progress Energy governs the release of waters from APGI developments to Progress Energy developments. Additional Project-related information is discussed in the Initial Consultation Document for the Project (Progress Energy 2003).

3.1.1 Tillery Development

The Tillery Hydroelectric Development is located in Montgomery and Stanly counties, approximately four miles west of Mount Gilead, North Carolina. Construction of the Tillery Development began in 1926, and the power plant was placed into service during 1928. The powerhouse contains four vertical shaft turbines. The Tillery impoundment, also known as Lake Tillery, extends upstream to the tailrace of the Falls Project powerhouse owned and operated by Alcoa Power Generation Inc. (APGI).

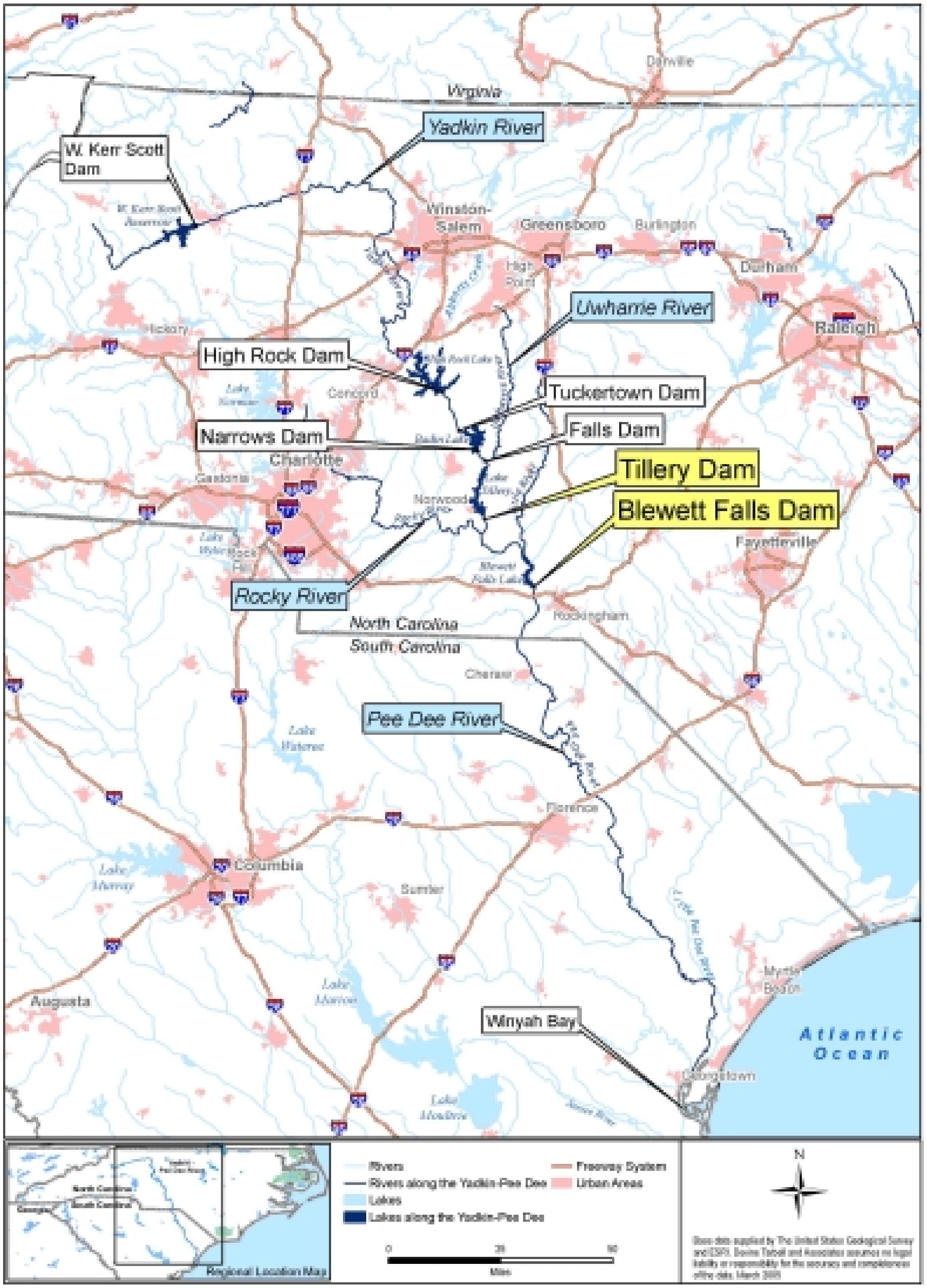

Figure 3-1 Yadkin-Pee Dee River Project (FERC No. 2206) location map.

Lake Tillery extends approximately 15 miles upstream to the tailrace of the Falls Project powerhouse. At the normal maximum operating elevation of 277.3 ft[1], Lake Tillery has an average depth of 23.6 ft and a maximum depth of approximately 71 ft at the dam. The depth of the intake extends from 39 to 62 ft (12 to 19 m) below the lake surface at normal maximum pool elevation. The lake has a reservoir surface area of approximately 5,697 acres and a total volume of 5.85 x 109 ft^3. The average retention time for the lake is approximately 8.3 days at normal maximum operating pool elevation based on 1983 to 2000 inflow data. Lake Tillery is dendritic in shape with several large tributary arms (e.g., Mountain Creek, Jacobs Creek, and Cedar Creek complex). The lake has a shoreline length of approximately 118 miles with 55 percent of the shoreline in residential or commercial development (Progress Energy 2003). The remaining shoreline areas are forested, pasture, or agricultural.

The inflows into Lake Tillery consist primarily of the outflow from the APGI's Falls Development and the inflow from the Uwharrie River. The Uwharrie River contributes about 8 percent of total inflow volume, based on watershed area size. The current Progress Energy license allows for drawdowns at Lake Tillery of up to 22 ft below full pond. However, over the past several years, Progress Energy has voluntarily made its best efforts to operate Lake Tillery within a 4-ft range under normal circumstances and much of the time operating within a 2-ft range except during FERC-required inspection and maintenance periods (12-ft drawdown) (Progress Energy 2003). Outflows from the Lake Tillery flow into Blewett Falls Lake after passing through a 17-mile reach of the Pee Dee River. Under normal circumstances, it takes

[1] NAVD 88 datum. Unless otherwise noted, all data are NAVD 88 datum. The NAVD 88 datum is 0.9 ft lower than the 1929 NGVD datum (NAD 29).

approximately eight hours for releases from the Tillery Hydroelectric Plant to be observed at the Blewett Falls Hydroelectric Plant powerhouse (Progress Energy 2003).

3.1.2 Blewett Falls Development

The Blewett Falls Hydroelectric Development is located in Richmond and Anson counties approximately six miles west of Rockingham, North Carolina. The Blewett Falls Dam is located approximately 17 miles north of the North Carolina-South Carolina State line. The powerhouse contains six horizontal shaft turbines. The Blewett Falls impoundment, also known as Blewett Falls Lake, extends approximately 11 miles upstream from the dam. Construction of the Blewett Falls Development began in 1905 and was completed in June 1912. The normal maximum pool elevation is 177.2 ft[1] and the reservoir extends approximately 11 miles upstream. The average lake depth is 10.8 ft and the maximum depth is approximately 35 ft. The depth of the intake extends from 20 to 33 ft (6 to 10 m) below the lake surface at normal maximum pool elevation. The surface area of the lake at normal operating level is approximately 2,866 acres with a total volume of 1.35 x 109 ft^3. The mean hydraulic retention time is 1.9 days at normal maximum operating pool elevation based on 1983 to 2000 inflow data. Blewett Falls Lake is relatively narrow with few large tributary arms. The lake has a shoreline length of approximately 46 miles including mainland and island shoreline areas. The Blewett Falls Lake shoreline is relatively undeveloped with surrounding lands mainly forested (Progress Energy 2003). Some limited residential development exists along the lake shoreline, primarily in the lower lake.

The Blewett Falls Hydroelectric Plant is operated in coordination with the upstream Tillery Hydroelectric Plant. The hydraulic capacity of Blewett Falls Lake is significantly less than Lake Tillery; therefore, Blewett Falls Lake must anticipate flows from Lake Tillery generation and begin generating in advance of flows reaching the lake. The normal operation of the Blewett Falls Hydroelectric Plant results in a daily drawdown of approximately 2 to 3 ft below the normal maximum operating level. This drawdown provides storage capacity needed to regulate flows from Lake Tillery. The Blewett Falls Hydroelectric Plant generating units normally begin operation at the same time that the Tillery Hydroelectric Plant begins generation. Generation at Blewett Falls Hydroelectric Plant is usually stopped by midnight to allow the reservoir to refill. This operation is consistent year round and varies only with seasonal availability of water (Progress Energy 2003).

Periodic maintenance can require the lowering of the reservoir levels at both power plants. At Lake Tillery, drawdowns are typically associated with the maintenance of the steel spillway gates, repairs to the trashrack system, or repairs to the upstream slope of the earthen embankment. Drawdowns required at the Blewett Falls Lake are similar to the Lake Tillery except that the most frequent maintenance requirement is to service the 4-ft-high, wooden flashboards atop the spillway.

During periods of high flow, such as those encountered with the passing of tropical storm systems during September of 2004, damage or loss of these flashboards may occur and repairs require the lake to be drawn down about 4 to 5 ft over a period of time (Progress Energy 2003).

3.2 Study Sites for Substrate Characterization

3.2.1 Pee Dee River Tailwater Area below Tillery Hydroelectric Plant

The study area for the Pee Dee River below the Tillery Hydroelectric Plant was a 1-mile (1.61 km) segment of the tailwater area immediately below the power plant (Figure 3-2). This tailwater area segment can be qualitatively characterized as consisting of shallow (1 to 2 m depth) runs and shoals with substrate of varying sizes, including bedrock outcroppings. Channel widths ranged from 527 to 1,271 ft with an average width of 903 ft within the study area.

