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Limnoarchaeology Using Commercially Available Side Scan Sonar:

The Locks of the Muscle Shoals Canal, Alabama

by

Robert Kavanaugh

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

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Limnoarchaeology Using Commercially Available Side Scan Sonar:

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Abstract

This research aims to introduce, utilize and analyze commercially available side-scan sonar units as a viable scientific research tool in the interest of historic preservation and archaeological inventory of submerged structures and landscapes using a case study of the Muscle Shoals Canal in Alabama. Opened in November 1890, the nine locks of the Muscle Shoals Canal allowed traffic on the Tennessee River to circumvent the treacherous "Muscle Shoals", an achievement that replaced an abandoned attempt from over a half century earlier. The canal would continue operations until April 1918, when construction of Wilson Dam blocked river traffic through the canal. After completion of the dam in 1924, the canal system was flooded by the newly formed Wilson Reservoir. This study used commercial grade sonar equipment to image flooded remains of the canal system. Along with inexpensive commercial software, a single low-cost sonar unit was capable of producing 3D bathymetry, side-scan imagery of the canal system, and detailed down-scan imagery of individual features of remaining lock components. Sonar output was compared to historical photographs of the canal and lock structures in order to examine what level of detail is possible from this consumer grade technology. Results show that the consumer grade sonar used in this study is capable of providing data suitable for creation of resource inventories of historical sites in the interest of historic preservation. The low cost and efficiency of consumer grade sonar units have potential to open the doors to future research and exploration of underwater treasures.

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Preface

Fishing has been a hobby of mine since I was strong enough to hold a rod. To those that know me well, it came as no surprise that my thesis research would center around being on the water. Having been involved with the sport for so long, I have been exposed to the constant evolution in technology behind GPS and sonar units produced for recreational fishermen. Several years ago, when Humminbird first introduced their Side Imaging Sonar to the market, I immediately became infatuated with the technology, and became curious about its capabilities. Lowrance would soon follow suit with their own side scan sonar system, and before long it seemed like everybody had one of the two systems on their boat. Prior to this research, I have never owned a side scan unit, but I have been fortunate enough to ride along with several top-level fishermen during major tournaments where I was able to see the sonar in use by professionals who relied upon it for their livelihoods. I was impressed with the functionality and resolution of these consumer grade units, and even as an avid fisherman all I could think of were additional uses for the technology. This research represents my opportunity to turn this curiosity into a reality.

The structure of this thesis builds around the creation of a journal article tailored for submission to a peer reviewed journal. Chapter 1 contains a traditional introduction, Chapter 2 contains a thorough literature review, and Chapter 3 details the methods used in the study. Chapter 4 is the journal article in its entirety, to include its own set of references. Included in the article are condensed versions of the introduction and literature review found in previous chapters. Methods were not condensed in the article, as they are the focus of the research. Findings are presented in Chapter 4 as well as a

conclusion for the article. Chapter 5 contains the conclusion for the thesis and is followed by a complete set of references. Due to this format, there will be some duplication of text and figures.

Chapter 1

INTRODUCTION

In recent years, side scan sonar technology has made its way into low cost commercially available units targeted at the recreational fishing industry. These units evolved from high cost scientific instruments which in turn have their origins in sonar developed for military use (Duck & Dow, 1994). This study will utilize this low-cost technology in a case study of the Muscle Shoals Canal in Alabama, in order to see if it is capable of providing usable data to local historical organizations that would otherwise not be able to afford underwater surveys. Technological innovations in sonar realized in the consumer market could have a positive impact on small scale or low budget scientific study. The accessibility and affordability of this level of sonar will open doors to research that was previously thought to be out of reach.

Over the past century, the damming of waterways has submerged landscapes that were once bustling with riverside activity. People were displaced from their homes, large agricultural areas were flooded and commercial structures were lost to the depths of these newly formed reservoirs. Entire towns were displaced and many have since been forgotten, lost to time, water, and a layer of silt. Bainbridge, Alabama, is one such town, lost to the same waters that now cover the Muscle Shoals Canal. Significant historic landscapes have been lost to damming in exchange for hydroelectric generation, clear navigation and flood control (Sonnenburg & Boyce, 2008). The riverbank settlements of early inhabitants of North Alabama are now exposed only during the low-water winter periods. Limnoarchaeology (an all but forgotten term describing the study of reservoirs

and lakes occupying areas formerly settled by man) seeks to investigate these once inhabited areas, and man-made landscapes and relics left behind.