3.2.2 Pee Dee River Tailwater Area below Blewett Falls Hydroelectric Plant

The study area for the Pee Dee River below the Blewett Falls Hydroelectric Plant was a 1.5-mile segment (2.41 km) of the tailwater area immediately below the power plant with the lower study boundary located at the Cartledge Creek confluence (Figure 3-2). This tailwater area segment can be qualitatively characterized as consisting of shallow to moderately deep runs and shoal habitat (1 to 3 m depth) with an island (i.e., Big Island) and side channel complex. There is a wide range of substrate sizes present in the study area and bedrock outcroppings are quite common. Channel widths ranged from 661 to 1,538 ft with an average width of 976 ft within the main river channel in the study area. The powerhouse tailrace channel ranged in width from 248 to 600 ft with an average width of 442 ft.

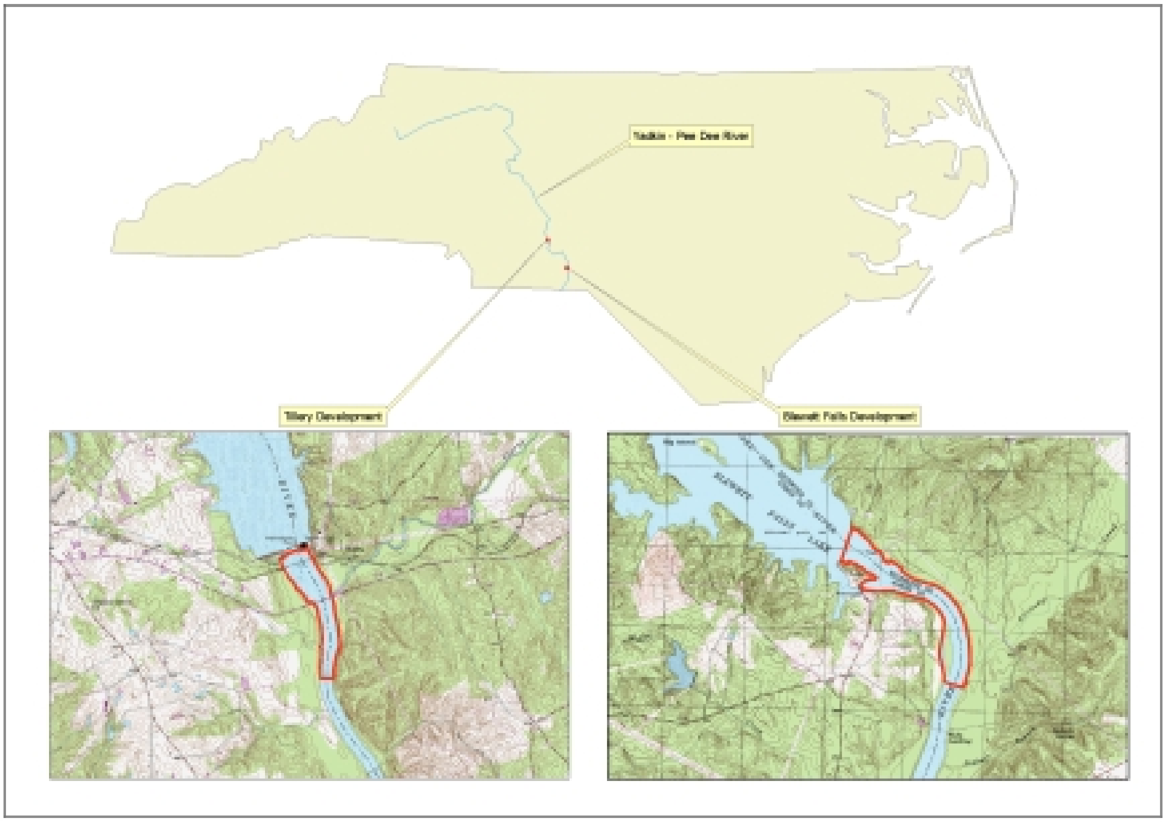

Figure 3-2 **Substrate characterization study sites (red outlined areas) below the Tillery and Blewett Falls Hydroelectric Plants (based on 1:24,000 scale USGS topographic)**

Section 4 – Methods

The field data collection phase of the study was conducted during January through March 2005. Field data collected included aerial photography of each study site followed with reference data surveys of substrate types using a transect-grid method. The study was divided into four stages: (1) photography acquisition which consisted of low altitude (500 ft) aerial photography of the study sites under low flow (i.e., no power plant operations and minimum dam spillage); (2) image processing which included scanning the aerial photographs into a photo-mosaic composite of the study site, orthorectifying the imagery to known ground control points, and georeferencing the images to a common latitude-longitude coordinate system; (3) substrate classification that consisted of GIS digitization of the river bottom substrates from the very high-resolution digital imagery and reference data using a scientifically accepted substrate classification system; and (4) accuracy assessment which consisted of developing a quantifiable estimate of the accuracy of the GIS-derived substrate classification maps. The accuracy assessment of the substrate mapping classification is presented in Section 5.1 prior to discussion of the substrate characterization results.

4.1 Aerial Photography Acquisition

KUCERA International was contracted by Progress Energy to acquire the low altitude, large scale aerial photography. The aerial photography was taken by KUCERA using a fixed-wing aircraft on February 19, 2005, at the Blewett Falls Hydroelectric Plant tailwater study site and on February 26, 2005, at the Tillery Hydroelectric Plant tailwater study site. The target scale for the hard copy natural color photographs (9 x 9 inches) was 1 inch on the map = 200 ft on the ground. Scanned resolution of the aerial photography resulted in 0.1 ft pixel resolution.

The aerial photography of each study site was acquired under low flow conditions when the power plants were not operating and the only flows in the study site were dam spillage, power plant wicket gate leakage, and tributary inflows. Flows were estimated to be approximately 100 cfs at the Tillery Hydroelectric Plant and approximately 300 cfs at the Blewett Falls Hydroelectric Plant on the dates of aerial photography acquisition. Both hydroelectric plants were off-line (i.e., no power generation) for 12-24 hours prior to image acquisition to allow water levels to decrease to low flow conditions and to help increase water clarity. Weather conditions, including cloud cover, wind speeds, and the time of day (i.e., sun angle and light reflection) were also taken into consideration during the photo acquisition.

4.2 Image Processing

As mentioned earlier, large scale aerial photography was scanned to produce very high-resolution digital imagery. KUCERA performed all image processing steps. The steps included scanning the natural color aerial photographs, orthorectifying the images to known elevation ground controls, georeferencing the images to a latitude-longitude coordinate grid system, and creating the final digital mosaics. Processing of the data included established quality control guidelines to ensure the final photographs were accurate in ground elevation and geographical location.

4.2.1 Image Scanning

The hard copy negatives were true color scanned into TIFF digital format using a Z/I PhotoScan 2002 first order (two micron precision + accuracy) photogrammetric scanner. The images were scanned at 24 bits per pixel with a compression ratio of -1.12. The scanner settings are shown in Table 4-1.

Table 4-1 Scanner settings used during photographic image scanning.

Scanner:	Z/I PhotoScan 2002
Type:	TIFF
Mode:	True color
Width:	16862
Height:	16861
Bits Per Pixel:	24
Colors:	16777216
DPIX:	1814 (14u)
DPIY:	1814 (14u)
Width (Inches):	9.2955
Height (Inches):	9.2949
Compression Ratio:	-1.12

4.2.2 Georeferencing of Digital Photographic Mosaics

The images were georeferenced after the hard copy aerial photography was scanned into a digital format and mosaiced. Georeferencing is the process of transforming the images into a common reference datum and makes the images useable in a GIS format (Jensen 1996). The reference datum used in this study was NAD83 with feet as the distance unit. At the time of aerial photograph exposures, the six orientation parameters (i.e., Latitude, Longitude, Altitude, Omega, Phi, and Kappa rotations) were recorded from the on-board GPS/Inertial Measurement Unit (IMU) system. The GPS/IMU data was further refined through a differential correction with input from a GPS ground base station with the final orientation parameters output translated to the North Carolina State Plane coordinate system. To further refine the orientation parameters, the scanned aerial imagery was combined with the post-processed GPS/IMU data and an automated Aerial Triangulation adjustment was performed to generate tie-in points for the entire mosaic block of photographs. The addition of the tie-in points between adjacent photography exposures strengthened the geometry of the entire photo-mosaic block to maximize the accuracy of the triangulated orientation parameters.

4.2.3 Orthorectification of Aerial Photography

The topographical variations in the earth's surface (i.e., elevation and slope aspect) and the tilt of the on-board camera can affect the distance and how the features are displayed on the aerial photograph images. Distortion of photographs becomes more of an issue with more topographically diverse landscape features. As a result, actual linear distances may not be uniformly represented on the photograph. Orthorectification is the systematic process used to remove these sources of distortion and to equilibrate photographic units to actual linear distances. Once an aerial photo has been orthorectified, it is commonly referred to as an orthophotograph.

Digital Elevation Models (DEMs) were used for the orthorectification of photographs in this study. Resampling of the DEM image involved warping the photograph image so that distance and area were uniform in relationship to the actual, "real world" linear measurements. In short, with the resampled DEM photo, an inch on the photographic image was corrected to measure the same distance, particularly on steep terrain, as it really measures with on-the-ground survey methods. After the photograph images were orthorectified, the resulting digital data were used with vector and raster data of the same coordinate plane system for accurate assessments of substrate composition.

4.3 Substrate Classification

4.3.1 Substrate Classification Scheme

The aquatic habitat substrate classification was based on the modified Wentworth scale for classifying substrate particle (originally Cummins 1962 as cited in McMahon et al. 1996) (Appendix A). However, modifications to the substrate classification were necessary for this study based on field observations of actual substrate composition (i.e., mixtures of substrate classes) and the resolution of the aerial photographs (Table 4-2). First, and most importantly, the heterogeneity of substrate types required multiple combinations of these classes, particularly with regard to mixtures of gravel and cobble with other substrate types. There were numerous instances where cobble, gravel, or a combination of these two substrate types were overlaid or formed pockets on top of bedrock. It should be noted that any reference to bedrock as a substrate type is pertaining to exposed bedrock, understanding that bedrock lies beneath all substrates at some level. Another example was substrate consisting of a mixture of gravel and cobble interspersed among small to large boulders and bedrock. Second, there was difficulty in distinguishing differences between some of the smaller substrate classes such as pebble (16 to 63 mm) and gravel (2 to 16 mm) from the digital imagery. In this case, both classes were lumped together and classified as gravel. Finally, the presence of exposed bedrock and structure features specific to a study site (i.e., Big Island below Blewett Falls Hydroelectric Plant and dam apron) warranted stand-alone categories.

Table 4-2 Substrate categories used in the characterization of study sites located in the tailwater areas of the Tillery and Blewett Falls Hydroelectric Plants during 2005.

Number	Substrate Category	Applicable Study Site
1	Cobble/gravel	Both study sites
2	Cobble/gravel/sand	Both study sites
3	Cobble/gravel/silt	Blewett Falls Hydroelectric Plant study site only
4	Cobble/gravel/boulder	Both study sites
5	Cobble/gravel/bedrock/boulder	Tillery Hydroelectric Plant study site only
6	Cobble/gravel/bedrock	Tillery Hydroelectric Plant study site only
7	Cobble/gravel with emergent and terrestrial vegetation	Both study sites
8	Bedrock/gravel	Tillery Hydroelectric Plant study site only
9	Bedrock/boulder/cobble	Blewett Falls Hydroelectric Plant study site only
10	Boulder/cobble	Blewett Falls Hydroelectric Plant study site only
11	Bedrock/boulder	Both study sites
12	Bedrock/boulder with emergent and terrestrial vegetation	Blewett Falls Hydroelectric Plant study site only
13	Bedrock	Both study sites
14	Riprap (introduced shoreline stabilization material)	Both study sites
15	Island	Blewett Falls Hydroelectric Plant study site only
16	Blewett Falls Hydroelectric Plant dam apron area	Blewett Falls Hydroelectric Plant study site only

Sixteen substrate or structure categories were defined for both the Tillery and Blewett Falls Hydroelectric Plant study sites (Table 4-2). Seven of the 16 substrate categories were common to both study sites while the remaining nine categories were specific to either study site. For example, there was a combination of bedrock/gravel present at the Tillery Hydroelectric Plant study site, but this substrate category was not observed at the Blewett Falls Hydroelectric Plant study site. The mixed categories were visually estimated to be equal mixtures of each substrate class or the leading substrate class in the category was considered predominant with the other substrate class comprising smaller percentages of a particular category. All substrate categories were based on field visual observations during the ground reference data collection and accuracy assessment phases of the study. No quantitative assessments were made with standardized sieves to determine actual fractions of each substrate class within a particular mixed category.

4.3.2 Digitizing Substrate Categories

The most common method to delineate substrate categories from digital imagery is to visually categorize the substrate on a computer screen and then manually digitize areas of similar composition using GIS software. This method is often called "heads-up" digitizing and it is widely used for selective capture of digital data (Longley et al. 2001). "Heads-up" digitizing was used for this study and areas of similar substrate composition were determined by the color, shape, texture, and patterns from the digital imagery. These areas were outlined digitally using GIS software to create a continuous coverage of polygons across the study area. Each polygon was assigned a substrate category and the assigned category was verified with the reference data. Each polygon area was termed a habitat area for the identified substrate category and these habitat areas varied in size and shape.

Many polygon substrate classifications were obvious due to their nature, such as exposed bedrock, and cobble/gravel bars (Figure 4-1). The shallow water conditions (usually less than 1 m depth) and the very high-resolution digital imagery usually provided suitable conditions for visual identification of substrate types (Figures 4-2 and 4-3). In some instances (i.e., deep run areas with depths greater than one meter, very turbid areas, and a few areas outside of the mosaic photography coverage), substrate classification was achieved by overlaying substrate classification data from GPS transect training points collected during the ground reference data collection phase of the study (Figures 4-4 and 4-5). To eliminate any potential bias, these training points were excluded from the accuracy assessment.

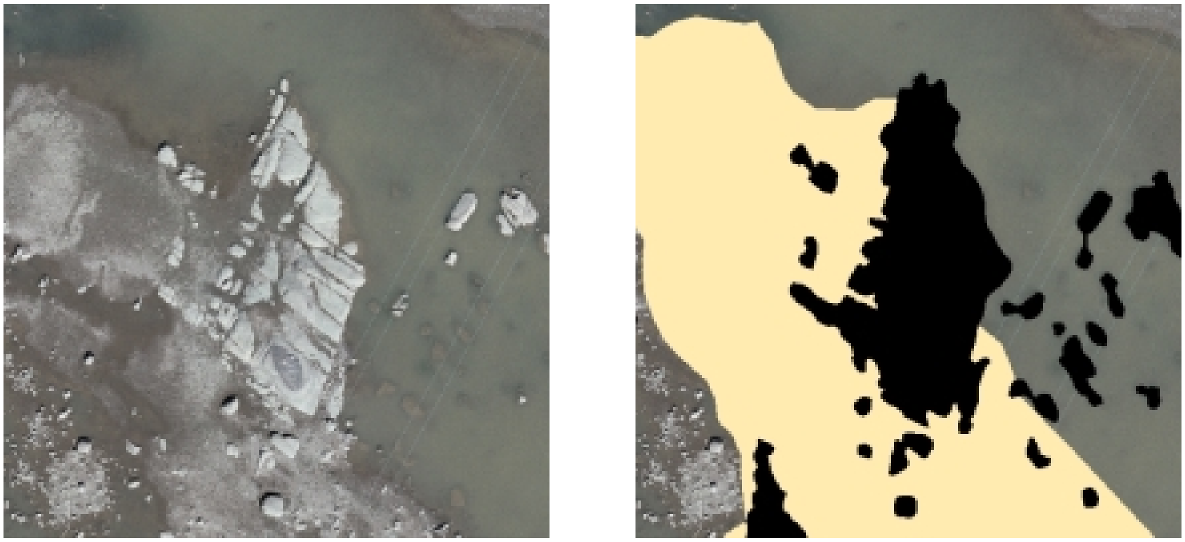

Figure 4-1 **Bedrock outcrops and areas of cobble/gravel detailed in very high-resolution digital imagery and in GIS-derived polygons. The image on the left provides an example of such areas from the Blewett Falls Hydroelectric Plant study site. The image on the right shows the GIS-derived delineations of bedrock and cobble/gravel substrate polygons. A discrete polygon delineated as a substrate category was termed a habitat area.**

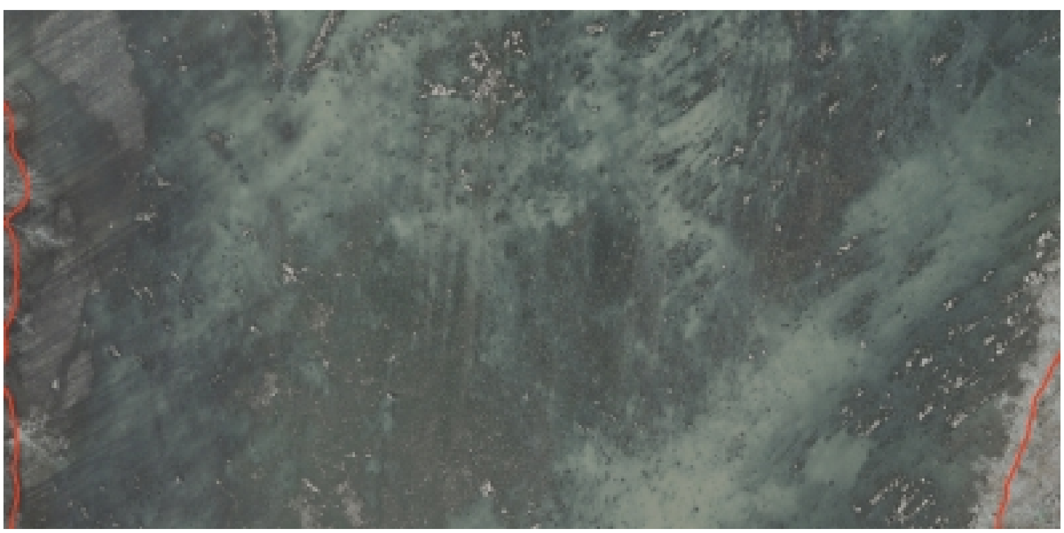

Figure 4-2 **Excerpt from very high-resolution digital imagery at the Tillery Hydroelectric Plant tailwater area study site illustrating the typical depth and water clarity conditions. This example was representative of the majority of the study site.**

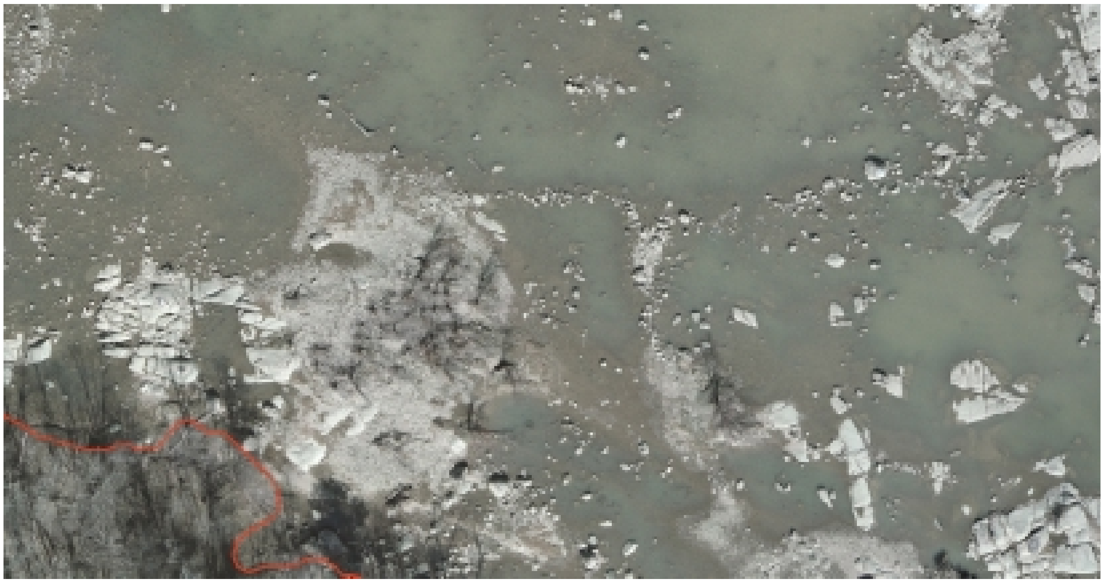

Figure 4-3 Excerpt from very high-resolution digital imagery at the Blewett Falls Hydroelectric Plant tailwater area study site illustrating the typical depth and water clarity conditions. This example was representative of the majority of the study site.