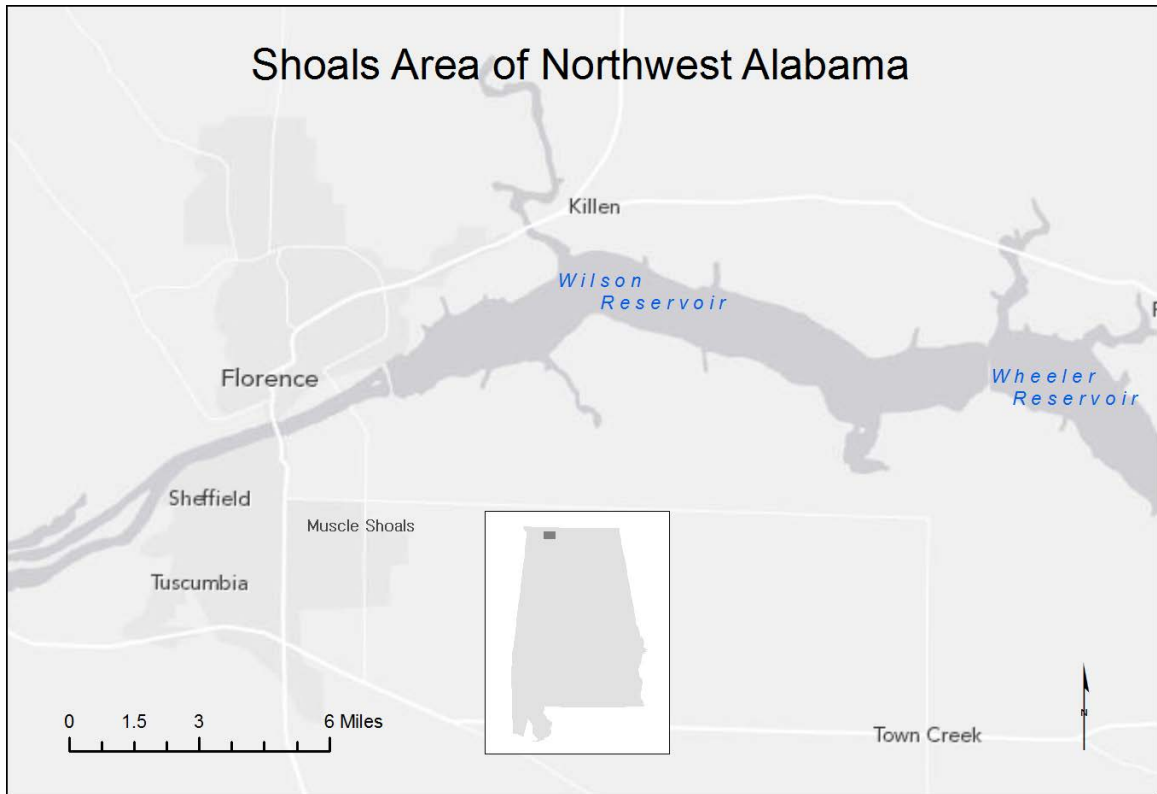


Figure 1.1 Location of the Shoals Area of Northwest Alabama

Along the Tennessee River in Northwest Alabama lies an area known as the Muscle Shoals. Once impassible to river traffic due to its rapid elevation change and rushing whitewater over an unforgiving riverbed of chert and limestone, it now lies tamed and forever buried under Wilson and Wheeler Reservoirs. The building of Wilson and Wheeler Dams have offered decades of unimpeded travel through the Muscle Shoals, but they were not the first solution to the problem of navigation through this stretch of the Tennessee River (Tennessee Valley Authority, n.d.; US Army Corps of Engineers, 2010).

Development of the steam engine by Robert Fulton and the subsequent redesign of the steamship for river travel by Henry Shreve in the early 1800's changed perceptions of river traffic in America (Winn, 1978). It became possible to move great amounts of raw materials and goods to drive increasing industrialization. In 1828, a Shreve designed boat successfully navigated through the Muscle Shoals during high water, effectively connecting the upper and lower reaches of the Tennessee River while bringing to attention the benefits of having a canal system built around the shoals. The original attempt at such a canal resulted in a 17 lock system built by the state of Alabama, called the Tennessee Canal. Completed in 1836, lack of maintenance funding and unreliability during the low water season would deem the canal obsolete and it would be abandoned only two years later. Following the Civil War, there was interest in rebuilding the canal. Work on the new canal would begin in 1875 after eight years of planning by the Corps of Engineers. The old canal was widened and the system would include only nine locks as well as an aqueduct over Shoal Creek (Winn, 1978). Work continued slowly until 1888 when Lieutenant George Washington Goethals was sent to direct the completion of the canal. His leadership resulted in the Muscle Shoals Canal opening to river traffic in November, 1890. Goethals would later go on to serve as Chief Engineer for the Panama Canal. The Muscle Shoals Canal would remain open from November 1890 until the summer of 1918, when coffer dams built for the construction of Wilson Dam would block the canal's path (Center of Military History, 2009; Winn, 1978).

The Muscle Shoals Canal is of archaeological significance due to its provenance (having been associated with George Washington Goethals) and the importance of successfully conquering a natural impediment to river traffic that played a significant role

in the settlement of the area. The importance of bringing to light the cultural landscapes that have been submerged was summed up by Arthur Cohn (2000):

The world's collection of submerged cultural resources belongs to the world's citizens, and bringing these sites to public attention will be the key to their effective management, study, and funding. The archaeological process must include steps that will connect the public, both here and abroad, to its own past and its own cultural resources. Private citizens must understand and care about these issues, because the archaeological community needs their assistance and support in order to manage the sites, to preserve them, to lobby for state and federal recognition, and to fund their documentation. Concerned public advocacy will give us our best opportunity to preserve, document, interpret, and learn from our ever more accessible submerged heritage.

Public awareness of underwater sites through GIS and websites will help to create a commitment to protection by those exposed to them (Zeebroek & Demerre, 2009). Side scan sonar imagery offers a look into the remains of cultural resources long lost to flooding.

Output from side scan sonar is generally not intuitively interpreted even by some technically savvy users. Google Maps and Google Earth have emerged as familiar places to display and share geographic data for trained geographers and neogeographers alike. Geovisualization of the data will include converting sonar output into georeferenced imagery tiles for use in these familiar platforms. Sonar output will be paired with historical photographs when available, with labels and annotations to point out and discuss common features.

This research will bring to light new information in two areas: condition of the archaeological remains of the Muscle Shoals Canal, and effectiveness of consumer grade sonar units in scientific research. The canal information will serve several interested historic preservation organizations, and could spark new interest in the canal system

leading to educational and preservation efforts moving forward. Understanding the suitability of the sonar used in this research to scientific study could give small organizations, universities, and private citizens access to underwater archaeology never before thought possible. Additional uses for the technology beyond archaeology could also be found, opening even more doors for future research.

The Muscle Shoals Canal was selected for study for several reasons. It is a culturally significant structure pushed to completion by George Washington Goethals, who would go on to become Chief Engineer for the Panama Canal. It was the first successful attempt to bypass a natural impediment to navigation that played a role in settlement patterns of North Alabama. It lies at varying depths and contains well preserved features of different shapes and sizes, offering a thorough test of the sonar's ability to return detailed imagery from objects of different shapes and depths. The canal lock locations are readily available, are close to the university and are close to ramp locations for ease of access. Overall, the Muscle Shoals Canal has proven to be the ideal test location for this study.

Side scan sonar has long been used for exploration of historically significant sites since its adaptation from wartime sonar units (Delgado, 2000; Hobbs *et al.*, 1994; Smith, 2005). This technology in its consumer grade form has been used for biomass volume surveys (Valley & Drake, 2005) and consumer broadband sonar units have been used along with standalone GPS units to create bathymetry (Sonnenburg & Boyce, 2008). This study is the first attempt to tie together consumer grade side scan sonar with the creation of resource inventories of historical sites. Other types of sonar surveys, such as

engineering surveys of dam structures (Song, 2005) could possibly be replicated at a fraction of the cost.

Chapter 2

LITERATURE REVIEW

Historic Preservation

Historic preservation in America has taken many forms. The earliest examples were patriotic in nature with the preservation of Washington's Mt. Vernon in by Ann Pamela Cunningham in 1853. The formation of her Mount Vernon Ladies Association would serve as a model for other early preservation organizations (Barthel, 1989). Later, the Antiquities Act of 1906 was passed allowing the President to set aside land in the interest of protecting "objects of historic and scientific interest." The 1930's saw a split among preservationists. Some were assigned to make-work programs aimed at the documentation and restoration of old buildings while others were employed in the River Basin Salvage Programs, a sort of emergency salvage ahead of dam creation projects such as those by the TVA. The differences in these two approaches, one in the interest of restoration and the other in the hurried inventory of heritage sites soon to be destroyed, has created tension among preservationists that remains to this day (King & Lyneis, 1978). The River Basin Salvage Programs would later be transformed into law in the form of the Reservoir Salvage Act of 1960, a federal mandate providing for the recovery and preservation of historical and archaeological data in advance of reservoir construction.