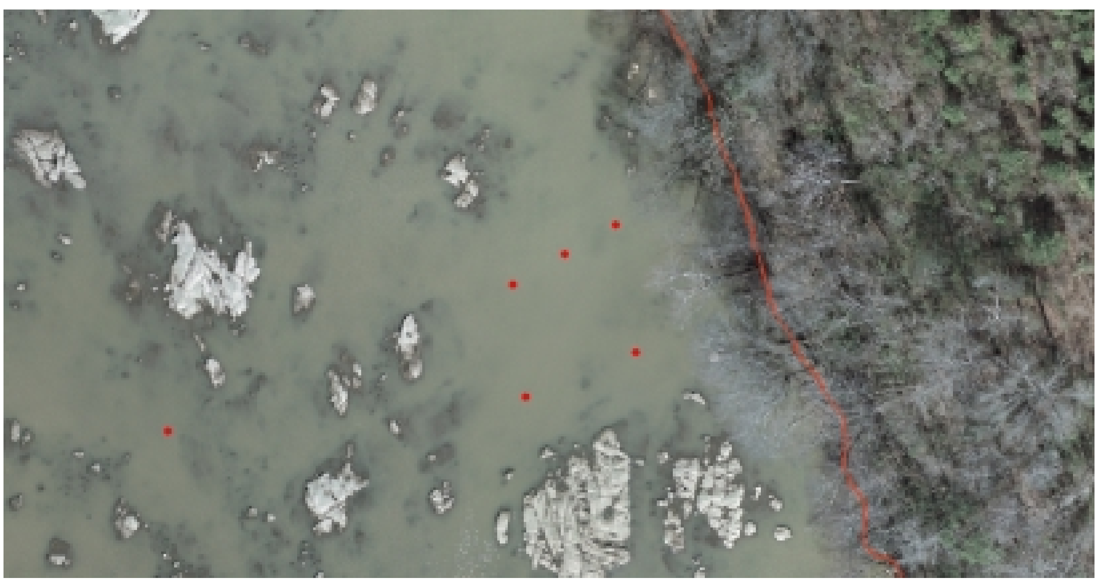

Figure 4-4 An example of a turbid, deep run area in the Blewett Falls Hydroelectric Plant tailwater study site where visual interpretation of substrate was difficult. Training points (red dots) used for substrate classification of this area and are shown overlaid onto the digital image.

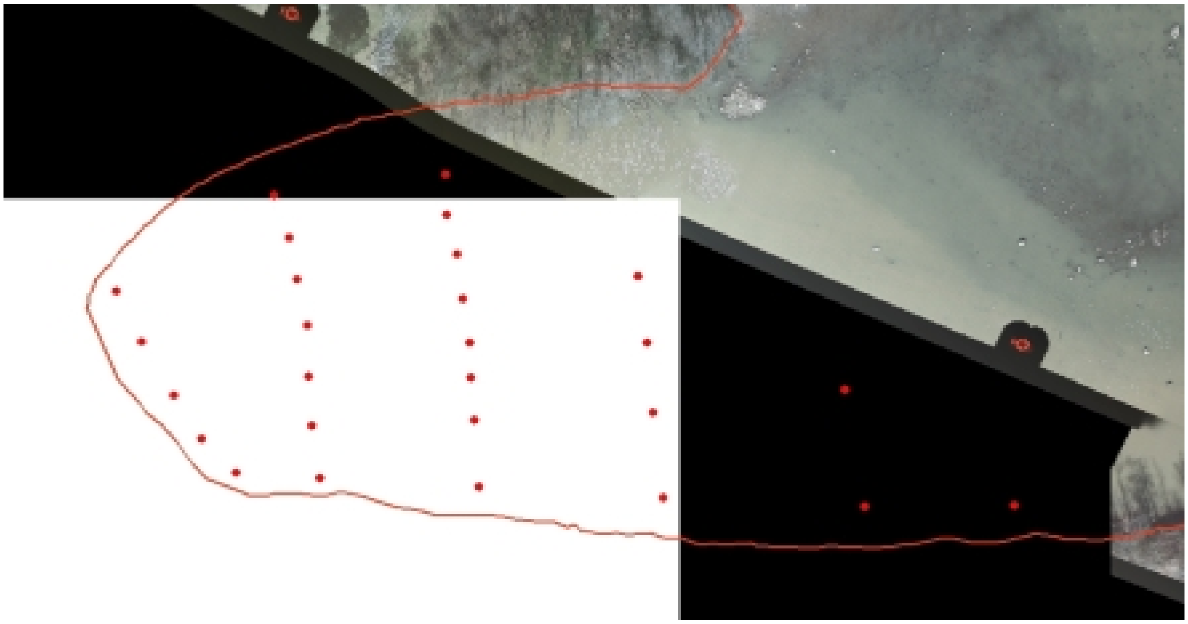

Figure 4-5 Area in the Blewett Falls Hydroelectric Plant tailrace without aerial mosaic photography coverage. Training points (red dots) used for substrate classification of this area are shown overlaid onto the image.

4.4 Accuracy Assessment of Digitized Substrate Categories

4.4.1 Reference Data Collection

Ground reference points obtained during the field data collection were used to provide an estimate of the accuracy of the "heads-up" digitizing method of substrate classification. Transects were established across the river channel from bank to bank at each study site. These transects were located approximately every 500 ft beginning below each hydroelectric dam and extending downstream for the entire length of the study site. Ground reference points were collected at approximately 50 ft intervals along each established transect (Figures 4-4 and 4-5).

Transect and ground reference point data were acquired using a Trimble GeoXT GPS unit with sub-meter accuracy (i.e., 1 m or approximately 3.3 ft radius around the mapped GPS point). A minimum of 30 GPS latitude-longitude readings were recorded at one second intervals for each ground reference point along a transect. The primary substrate type (i.e., ≥ 50 percent of substrate composition) was determined visually and physically in an area approximately one meter (3.3 ft) around the GPS survey rod while collecting the latitude and longitude positions. The second most abundant substrate type in the surveyed ground reference point was identified as the secondary substrate type. Any other minor substrates present were also noted.

4.4.2 Error Matrices

An error matrix for the digitized thematic maps for each study site was generated using 494 ground reference points for both study sites and 8 substrate assessment classes per study site. An error matrix is a square array of numbers set out in rows and columns that express the number of sample units (pixels, clusters, or polygons) assigned to a particular category in one classification relative to the number of sample units assigned to a particular category in another classification (Congalton 1991; Fitzgerald and Lees 1994; Khorram et al. 1999).

An error matrix is an effective way to represent map accuracy in that the individual accuracies for each category (class) are described along with both omission and commission errors. In addition to these accuracy measures, the overall accuracy (does not account for data source errors), the Producer's Accuracy and the User's Accuracy were produced for the accuracy assessment. The Producer's Accuracy is a referenced-based accuracy that is computed by looking at the predictions produced for a class and determining the percentage of correct predictions. The User's Accuracy is a map-based accuracy that is computed by looking at the reference data for a class and determining the percentage of correction predictions for the samples. The accuracy assessment produced a level of confidence in the “heads-up” digitizing approach of the digital imagery under the environmental conditions present at the time that the aerial photographs were taken at each study site.

Section 5 – Results

5.1 Accuracy Assessment of Substrate Classifications

5.1.1 Tillery Hydroelectric Plant Tailwater Area Study Site

The classification accuracy assessment results and associated error matrix for substrate categories at the Tillery Hydroelectric Plant tailwater area study site are shown in Table 5-1. Two substrate categories — cobble/gravel with emergent and terrestrial vegetation and riprap — were not included in the accuracy assessment. These substrate categories were infrequently mapped and consisted of only a few small areas within the study site (approximately 0.5 acre). These substrate categories were not present at any of the reference data collection transects.

The overall substrate classification accuracy was 95 percent for the Tillery Hydroelectric Plant tailwater area study site (Table 5.1). The User's Accuracy, defined as the proportion of each interpreted substrate category that was actually in that category, ranged from 86 percent (bedrock category) to 100 percent (cobble/gravel, cobble/gravel/bedrock/boulder, cobble/gravel/sand, and bedrock/boulder categories). In other words, approximately 86 percent of the area classified as bedrock using the "heads-up" digitizing method was actually bedrock based on the ground-truth data. It should be noted that only seven ground reference points were observed for this class and six of these points were correctly classified. The bedrock in the study area was more difficult to delineate from the digital imagery than bedrock at the Blewett Falls Hydroelectric Plant tailwater area study site because of: (1) lack of boulder outcrop exposure in the Tillery Hydroelectric Plant tailwater area study site; (2) striated, fractured pattern of bedrock in the Tillery Hydroelectric Plant study site versus the clumped pattern of bedrock in the Blewett Falls Hydroelectric Plant study site; and (3) fractured nature of many bedrock outcrops in both study sites that often transitioned into large boulders. The majority of substrate categories (i.e., seven of the eight categories) in the Tillery Hydroelectric Plant tailwater area study site exceeded 90 percent for User's Accuracy.

Table 5-1 Error matrix and accuracy assessment of substrate categories in the Tillery Hydroelectric Plant tailwater area study site.

Digitized Map Substrate Category	Reference Data Substrate Category								Number of Pixels	User's Accuracy
	Cobble / Gravel	Cobble / Gravel / Bedrock	Cobble / Gravel / Bedrock / Boulder	Cobble / Gravel / Boulder	Cobble / Gravel / Sand	Bedrock	Bedrock / Boulder	Bedrock / Gravel		
Cobble/Gravel	**31**	0	0	0	0	0	0	0	31	**100.0%**
Cobble/Gravel/Bedrock	0	**51**	0	3	0	0	0	0	54	**94.4%**
Cobble / Gravel / Bedrock / Boulder	0	0	**24**	0	0	0	0	0	24	**100.0%**
Cobble/Gravel/Boulder	0	1	0	**37**	0	0	3	0	41	**90.2%**
Cobble/Gravel/Sand	0	0	0	0	**7**	0	0	0	7	**100.0%**
Bedrock	0	0	0	1	0	**6**	0	0	7	**85.7%**
Bedrock/Boulder	0	0	0	0	0	0	**11**	0	11	**100.0%**
Bedrock/Gravel	1	0	0	0	0	0	1	**19**	21	**90.5%**
Number of ground truth reference pixels	32	52	24	41	7	6	15	19	**196**	
Producers Accuracy	**96.9%**	**98.1%**	**100.0%**	**90.2%**	**100.0%**	**100.0%**	**73.3%**	**100.0%**		**94.9%**

The Producer's Accuracy, defined as the proportion of a given category that was correctly classified by the person performing the "heads-up" digitizing, ranged from 73 percent (bedrock/boulder category) to 100 percent (cobble/gravel/bedrock/boulder, cobble/gravel/sand, bedrock/gravel, and bedrock categories). Similar to the User's Accuracy results, the majority of substrate categories in the Tillery Hydroelectric Plant study site exceeded 90 percent for Producer's Accuracy (Table 5-1).

5.1.2 Blewett Falls Hydroelectric Plant Tailwater Area Study Site

The classification accuracy results and associated error matrix for substrate categories at the Blewett Falls Hydroelectric Plant tailwater area study site are shown in Table 5-2. Five substrate or structure categories were not included in the accuracy assessment because they were not encountered along established transects during the reference data field work. The excluded substrate or structure categories were: (1) bedrock/boulder with emergent and terrestrial vegetation; (2) cobble/gravel with emergent and terrestrial vegetation; (3) riprap; (4) island; and (5) Blewett Falls Hydroelectric Plant dam apron. These substrate or structure categories comprised approximately 20 acres within the study site. The island was considered to be an obvious delineation, coupled with the fact that it was heavily wooded which affected GPS satellite reception, so no reference points were collected during the field work. The island comprised 58 percent of the 20 acres of substrate or structure categories that were not included in the accuracy assessment.

The overall classification accuracy of the Blewett Falls Hydroelectric Plant tailwater area study site was 94 percent. The User's Accuracy ranged from 83 percent (cobble/gravel/sand) to

100 percent (cobble/gravel/silt). For the cobble/gravel/sand substrate category, it should be noted that only six reference points were observed for this category with five points correctly classified. The remaining substrate categories had a User's Accuracy greater than 90 percent (Table 5-2). The Producer's Accuracy ranged from 83 percent (cobble/gravel/sand) to 100 percent (cobble/gravel/boulder).

5.2 Tillery Hydroelectric Plant Tailwater Area Substrate Classification

The unclassified map of the Tillery Hydroelectric Plant tailwater study site and the resulting classified, thematic map showing digitized substrate categories are shown in Figures 5-1 and 5-2, respectively. Ten substrate categories comprising 617 substrate areas and 112 acres were mapped in the study site (Table 5-3). The substrate composition was diverse in the study site, particularly mixtures of the smaller substrates cobble and gravel (Figure 5-2). Substrates comprised of cobble, gravel or mixtures of cobble and gravel with other substrates comprised approximately 80 percent of the study site area (Table 5-3).

Bedrock outcrops were the most frequently mapped habitat type (554 substrate areas) but only comprised 7 percent of total area acreage (Table 5-3). Cobble/gravel/boulder was the second numerically dominant substrate type (24 substrate areas) followed by cobble/gravel (13 substrate areas), and cobble/gravel/bedrock (12 substrate areas). The other substrate categories comprised the remaining 14 substrate areas that were mapped.

Table 5-2 Error matrix and accuracy assessment of substrate categories in the Blewett Falls Hydroelectric Plant tailwater area study site.

Digitized Map Substrate Category	Reference Data Substrate Category								Number of Pixels	User's Accuracy
	Cobble / Gravel	**Cobble / Gravel / Boulder**	**Cobble / Gravel / Sand**	**Cobble / Gravel / Silt**	**Bedrock**	**Bedrock / Boulder**	**Bedrock / Boulder / Cobble**	**Boulder / Cobble**		
Cobble / Gravel	**40**	0	1	0	0	0	0	2	43	**93.0%**
Cobble / Gravel / Boulder	2	**29**	0	0	0	0	0	0	31	**93.6%**
Cobble / Gravel / Sand	0	0	**5**	0	0	0	0	1	6	**83.3%**
Cobble / Gravel / Silt	0	0	0	**15**	0	0	0	0	15	**100.0%**
Bedrock	1	0	0	1	**67**	0	0	2	71	**94.4%**
Bedrock / Boulder	0	0	0	0	0	**20**	0	1	21	**95.2%**
Bedrock / Boulder / Cobble	2	0	0	0	0	0	**29**	0	31	**93.6%**
Boulder / Cobble	1	0	0	0	1	1	1	**76**	80	**95.0%**
Number of ground truth reference pixels	46	29	6	16	68	21	30	82	**298**	
Producers Accuracy	**87.0%**	**100.0%**	**83.3%**	**93.8%**	**98.5%**	**95.2%**	**96.7%**	**92.7%**		**94.3%**

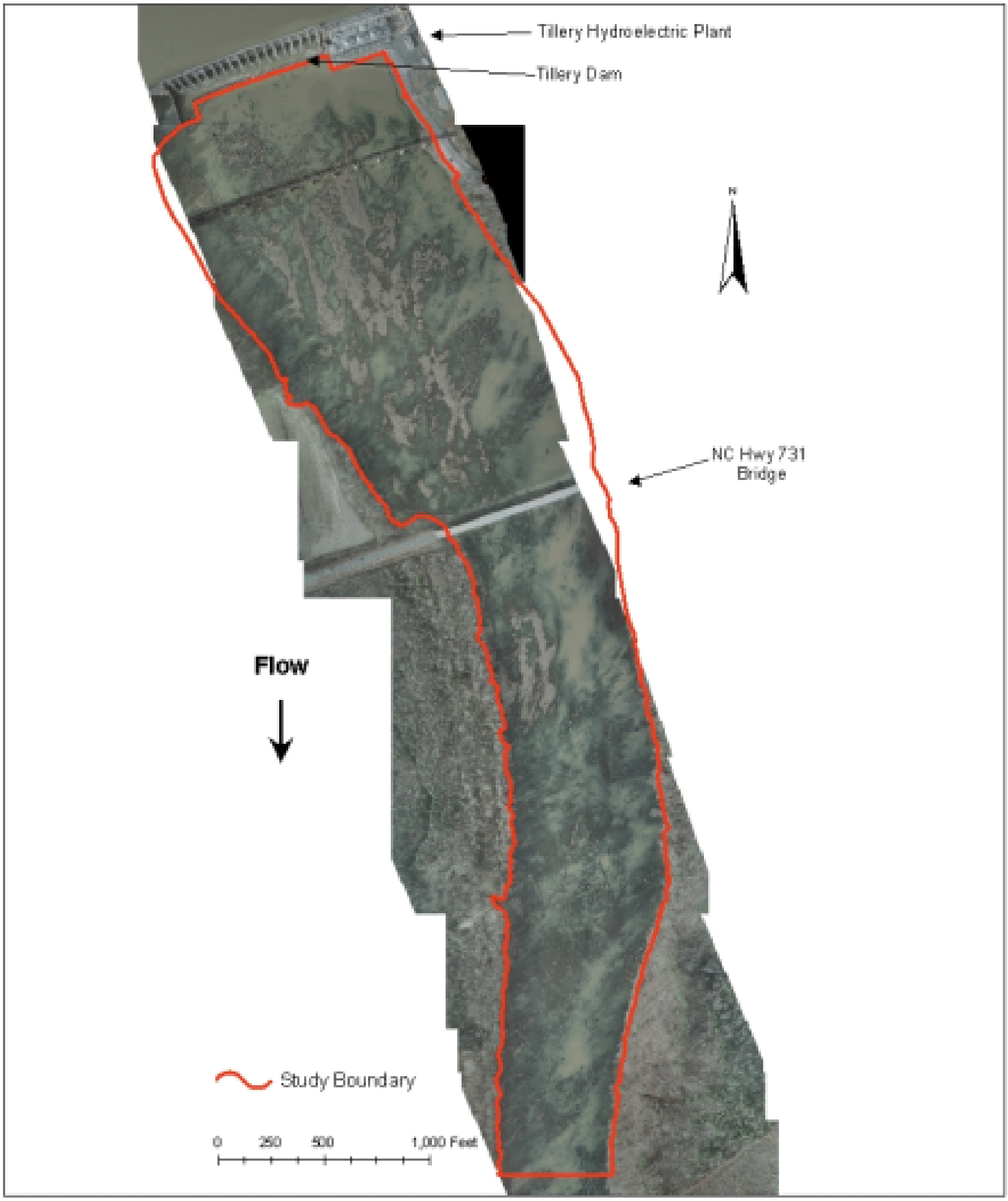

Figure 5-1 Tillery Hydroelectric Plant tailwater area study site showing mosaic of orthophotographs and the study site boundary (red line).