Federal involvement in historic preservation largely stems from the vision and efforts of the United States Conference Of Mayors and the publication of *With Heritage So Rich*, a report of a special committee on historic preservation, ultimately leading to the development of the *National Historic Preservation Act* (NHPA) of 1966. The NHPA

called for an expansive inventory of properties reflecting the full range of the national heritage, a mechanism to protect those properties from unnecessary harm caused by federal activities, a program of financial incentives, embracing both grants and tax incentives, to encourage the preservation of non federally owned historic properties, and an independent federal preservation body to coordinate the actions of federal agencies affecting historic preservation (Stipe, 2003). The NHPA recognizes that effective preservation relies on cooperation between levels of federal and state governments as well as private organization, and has long recognized that the bulk of preservation efforts occur outside of federal programs at the local level by private interests.

The flooding of the structures in this study began in 1918, well in advance of any federal preservation programs. A resource inventory of the canal system prior to flooding would have been an invaluable resource to local historians, but none are known to have taken place. As such, the current state of the Muscle Shoals Canal system is largely unknown, its secrets given up to only a handful of divers willing to brave the dark, silty waters of Wilson Reservoir. This raises the issue of whether preservation efforts should be aimed at the recovery of related artifacts or if they should be documented and left in place. In situ preservation is increasingly being used in archaeological sites (Corfield, 1996). Martijn Manders (2009) advocates in situ preservation, creating an "underwater archive" for "future enjoyment and research." The difficulty in this type of approach in underwater archaeology is obvious, the remains are under water. How does one gain access to such sites? Should artifacts be salvaged so that everyone has equal access? This is a highly contested area of debate between salvage lawyers and archaeologists, most often with salvage attorneys in favor of removal for public use and archaeologists in

favor of in situ preservation for further study (Abbass, 1999). The in situ conservation approach is ideally suited to the non-invasive nature of the sonar surveys to be carried out in this study. An entire resource inventory can be collected without disturbing the site.

Underwater Archaeology

Geographic research often crosses disciplines, and this study is no exception. Geographic techniques and technology combine with limnology and archaeology to form a study in geoarchaeology, which can be described as application of the geosciences to solve research problems in archaeology (Pollard, 1999). A geographic information system (GIS) can serve to manage and display vast amounts of archaeological data both in space and in time, while digital elevation models (DEM) allow the three-dimensional reconstruction of landscapes (Ghilardi & Desruelles, 2009). This research will pair remote sensing and cartography with limnology (the study of inland waters) to investigate submerged historical artifacts, continuing the efforts of Robert Duck and John McManus (1987), albeit with the latest in consumer grade equipment in lieu of a more extravagant setup.

Side scan sonar can be used as the primary method in identifying archaeological remains on the seafloor or it can be used in conjunction with diver surveys as a sort of underwater ground truthing (Quinn *et al.*, 2002). In studies where diving is the end goal, side scan sonar can reduce the amount of time spent on the water searching for remains and better prepares divers for what they will encounter by giving them a photograph-like view of the seafloor or lakebed prior to entering the water (Pasqualini *et al.*, 2000).

Maritime exploration typically involves the use of expensive specialized equipment aboard large research vessels, whether in the form of an autonomous underwater vehicle (AUV) complete with chemical and imaging sensors, a remotely operated vehicle (ROV) with live video and sub-bottom profilers, or as towable sonar systems and their array of processing equipment and analysis software (Foley *et al.*, 2009; Conte *et al.*, 2010). These traditional maritime methods, typically used in high value or high profile searches are not suited to underwater archaeology due to the high costs of operation. The daily cost of running a large research vessel, in the tens of thousands of dollars, could fund an entire season of land-based archaeological research (Coleman & Ballard, 2008). Based on the understanding that most historical preservation occurs at the local level, efforts are being made to downscale underwater archaeological research to allow local private entities to manage preservation of heritage sites (Gregory, 2012). Repurposing of inexpensive side scan sonar units in this research builds on these efforts to downscale operational scale and costs.

Reconstruction of underwater landscapes presents a challenge to conventional geotechniques, often requiring repurposing of existing equipment to achieve desired results. High resolution bathymetry can be used to reconstruct underwater landscapes. Evidence of past sea-level change can be extracted as well as identification of settlement sites with high levels of archaeological significance. Identification of sites via bathymetric survey can form the basis of future research and exploration (Westley *et al.*, 2011). A low cost geotechnique has been introduced that allows three dimensional reconstruction of underwater structures and objects. Using multiple inexpensive cameras and an algorithm which identifies common points among pictures, a point cloud can be

created allowing three dimensional reconstruction of objects such as coral reefs, shipwrecks, or geological formations (Andono, 2012). Additional techniques involve the use of high definition video as a basis for three dimensional reconstruction. This technique results in a highly accurate representation of underwater structures (Beall *et al.*, 2010).

Underwater archaeology serves to aid in the understanding of patterns of past human settlements, often directly associated with the study of Pleistocene sea-level change. As water levels fluctuated, so too did coastlines and settlement areas. The study of these submerged records, spurred on by ever evolving techniques and technologies, are part of the rapidly growing field of underwater archaeology (Bailey & Flemming, 2008). The evolution of underwater techniques raises concern among archaeologists, as visualization of submerged structures becomes more detailed. Some argue that the advanced visualization techniques are being substituted for interpretation instead of being treated as data (Sperry, 2009). The images produced in this study form the basis for further interpretation and comparison to existing historical photography, and do not serve as replacements for interpretation.

Remote Sensing

There are conflicting views concerning whether sonar is considered remote sensing. Confusion stems from the belief that remote sensing is limited to airborne sensors, a narrow point of view that eliminates sonar from consideration. In some cases, all techniques outside of viewing the Earth's surface through the atmosphere with electromagnetic radiation are considered to be *Earth Observation* (Rees, 2001). Others

include sonar in their definition of remote sensing. "The broad definition of remote sensing would encompass vision, astronomy, space probes, most of medical imaging, nondestructive testing, sonar, observing the earth from a distance, as well as many other areas" (Schott, 2007). Tueller (2006) also includes sonar in his definition of remote sensing: "Remote sensing information is derived from measurements of electromagnetic radiation by air- or satellite-borne cameras, video cameras, ultraviolet and infrared detection apparatus; radar and radio frequency receivers; the measurement of acoustical energy by seismographs, sonar and microphones; the measurement of nuclear or ionizing radiation; and the measurement of force fields by gravimeters and magnetometers."