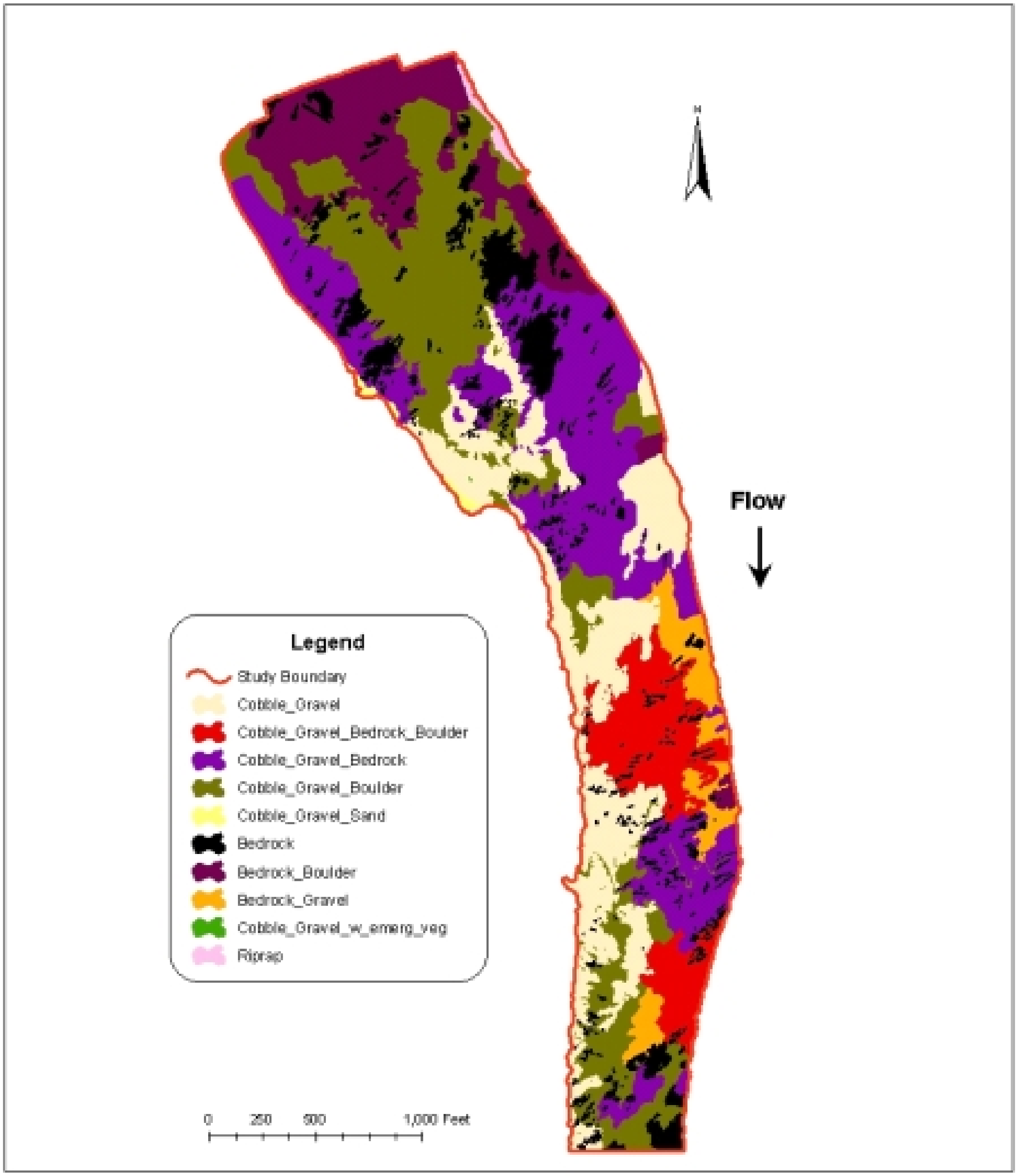

Figure 5-2 Substrate classification map of the Tillery Hydroelectric Plant tailwater area study site.

Table 5-3 Area estimates of substrate categories in the Tillery Hydroelectric Plant tailwater area study site.

Substrate Category	Number of Mapped Areas	Minimum Square Feet	Maximum Square Feet	Total Square Feet	Total Acres	Percent of Total Acreage
Cobble / gravel	13	1,524	177,553	813,652	18.7	16.8%
Cobble / gravel / bedrock	12	1,268	401,627	1,158,488	26.6	23.8%
Cobble / gravel / bedrock / boulder	2	122,077	326,543	448,620	10.3	9.2%
Cobble / gravel / boulder	24	32	778,218	1,240,047	28.5	25.5%
Cobble / gravel / sand	3	4,389	8,908	21,603	0.5	< 1.0%
Bedrock	554	3	53,531	318,294	7.3	6.5%
Bedrock / boulder	4	13,189	466,395	624,943	14.3	12.8%
Bedrock / gravel	3	39,443	116,442	211,629	4.9	4.4%
Cobble / gravel with emergent and terrestrial vegetation	1	450	450	450	< 0.1	< 1.0%
Riprap	1	23,445	23,445	23,445	0.5	< 1.0%
Total[1]	**617**			**4,861,172**	**111.6**	**100.0%**

1 Total area estimates may vary from summation of columns due to rounding.

Cobble/gravel/bedrock and cobble/gravel/boulder were the most prevalent substrate categories on an area basis, comprising 27 and 28 acres, respectively. These two substrate categories comprised almost half of the total mapped area in the Tillery Hydroelectric Plant tailwater area study site (Table 5-3). Cobble/gravel was the third most prevalent substrate type on an area basis consisting of 19 acres followed closely by bedrock/boulder (14 acres). These two substrate categories accounted for 30 percent of the total mapped area within the study site. Riprap, cobble/gravel/sand, and cobble/gravel with emergent and terrestrial vegetation were minor substrate categories comprising approximately 1 percent of the total acreage (Table 5-3).

The spatial distribution of substrates indicated a diverse mixture of substrate types throughout the Tillery Hydroelectric Plant tailwater area study site (Figure 5-2). There was a large expanse of cobble/gravel along the west shoreline of the study site. This cobble/gravel bar extended along two-thirds of the study site. Visual observations indicated this cobble/gravel bar persisted along the west shoreline for another one to two miles downstream of the study site. Another large area of cobble/gravel was present on the east shoreline near the midpoint of the study site. Mixtures of cobble/gravel with boulder and/or bedrock were dispersed throughout the study site along channel margins and at mid channel areas. Bedrock outcroppings were found throughout the study site with the greatest concentration located in the upper third of the study site just downstream of the Tillery Hydroelectric Plant. Bedrock/boulder substrate was located at the base of Tillery Hydroelectric Plant Dam and at the powerhouse and extended downstream on the east shoreline (Figure 5-2). This coarse substrate area was located in a high energy zone where dam spillage and power plant discharges would tend to scour out smaller substrate types. However, the scour zone was confined to the immediate area in front of these structures. Large areas of cobble/gravel/boulder and cobble/gravel/bedrock were located in close proximity of these bedrock/boulder areas, immediately downstream of the hydroelectric plant. Very small substrate types — such as sand and silt — were not prevalent in the study site. There were a few small patches of sand intermixed with cobble/gravel (cobble/gravel/sand category) located along the west shoreline.

5.3 Blewett Falls Hydroelectric Plant Tailwater Area Substrate Classification

The unclassified map of the Blewett Falls Hydroelectric Plant tailwater study site and the resulting classified, thematic map showing digitized substrate categories are shown in Figures 5-3 and 5-4, respectively. Eleven substrate categories and two special areas (i.e., Blewett Falls Hydroelectric Plant dam apron and island areas) were mapped in the study site. These 13 categories comprised 644 substrate or structure areas and 184 acres in the study site (Table 5-4). The substrate composition was also diverse in the Blewett Falls Hydroelectric Plant tailwater area study site, although bedrock was more predominant due to the study site's location in the Fall Line zone. Mixtures of the smaller substrates (cobble, gravel, sand, and silt) were prevalent in the study site and accounted for over 21 percent of the total acreage (Table 5-4 and Figure 5-4). Substrates comprised of cobble, gravel or mixtures of cobble and gravel with other substrates comprised approximately 62 percent of the study site area.

Bedrock outcrops were the most frequently mapped substrate category, on a numerical basis, consisting of 552 areas (Table 5-4). Bedrock/boulder with emergent and terrestrial vegetation was the second numerically dominant substrate category (22 areas) but only comprised 7 percent of the total acreage in the study site. Boulder/cobble, cobble/gravel, cobble/gravel/boulder, and cobble/gravel/silt were the next most frequently observed substrate categories with the number of mapped areas between 12 to 14 areas.

On an area basis, boulder/cobble and bedrock were the most prevalent substrate categories comprising 38 and 41 acres, respectively, and represented approximately 43 percent of the total acreage in the study site (Table 5-4). Bedrock/boulder/cobble and cobble/gravel were the next most prevalent substrate categories accounting for almost equal amounts of acreage (22 and 23 acres, respectively). These two latter substrate categories comprised 25 percent of the total acreage in the study site. Cobble/gravel with emergent and terrestrial vegetation, riprap, and the Blewett Falls Hydroelectric Plant dam apron structure were minor categories accounting for less than 1 percent of the total mapped area. The island comprised 6 percent of the total mapped area.