Utilization of sensors at or near the surface of Earth is often useful to archaeologists (Wiseman & El-Baz, 2007). Sonar is particularly useful in search and location of underwater objects, a feat not within the capabilities of airborne sensors (Caiti, *et al.*, 2006). As with airborne active remote sensing platforms, sonar (sound navigation and ranging) emits pulses of energy, in this case sound, that interact with the target surface and reflections are interpreted by a sensor. Side scan sonar units emit a thin beam of sound, or 'chirp' several times per second perpendicular to the direction of travel. Returns from these chirps are then stacked against one another forming images of the sea floor or lake bed. As is the case with other remotely sensed data, image analysis is key to the extraction of information about objects from sonographs. Key topics relevant to information extraction include edge detection; perimeter, distance, area, and volume measures; shape from shading, texture, and motion; morphologic analysis; pattern recognition; correlation and feature extraction (Beck, 1993). Atallah *et al.* (2005) note a concern that the relatively low resolution found in commercial sonar units may lead to

misinterpretation of natural (rocks) and anthropogenic objects (fishing equipment) on the seafloor as archaeological artifacts.

Sonar

Sonar and side scan sonar, like many other remote sensing techniques, evolved from military use. Originally developed during World War II to locate enemy submarines, side scan sonar was later extensively used in marine exploration efforts to map the seafloor (Duck & Dow, 1994). Ability to view relief and distinguish various types of deposits and outcroppings on the sonographs (side scan sonar output) made this technique particularly useful. As the technology was refined and higher resolution sonographs became available, an additional use for side scan sonar was realized; it became possible to detect and identify remains of anthropogenic structures on the seafloor, distinguishing them from naturally occurring formations (Duck & McManus, 1987). Additional uses for side scan sonar are discussed by Duck & Dow (1994):

Side-scan sonar systems have found significant applications in, for example, coastal structures inspection, dam and bridge inspection, pre- and postdredging inspections and pre- and postpipeline installation inspections. Primarily in the search for shipwrecks and the remains of crashed aircraft, sidescan sonar has also been widely utilized in maritime archaeology and, for the study of submerged lake dwellings and flooded settlements, in limnoarchaeology.

Traditionally, utilizing sonar equipment for these purposes has been an expensive undertaking well out of the reach of many historical organizations, such as those who stand to benefit from this research. Due to the high cost of equipment and operation, few advanced research projects have been carried out. The few studies that have been conducted generally result from borrowed equipment from a university with similar

archaeological interests, borrowed equipment from manufacturers who want to prove the potential of their technology, or surveys driven by treasure hunting (Soreide, 2000).

High end sonar units (Singh, *et al.*, 2000) typically consist of a towable transducer ("towfish" or "fish") pulled behind a vessel connected by a tether that relays sonar data to an onboard computer running specialized software. Each towfish contains two sonar transducers that fan out to either side of the boat. Depth of the towfish can be varied based on the bottom depth, and swath width can be several hundred meters. Even smaller towable side scan units can cost upwards of \$35,000. Side scan and broadband sonar is now available in an affordable off the shelf package that includes charting and GPS capability (Strawn, 2009). These units are targeted at the recreational fishing industry and can be purchased for \$1,000-\$3,000 depending on options such as screen size. This pricing becomes even more remarkable given the fact that the units are self contained and available with large displays, eliminating the need and expense of having a computer in the vessel to control the sonar. However, should the researcher want to perform more advanced on the water analysis, networking between the sonar unit and a computer is available through the use of NMEA networking. Of course, the lower price does include reduced power and resolution as compared to larger towable units. Additionally, the transducers on these units are mounted directly to the vessel. This limits the flexibility of the system regarding depth range, effectively limiting these consumer-grade systems to shallow-water operation only, such as limnoarchaeological surveys in manmade reservoirs. Consumer grade sonar units also require optimal water conditions for accurate data collection. Wind and waves can affect pitch and roll of the vessel, skewing results as

these are not corrected within the sonar units. Many towable units will include pitch, roll, and heading sensors for increased accuracy.

Consumer grade sonar units were used with great success to create bathymetry as a base for side scan sonar output in research performed to locate the flooded channel and canal system hidden beneath Colonel By Lake in Ontario, Canada. Broadband sonar was used to measure depth in a crosshatched track line pattern. Data were then aggregated and analyzed to remove errors in positioning or depth readings (Sonnenburg & Boyce, 2008). Consumer grade sonar units are also currently being used to measure submerged vegetation biomass volumes in lakes. Sonar data from these units is processed to measure bottom depth and vegetation height from a single sonar return. Resultant differences between bottom depth and vegetation height result in an accurate biomass volume assessment. Results were checked for accuracy and precision by comparing sonar results to diver surveys (Valley & Drake, 2005). This raises the issue of how to check for accuracy in the side scan sonar returns recorded in this study without ground truthing via diving.

Image Interpretation

Sonograph interpretation is inherently subjective due to the many sources of error possible in their creation (Singh, *et al.*, 2000). One method, when available, is to compare sonographs to historical photography. This method is also subjective and prone to error due to the vast majority of historical photographs being taken at ground level, resulting in high oblique images that are compared to sonographs with a vertical orientation. However, for the purposes of this study, this comparison will be adequate as most

features to be identified are rather coarse, such as lock chambers, the limestone blocks of which they are constructed and even remains of a levy constructed to contain canal waters.

Much like analyzing aerial photography, shadows, shading, textures and patterns become visual clues to interpreting sonar imagery. "Shadows have played an important role in remote sensing for almost as long as the science has been in existence. From the earliest days of aerial photography, the effects of shadowing have been utilized to highlight ground features in applications such as archaeology and aerial reconnaissance" (Dare, 2005). Shadows play an important role in analysis of vertical imagery, as they offer clues about an object's size and shape that cannot be seen from above.

Chapter 3

METHODS

Data collection performed in this study utilized active remote sensing equipment in the form of a consumer grade side scan sonar unit installed on a 17-foot recreational fishing vessel. Sonar equipment is readily available at major sporting goods suppliers and comes in a range of display configurations to suit various applications and budgets. The 17-foot fishing vessel represents one of the most popular and readily available boats on the market. The equipment chosen for this study are truly mass produced off the shelf items available at a fraction of the cost of specialized scientific equipment. Consumer grade side scan sonar systems retail for \$1,300 to \$4,000 depending on screen size and transducer options.

The points of interest for this study are the nine locks of the Muscle Shoals Canal. This canal system was flooded by the creation of Wilson and Wheeler Reservoirs on the Tennessee River at depths ranging from 0-60 feet. Not all of the locks will be featured in this research. It is not necessary to inventory the entire canal system in order to evaluate the effectiveness of the equipment and software chosen for this study. A selection of locks will be chosen based on the availability of historical photographs, which will aid in the validation of sonar output.

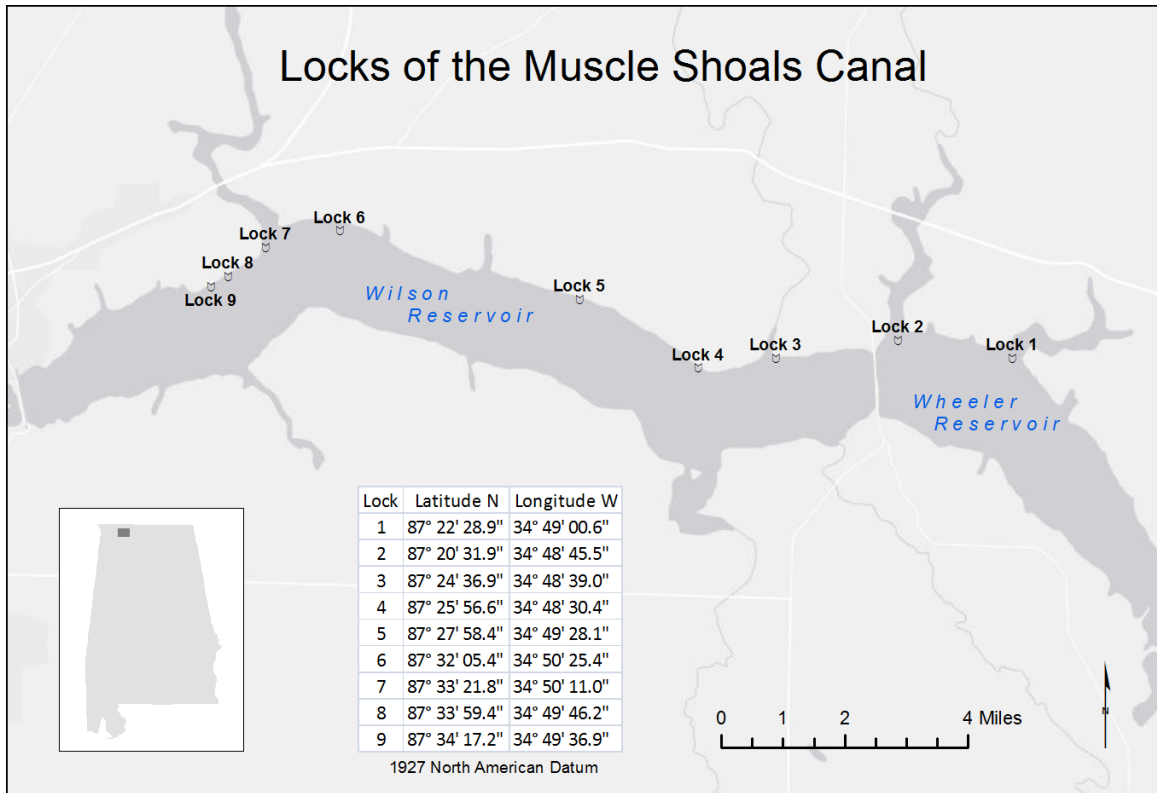


Figure 3.1 Location of the 9 locks of the Muscle Shoals Canal. Symbols indicate the position of each lock chamber based on commercially available fishing maps.

Equipment

Both Lowrance and Humminbird produce side scan sonar units aimed at the recreational fishing industry. Ideally, the capabilities of both brands would be analyzed in this research, however budget limitations resulted in the need to choose only one unit for testing. The Lowrance sales team offered industry insider pricing on equipment used in this research, while Humminbird was unable to offer any assistance. The Lowrance LSS-2 (StructureScan® HD Processor Module) sonar unit and StructureScan® HD Skimmer® Imaging Transducer were paired with a Lowrance HDS-8 Gen2 head unit for on the water display and data retrieval. The sonar is a dual band (Enhanced 455 kHz and 800

kHz) unit with output power of 500W max RMS and 4000W peak-to-peak. The max range is 600 ft side to side and 300 ft down scan.

A notable difference between consumer grade sonar and commercial units is the transducer type. The Lowrance StructureScan® transducer is mounted to the transom of the vessel, unlike the towable transducers typically found on commercial setups. The StructureScan® HD Skimmer® Imaging Transducer is 10.1 inches long by 2.1 inches wide.



Figure 3.2 Mounting location of Skimmer® Imaging Transducer on vessel transom.

For this application, the transducer was mounted slightly inboard of the transom, utilizing the available area in the stepped section of the transom to better position the transducer away from the lower unit of the outboard engine in order to have an unobstructed side to side view of the lake bottom as well as avoiding prop wash at the low speeds required for scanning (Figure 3.2). Typical installations are on larger boats with much more room between the outboard and transom due to increased motor size and often, the use of a

motor jack-plate. The jack plate serves not only to raise and lower the outboard vertically, independent of the tilt/trim function built into the motor, but as a way to set the motor back from the transom anywhere from 6 to 12 inches or more. Jack plate installation is the ideal mounting method for this type of transducer, since it affords ample space between the transom and lower unit of the motor and eliminates the need to drill holes into the hull of the vessel. The installation shown in Figure 3.2 shows the flexibility of this system, as it is mounted successfully on a vessel that is not ideally suited for a transducer of this size.

It is important to mount the transducer such that it is perpendicular to the surface of the water while in operation. This is not an easy task, as the pitch of the vessel can vary with changes in speed, trim angle, passenger load, fuel levels, wind and so on. This means that checking the position of the transducer while at rest will do little good. A simple solution was developed, which will not only aid in setting the mounting angle of the transducer, but will ensure that the proper angle is maintained during scanning and that this setting is repeated for each scan throughout the study.

First, a carpenter's spirit level will be attached to a gimbal head, which will then be attached near the driver's console aboard the vessel. Then, the vessel will be taken out to the water to make simulated scanning runs in order to determine the optimum speed and trim angle for data collection. Once these settings have been determined, the level will be locked into a level setting by the gimbal mount, where it shall remain for the duration of the study. Next, the vessel will be trailered and set to the pitch used during scanning by adjusting the jack on the front of the trailer and referencing the spirit level. Once the vessel is properly oriented according to the spirit level, the transducer angle can

be adjusted to level using another spirit level. This will permanently orient the transducer and the onboard spirit level so that it is possible to view the transducer orientation while on the water and/or underway while scanning, thus ensuring optimal and consistent transducer orientation throughout the study.