The spatial distribution of substrates also indicated a diverse mixture of substrate types throughout the Blewett Falls Hydroelectric Plant tailwater area study site (Figure 5-4). There was a large expanse of cobble/gravel along the west shoreline in association with the Big Island and side channel complex (Figure 5-4). The cobble/gravel bar encompassed the entire island. As mentioned previously, bedrock was prevalent in the study reach due to the study site's location in the Fall Line zone and the large shoal complex located in the study site. Bedrock outcrops were concentrated in the mid channel and east shoreline areas, particularly in the lower half of the study site. Smaller substrates (sand and silt) were more frequently observed in the Blewett Falls Hydroelectric Plant tailwater area when compared to the Tillery Hydroelectric Plant tailwater area (Figures 5-2 and 5-4). There were mixed categories of these two smaller substrates with cobble/gravel on the east and west shorelines in close proximity to the powerhouse and dam. The presence of these smaller substrates suggested downstream transport of these substrates from Blewett Falls Lake and the Pee Dee River

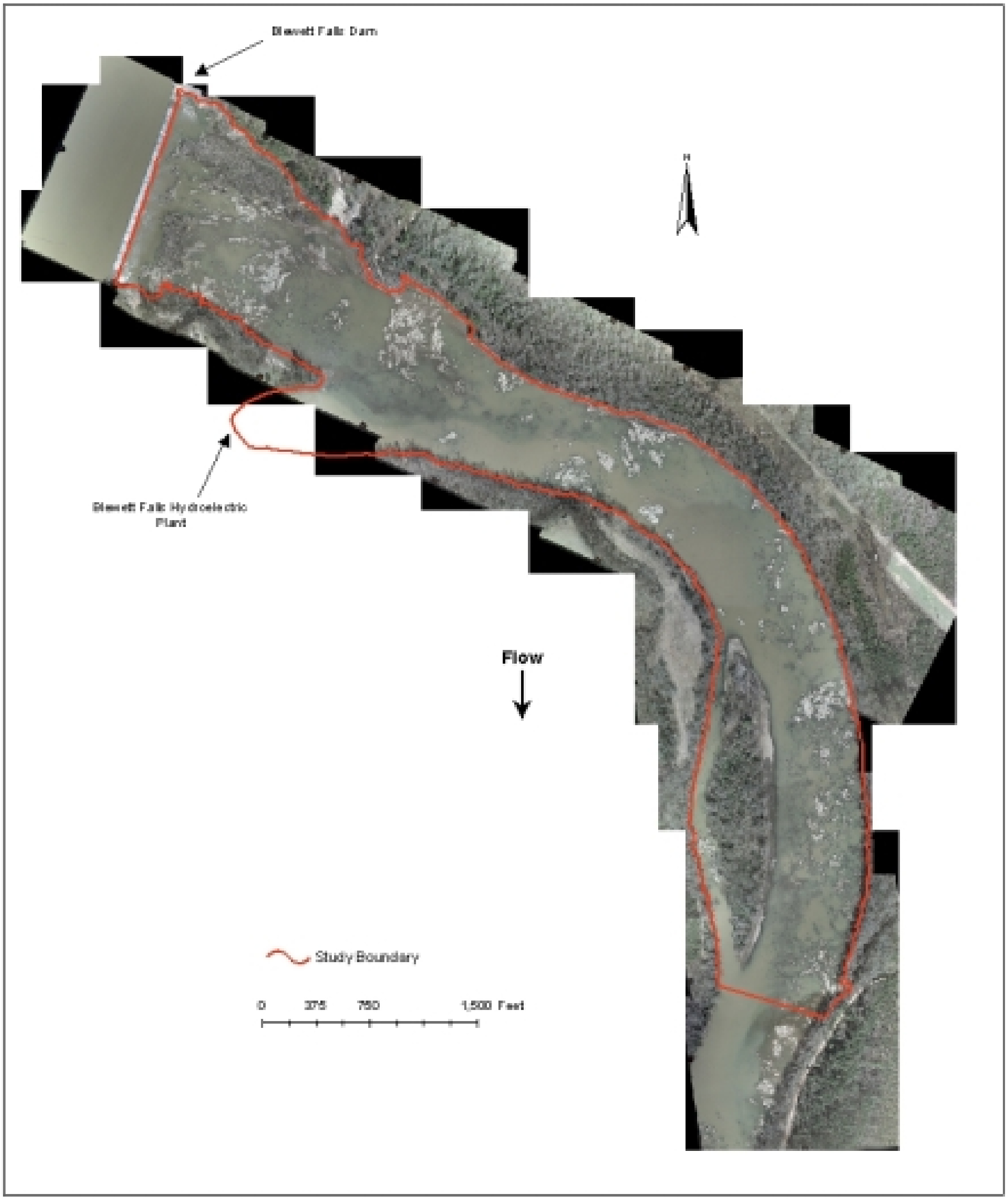

Figure 5-3 Blewett Falls Hydroelectric Plant tailwater area study site showing mosaic of orthophotographs and the study site boundary (red line).

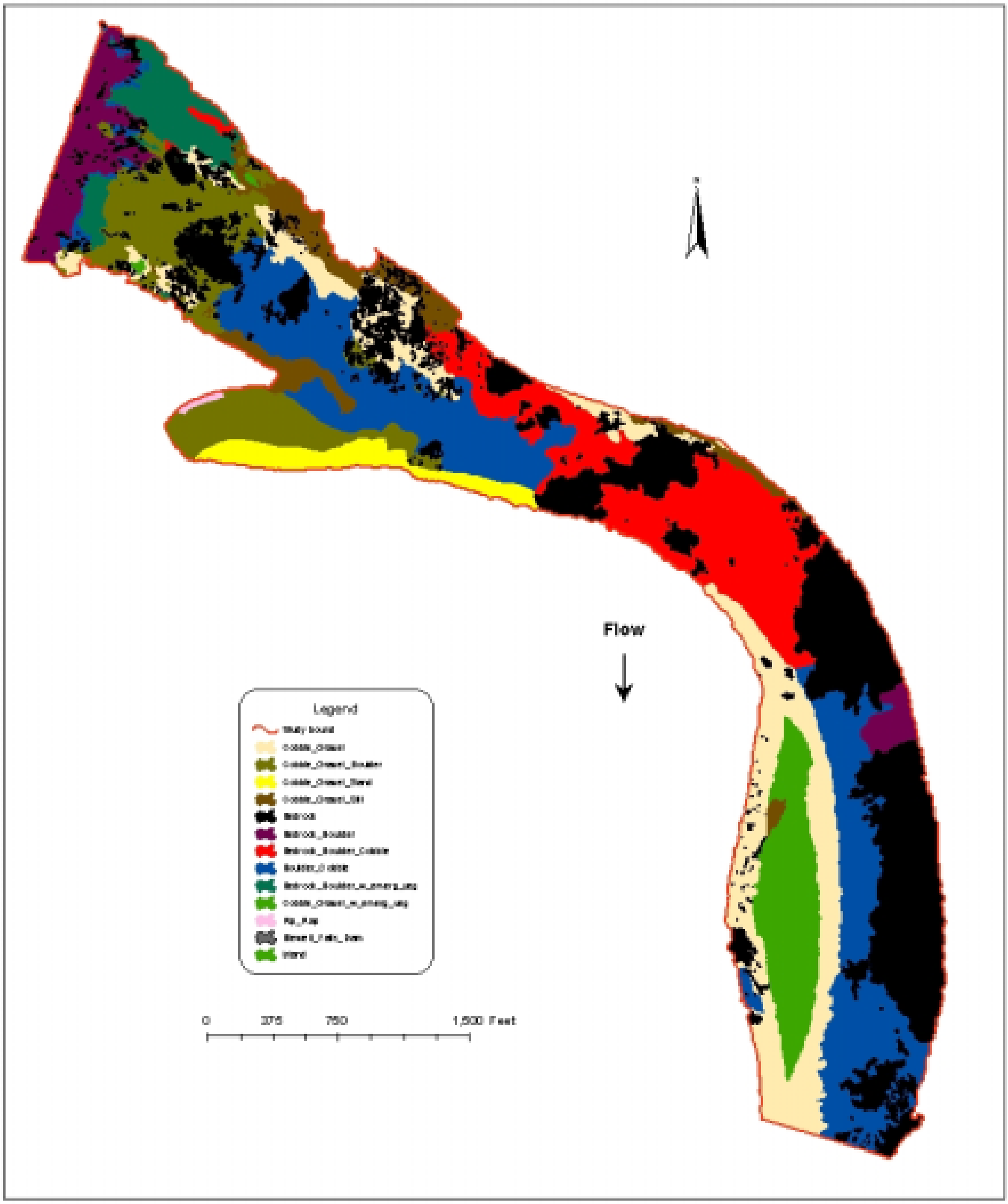

Figure 5-4 Substrate classification map of the Blewett Falls Hydroelectric Plant tailwater area study site.

Table 5-4 Area estimates of substrate/structure categories in the Blewett Falls Hydroelectric Plant tailwater area study site.

Substrate/Structure Category	Number of Mapped Area	Minimum Square Feet	Maximum Square Feet	Total Square Feet	Total Acres	Percent of Total Acreage
Cobble/gravel	13	404	716,717	1,010,032	23.2	12.6%
Cobble/gravel/boulder	12	61	437,005	768,561	17.6	9.6%
Cobble/gravel/sand	1	225,764	225,764	225,764	5.2	2.8%
Cobble/gravel/silt	12	256	98,467	375,705	8.6	4.7%
Bedrock	552	4	582,851	1,785,921	41.0	22.3%
Bedrock/boulder	2	79,058	291,518	370,576	8.5	4.6%
Bedrock/boulder/cobble	5	157	672,244	970,509	22.3	12.1%
Boulder/cobble	14	219	829,552	1,644,891	37.8	20.6%
Bedrock/boulder with emergent and terrestrial vegetation	22	25	229,689	306,826	7.0	3.8%
Cobble/gravel with emergent and terrestrial vegetation	8	42	6,227	15,977	0.4	< 1.0%
Riprap	1	12,002	12,002	12,002	0.3	< 1.0%
Blewett Falls Hydroelectric Plant dam apron	1	13,981	13,981	13,981	0.3	< 1.0%
Island	1	499,734	499,734	499,734	11.5	6.3%
Total[1]	**644**			**8,000,479**	**183.7**	**100.0%**

[1] Total area estimates may vary from summation of columns due to rounding.

and associated tributaries, most notably the Rocky River. An unnamed tributary on the east shoreline was also likely responsible for some of the silt deposition in that mapped area. Bedrock/boulder/cobble and boulder/cobble were dispersed throughout the study site, especially mid channel areas (Figure 5-4). Bedrock/boulder and bedrock/boulder with emergent and terrestrial vegetation were prevalent in front the Blewett Hydroelectric Plant dam. This area was a high energy zone during dam spillage events and most small sediments were scoured out of this immediate area. However, there was a large area of bedrock/cobble and smaller patches of cobble/gravel just below this area indicated the scour zone was not extensive.

Section 6 – Discussion

The use very high-resolution digital imagery derived from large scale aerial photography resulted in accurate classifications of substrates in the tailwater areas. Water clarity conditions, during the aerial photography acquisition, were somewhat turbid due to inflow resulting from precipitation events in the river basin prior to the study (Figures 4-2 and 4-3). Turbidity ranged from 7.2 to 38 NTU at the Tillery Hydroelectric Plant study site and from 21 to 38 NTU at the Blewett Falls Hydroelectric Plant study site on the dates that the aerial photographs were taken. For reference, the North Carolina water quality standard for turbidity is 50 NTU for streams (NCDWQ 2004). A large portion of the substrate was either exposed or submerged in very shallow water (1 to 2 ft) on the dates that the aerial photographs were taken so visual classification was achievable even with the reduced water clarity (Figure 4-1). As mentioned under Section 4.3.2, the areas of uncertainty regarding substrate classification were areas that were either too deep and/or too turbid to correctly categorize the substrate. The reference data approach using transects and ground reference points was used to validate the "heads-up" digitizing approach and also overcome any difficulties in areas where this approach was problematic due to depth or reduced water clarity.

Despite less than ideal conditions, the overall classification accuracy exceeded 94% at both study sites. A couple of things to note that may explain the overall high accuracies. First, the very high-resolution digital imagery lent itself to straightforward delineations in areas where water depth and clarity permitted. The 0.1 ft pixel resolution allowed even small substrates to be identified (i.e. individual cobbles could be measured in inches) and even the smallest substrate such as gravel and sand could be easily determined based on the texture and color.

Secondly, the individual class accuracies may be higher because of the combined substrate classes. Combined classes (combined to capture the heterogeneous substrate compositions) are inherently more likely to agree with a reference point thus increasing the individual class accuracies.

The substrate mapping indicated there was a diverse mixture of substrate types in the immediate tailwaters located below the Tillery and Blewett Falls Hydroelectric Plants. Smaller substrate types, mainly gravel and cobble, were well represented in each tailwaters. Mixtures of these two substrate types solely comprised 13 percent and 17 percent of the total mapped areas in the Blewett Falls and Tillery tailwaters, respectively. Cobble and gravel were also closely associated with other substrate types such as sand, boulders, and bedrock. Considering these substrate combinations, approximately 63 percent and 80 percent of the mapped substrate area in the Blewett Falls and Tillery tailwaters study sites, respectively, had some association of cobble and gravel. Pockets of cobble and gravel were numerous and closely associated with large boulders and bedrock indicating numerous micro-habitat areas throughout the study reach, in addition to the larger cobble and gravel areas. Although not captured in this mapping, visual observations during other environmental studies indicated there was also sand, periphyton, and aquatic vegetation (mainly filamentous algae and Podostemum) present in the interstitial spaces between large substrate and on substrate surfaces (aquatic vegetation and periphyton). Submerged woody debris was also prevalent in each tailwaters study site which provided additional aquatic habitat diversity for aquatic organisms.

Recent surveys of fish, mussels, and crayfish in shallow and deeper water habitats in the tailwaters of both power plants found diverse and abundant populations in these areas, particularly below the Blewett Falls Hydroelectric Plant (Progress Energy 2003, 2005). Mussels, which prefer the smaller particle substrates such as sand, gravel, and cobble, were abundant in the transects located in the immediate tailwaters below each hydroelectric plant. The diversity of mussels was high in these tailwater areas compared to other transects sampled downstream, including those species with special conservation status listing.

Migratory fish species -- American shad (*Alosa sapidissima*), blueback herring (*Alosa aestivalis*), American eel (*Anguilla rostrata*), and striped bass (*Morone saxatilis*) have been documented in the immediate tailwaters of the Blewett Falls Hydroelectric Plant (Progress Energy 2003). American shad and striped bass likely utilize this area for spawning based on observations of sexually mature adults or eggs and larvae (Progress Energy 2003). In addition, adult rare native suckers -- highfin carpsucker (*Carpiodes velifer*), Carolina redhorse (undescribed *Moxostoma* species), and robust redhorse (*Moxostoma robustum*) – have been documented in the power plant tailwaters since fishery surveys began in 1998 (Progress Energy 2003). Sexually ripe adults of Carolina redhorse and robust redhorse were also recently discovered in the vicinity of Big Island during May 2005, which indicated that these rare native suckers were likely utilizing the immediate tailwaters for spawning habitat (personal communication with Mr. Ryan Heise, North Carolina Wildlife Resources Commission). Results of these recent aquatic surveys would suggest the substrate, per se, is not a limiting factor for either the inhabitation or reproduction of aquatic organisms in the immediate tailwaters below the Tillery and Blewett Falls Hydroelectric Plants.

The presence and operation of each hydroelectric development has not resulted in river channel "armoring" of the immediate tailwater area below each power plant. River channel armoring is typically characterized as a complete absence of smaller substrates such as sand and gravel with only larger coarse substrate types present such as bedrock and boulders. Smaller substrate categories, which included combinations of silt, sand, gravel, and cobble, comprised 18 and 22 percent, respectively, in the Tillery and Blewett Falls Hydroelectric Plants tailwater areas. Additionally, combinations of cobble and gravel with boulder and bedrock substrates, accounted for 42 and 63 percent of the total mapped areas in the Tillery and Blewett Falls Hydroelectric Plants study sites, respectively.

Recruitment rates of gravel and other small particle substrate types into the immediate tailwater areas were not determined by this study. Moreover, no comparable historical data exists to determine the stability or persistence of small particle substrate types over the life span of the Project. However, the prevalence of smaller substrate types throughout each power plant tailwater study site suggested that the flow regimes of each hydroelectric development have not been of a magnitude to scour away smaller particle substrates.

Section 7 – Summary of Results and Recommendations

These results show the potential of using very high-resolution digital imagery to delineate and quantify aquatic substrates. Given the range of substrate sizes and depths examined, the results of this study should apply to others interested in sediment transport issues. The results support the value of utilizing remote sensing, coupled with ground reference data, to effectively document the diversity and spatial distribution of aquatic substrates.

These results are directly dependant on the visibility of the substrate through the water column. Visibility is affected by water depth, turbidity, shadows, overhanging vegetation, and sun glare. Results will improve as this visibility is maximized. If controllable, as was the case in this project, water depth should be at minimum and during low flow conditions. This can be further improved by acquiring aerial photographs during a time of the year that lends itself to the lowest rainfall. This will reduce the overall flow in the system and minimize unwanted turbidity from runoff. The aerial photography should also be tasked on a day with minimum cloud cover to reduce cloud shadowing and maximize the light penetrating the water thus illuminating the substrate as much as possible. Photography should also be taken during mid-day hours or at the highest angle possible. This increases the amount of light available, minimizes shadowing from near shore vegetation, and reduces the chance of sun glare on the water surface. Results can further be improved by acquiring photography during the winter or leaf off conditions. This will improve visibility by reducing the amount of overhanging vegetation in near shore areas. If winter is not suitable for lowest flow conditions, it may be helpful to take photography in both seasons.

Future applications of this project will include repeating these methods / study, at the same study sites, every five years to document any change in substrate composition or spatial distribution. Referenced to the results of this study, Progress Energy will be able to monitor the patterns of sediment transport below these two hydroelectric developments. Another extension of this study will be to relate water quality, fish, crayfish, and benthic invertebrate survey data collected within these study areas and determine if there certain substrate types can be associated with specific parameters, species or population densities. It will be important to make sure that future aerial photography is comparable to the photography used in this study.

Remote sensing technology is quickly advancing and in five years there may be a better method to use in completing this study. Digital cameras are becoming better options as their resolution and availability improve. The resolution and availability of satellite imagery is also improving and should be considered for future applications. Both digital aerial imagery and satellite imagery will preserve the spectral signatures of the surfaces being sensed. This would add another dimension to data and lend itself to automated digital classifications as the problems with sensing through water are solved. These probable advancements in technology and science will make studies similar to this even more feasible and cost effective.

Section 8 – Acknowledgments

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Section 10 - APPENDICES

APPENDIX A
MODIFIED WENTWORTH CLASSIFICATION FOR SUBSTRATE PARTICLE SIZE UTILIZED DURING THE SUBSTRATE CHARACTERIZATION STUDY OF THE TAILWATER AREAS OF THE TILLERY AND BLEWETT FALLS HYDROELECTRIC PLANTS DURING 2005

Appendix A Modified Wentworth classification for substrate particle size utilized during the substrate characterization study of the tailwater areas of the Tillery and Blewett Falls Hydroelectric Plants during 2005.

Substrate Classification	Particle Size Range (mm)
Boulder	> 256
Cobble	64-256
Pebble	32-64
	16-32
Gravel	8-16
	4-8
	2-4
Very coarse sand	1-2
Coarse sand	0.5-1
Medium sand	0.25-0.5
Fine sand	0.125-0.25
Very fine sand	0.0625-0.125
Silt	0.0039-0.0625
Clay	< 0.0039