Scanning

Locks 1 and 2 are in Wheeler Reservoir while Locks 3-9 are in Wilson Reservoir (see Figure 3.1). Specific X/Y coordinates for Locks 3-9 can be found on the Lake Wilson Recreation and Fishing Guide published by Atlantic Mapping, Inc. and approximate locations available for Locks 1 and 2 from historical literature. Utilizing the charting/GPS features of the HDS-8 head unit, waypoints were entered for each point of interest and scans were made in the general area of waypoint locations until features are found.



Figure 3.3 HDS-8 head unit showing side scan (left) down scan (upper-right) and charting (lower-right)

Figure 3.3 shows the HDS-8 head unit in the configuration used during these scans. The left half of the screen shows left and right side scan, the upper right shows down scan, while the lower right contains the GPS and charting functions. This display setup allows for simultaneous review of location, bearing, speed as well as a live view of the returns from the side scan and down scan sonar.

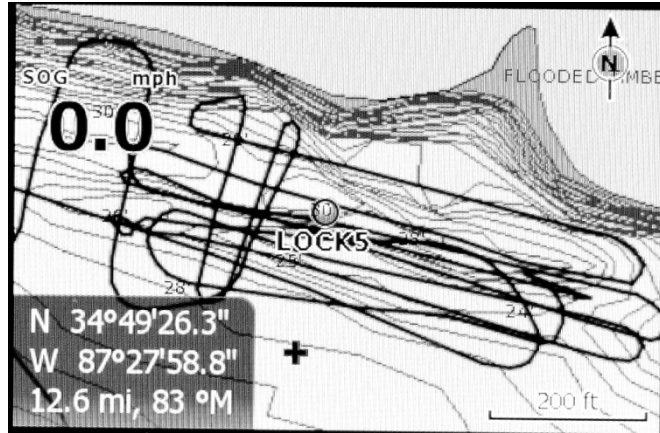


Figure 3.4 Screenshot of track lines from preliminary scans of Lock 5 in the Muscle Shoals Canal.

The features to be scanned are relatively long and narrow, so to avoid possible distortion of side scan results it may be necessary to make several passes of each feature until correct bearing and offset are found. While the general direction of features can be found by orienting scans parallel to bluff walls, it may be necessary to perform a series of perpendicular scans to view a cross section of the area to locate the depression of the lock chamber (Figure 3.4). Finding the correct bearing will produce a scan that represents linear elements of features as a straight line, without having to rely on software correction that may produce skewed results (Figure 3.5). Finding the correct offset is necessary to place the feature in the optimal location in the side scan sonar path. Scanning too far from the feature could lose detail and introduce distortion while scanning too close could result in the feature being split between the right and left sonar paths. This would likely result in distortion and missing information from the area between the two sonar paths.

Bathymetry was collected during separate scans, with track lines running both parallel and perpendicular to the canal. While it is possible to record bathymetry with the

broadband sonar simultaneously with the side scan and down scan imaging, performing a set of scans with crosshatched track lines for the purpose of obtaining depth readings will likely produce better results. Due to the nature of down scan imaging, results from this sonar band can be pulled from either the side scan or broadband runs, as all three bands will be recording for all runs.

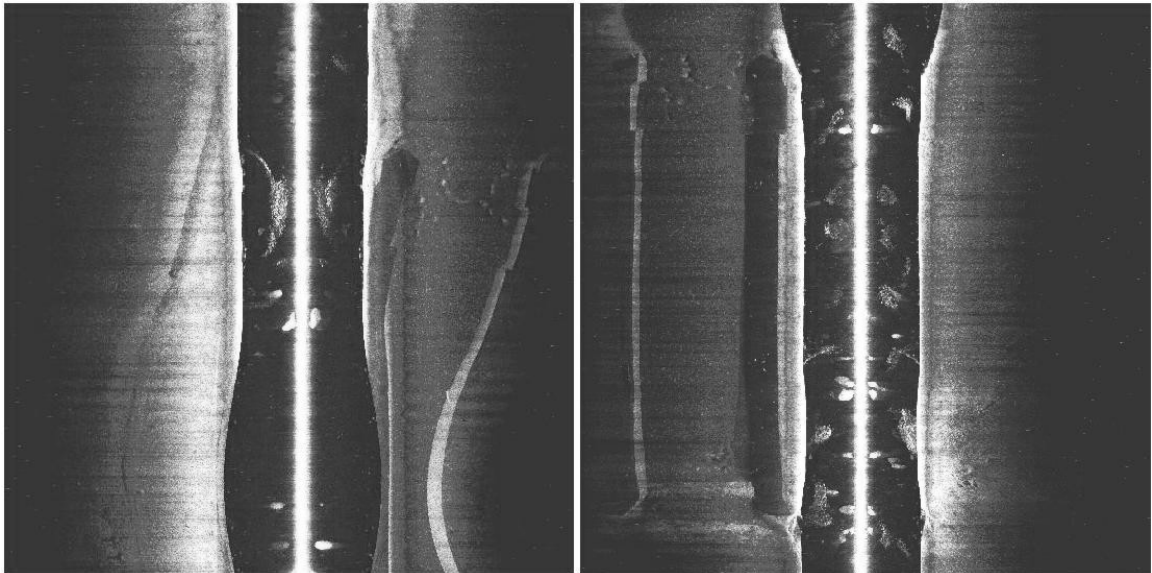


Figure 3.5 Examples of skewed (left) and straight (right) track lines. The scan on the left shows a skewed lock chamber due to an incorrect initial bearing as well as a steering over-correction. The scan on the right shows an undistorted lock chamber due to correct bearing and offset.

Data Processing

In keeping with the theme of utilizing commercially available and affordable products for scientific study, commercial off the shelf (COTS) software will be used to correct and produce custom bathymetry for each area of interest, georeference and

overlay the side scan sonar data over the bathymetry, and export the data into image tiles for use in Google Maps and Google Earth. This software, DrDepth 5.0.8, offers gain correction, depth refinement for mosaics as well as a host of other features for the manipulation, interpretation and exporting of sonar data. The primary market for this software parallels that of the Lowrance sonar used in the study: fishermen and other non-scientific use. As is the case with the hardware used in this study, this software is readily available at fraction of the price of software typically used in scientific studies. The software retails for \$225, and educational discounts are available.

Data collected in this study will be presented in several forms. Side scan sonar imagery will be adjusted for contrast and sensitivity before being exported to georeferenced image tiles for use in mapping applications. The same imagery will be presented alongside historic photography for feature comparison and output evaluation. Down scan sonar will be presented in the same manner. Broadband sonar data will be used to create bathymetric maps of selected canal locations. The end result will be a partial resource inventory of selected locks from the Muscle Shoals Canal.

While the advertised range of the equipment used in the study is 600 ft side scan and 600 ft down scan, initial trials have found that it is difficult to interpret results from more than 120 feet out to the side. Due to the limited depth of study sites, no issues have yet been found with the down scan range. Vessel size and stability will be an obstacle during this study. It is relatively lightweight for its size, and is susceptible to being pushed off course by the wind. Also, wind and water traffic disturb the surface of the water causing the small vessel to rock side to side during scanning which distorts the returns from the transom mounted transducer. These issues would not be present with a

towable sonar. As such, scans will need to be made during early morning hours during the week to avoid wind and disturbance from traffic.

Chapter 4

CREATING A RESOURCE INVENTORY USING CONSUMER GRADE SONAR

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ABSTRACT

This research aims to introduce, utilize and analyze commercially available side-scan sonar units as a viable scientific research tool in the interest of historic preservation and archaeological inventory of submerged structures and landscapes using a case study of the Muscle Shoals Canal in Alabama. Opened in November 1890, the nine locks of the Muscle Shoals Canal allowed traffic on the Tennessee River to circumvent the treacherous "Muscle Shoals", an achievement that replaced an abandoned attempt from over a half century earlier. The canal would continue operations until April 1918, when construction of Wilson Dam blocked river traffic through the canal. After the completion of the dam in 1924, the canal system was flooded by the newly formed Wilson Reservoir. This study used commercial grade sonar equipment to image the flooded remains of the canal system. Along with inexpensive commercial software, a single low-cost sonar unit was capable of producing 3D bathymetry, side-scan imagery of the canal system, and detailed down-scan imagery of individual features of remaining lock components. Sonar output was compared to historical photographs of the canal and lock structures in order to examine what level of detail is possible from this consumer grade technology. The results show that the consumer grade sonar used in this study is capable of providing data suitable to the creation of resource inventories of historical sites in the interest of historic preservation. The low cost and efficiency of consumer grade sonar units has the potential to open the doors to future research and exploration of our underwater treasures.

INTRODUCTION

This study has repurposed a commercially available side scan sonar unit developed for the recreational fishing industry into a scientific instrument capable of collecting imagery of underwater heritage sites. This study utilized this low-cost technology in a case study of the Muscle Shoals Canal in Alabama, to see if it is capable of providing usable data to local historical organizations that would otherwise not be able to afford underwater surveys of flooded points of interest. Imagery can be used to determine the current condition of remaining canal structures, as an inventory of what remains of the original canal, or most importantly, can raise awareness of a historically

and culturally significant structure that many are completely unaware of. Traditionally, utilizing sonar equipment for these purposes has been an expensive undertaking well out of the reach of many historical organizations, such as those who stand to benefit from this research. Due to high cost of equipment and operation, few advanced research projects

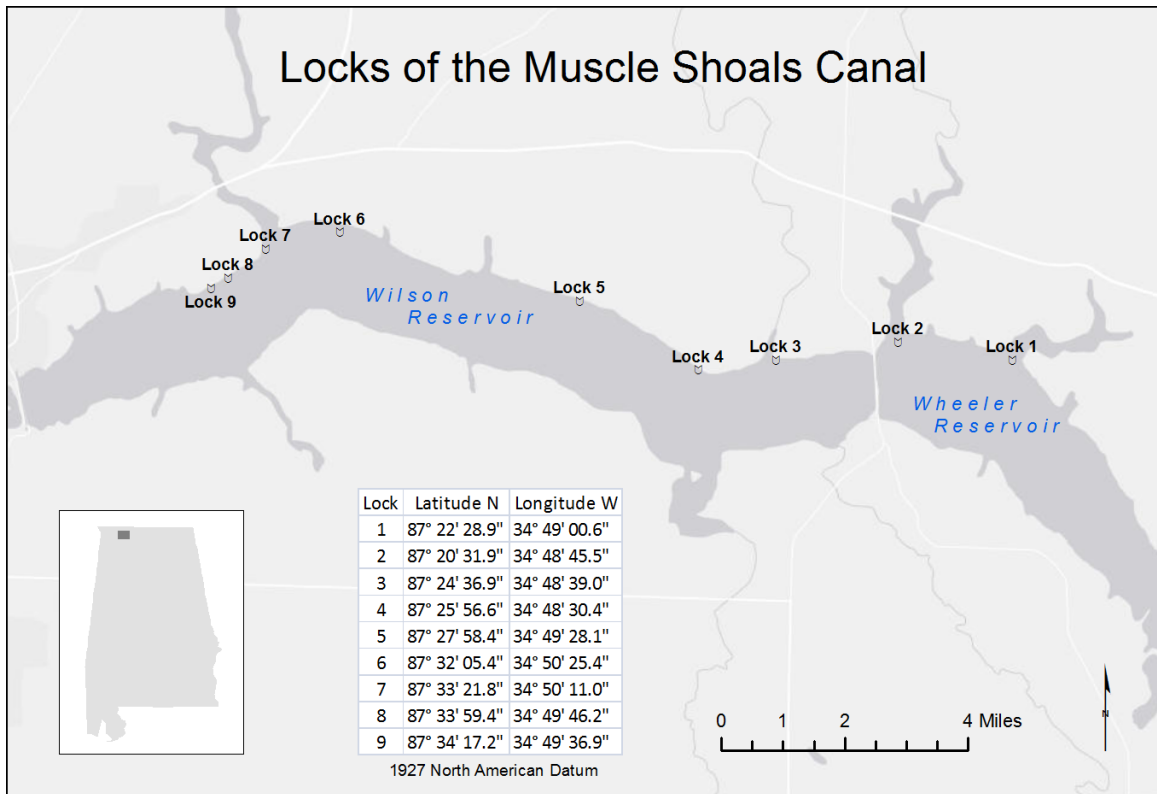


Figure 4.1 Location of the 9 locks of the Muscle Shoals Canal

have been carried out. Research vessels can cost tens of thousands of dollars per day to operate. Studies that have been conducted generally result from borrowed equipment from a university with similar archaeological interests, borrowed equipment from manufacturers who want to prove the potential of their technology, or survey driven by treasure hunting (Soreide, 2000). To date, there have been no academic sonar surveys of the submerged Muscle Shoals Canal. There are accounts of salvage dives around the

Lock 6 area in an attempt to recover a submerged locomotive engine used on the canal, with one account describing a ten year search for the engine prior to an unsuccessful salvage attempt (Stansell, n.d. 1995?). The equipment and methodology described in this research located the locomotive engine in less than one hour, an incredible increase in efficiency over salvage diving alone. It is possible that this increase in efficiency could lead to a renewed interest in diving the canal as points of interest could be found, plotted on a map, and even presented as imagery to divers.

The importance of bringing to light the cultural landscapes that have been submerged was summed up by Arthur Cohn (2000):

The world's collection of submerged cultural resources belongs to the world's citizens, and bringing these sites to public attention will be the key to their effective management, study, and funding. The archaeological process must include steps that will connect the public, both here and abroad, to its own past and its own cultural resources. Private citizens must understand and care about these issues, because the archaeological community needs their assistance and support in order to manage the sites, to preserve them, to lobby for state and federal recognition, and to fund their documentation. Concerned public advocacy will give us our best opportunity to preserve, document, interpret, and learn from our ever more accessible submerged heritage.

The Muscle Shoals Canal played a significant role in the history of northwest Alabama, and its contributions are well documented. Although it is now flooded, documenting its current condition will provide the latest chapter in the history of this important structure. Public awareness of underwater sites through GIS and websites will help to create a commitment to protection by those exposed to them (Zeebroek & Demerre, 2009).

Over the past century, damming of waterways has submerged landscapes that were once bustling with riverside activity. People were displaced from their homes, large agricultural areas were flooded and commercial structures were lost to the depths of these

newly formed reservoirs. Entire towns were displaced and many have since been forgotten, lost to time, water and a layer of silt. Significant historic landscapes have been lost to damming in exchange for hydroelectric generation, clear navigation, and flood control (Sonnenburg & Boyce, 2008). Limnoarchaeology, which describes the study of reservoirs and lakes occupying areas formerly settled by man, seeks to investigate these once inhabited areas and the man-made landscapes and relics left behind.

Along the Tennessee River in northwest Alabama lies an area known as the Muscle Shoals, once impassible to river traffic due to its rapid elevation change and rushing whitewater over an unforgiving riverbed of chert and limestone, it now lies tamed and forever buried under Wilson and Wheeler Reservoirs. Wilson and Wheeler Dams have offered decades of unimpeded travel through the Muscle Shoals, but they were not the first solution to the problem of navigation through this stretch of the Tennessee River (Tennessee Valley Authority, n.d.; US Army Corps of Engineers, 2010). The original attempt at circumventing the Muscle Shoals resulted in a 17 lock system built by the state of Alabama, called the Tennessee Canal. Completed in 1836, lack of maintenance funding and unreliability during the low water season deemed the canal obsolete, and it would be abandoned only two years later.

Following the Civil War, there was interest in rebuilding the canal. After eight years of planning by the Corps of Engineers, work on the new canal would begin in 1875. The old canal was widened and the system would now include only 9 locks (Figure 4.1) as well as an aqueduct over Shoal Creek (Winn, 1978). Work would continue slowly until 1888 when Lieutenant George Washington Goethals, who would later go on to serve as Chief Engineer for the Panama Canal, was sent to direct the completion of the canal. His

leadership resulted in the Muscle Shoals Canal opening to river traffic in November, 1890. The canal would remain open from November 1890 until the summer of 1918, when coffer dams built for the construction of Wilson Dam would block the canal's path (Center of Military History, 2009; Winn, 1978). The Muscle Shoals Canal is of archaeological significance due to its having been associated with George Washington Goethals and the importance of successfully conquering a natural impediment to river traffic that played a significant role in the settlement of the area.

METHODS

Equipment

While low cost consumer grade available side scan sonar is available from Lowrance and Humminbird, time and budget constraints allowed only one brand to be tested in this study. The Lowrance LSS-2 sonar unit was chosen and paired with a Lowrance HDS-8 Gen2 head unit (Figure 4.2) for on the water display and data retrieval. The side scan/ down scan sonar is a dual band 455 kHz and 800 kHz unit with output power of 500W max RMS and 4000W peak-to-peak. The published maximum range is 600ft side to side and 300ft down scan. The unit also features broadband sonar from a second transducer with output frequencies of 50 kHz, 83 kHz and 200kHz with a published maximum depth range of 1524 meters. The head unit contains two SD/MMC slots for mapping cards or data storage. All sonar data for this study was stored to SD cards in the Lowrance .sl2 format. NMEA 2000 and NMEA 0183 networking are available for those wishing to capture live data via laptop or PC.

A notable difference between consumer grade sonar and commercial units is transducer type. The Lowrance transducer is mounted to the vessel transom, unlike towable transducers typically found on commercial setups. The Lowrance transducer measures 10.1 inches long by 2.1 inches wide, considerably smaller than commercial tow fish transducers that can be several feet long and weigh over 100 pounds, but relatively large compared to typical broadband transducers typically mounted to the transom of a recreational boat.

For this application, the transducer was mounted slightly inboard of the transom, utilizing the available area in the stepped section of the transom to better position the transducer away from the lower unit of the outboard engine in order to have an unobstructed side to side view of the lake bottom as well as avoiding prop wash at the low speeds required for scanning (Figure 4.2).



Figure 4.2 HDS-8 head unit showing side scan (left) down scan (upper-right) and charting (lower-right)



Figure 4.3 Mounting location of Skimmer® Imaging Transducer on vessel transom.

Typical installations are on larger boats with much more room between the outboard and transom due to increased motor size and often, use of a motor jack-plate. The jack plate serves not only to raise and lower the outboard vertically, independent of the tilt/trim function built into the motor, but as a way to set the motor back from the transom anywhere from 6 to 12 inches or more. Jack plate installation is the ideal mounting method for this type of transducer, as it affords ample space between the transom and lower unit of the motor and eliminates the need to drill holes into the hull of the vessel. The installation shown in Figure 4.2 shows the flexibility of this system, as it is mounted successfully on a vessel that is not ideally suited for a transducer of this size.

It is important to mount the transducer such that it is perpendicular to the surface of the water while in operation. This is not an easy task, as the pitch of the vessel can vary with changes in speed, trim angle, passenger load, fuel levels, wind and so on. This means that checking the position of the transducer while at rest will do little good. A spirit level was mounted near the boat's console and set to show level during test runs at optimal scanning speed and conditions. The boat was then placed on the trailer and the pitch was adjusted until the bubble in the level mounted near the console was centered. The transducer angle was then adjusted with an additional level. By observing the mounted level during scanning, it was possible to ensure that the proper transducer angle was maintained during scanning and that this setting was repeated for each scan throughout the study.

Data Collection

Locks 1 and 2 are in Wheeler Reservoir while locks 3-9 are in Wilson Reservoir (Figure 4.1). Specific X/Y coordinates for locks 3-9 were found on the Lake Wilson Recreation and Fishing Guide published by Atlantic Mapping, Inc. and approximate locations were plotted for locks 1 & 2 based on historical maps and literature. Utilizing the charting and GPS features of the HDS-8 head unit, waypoints were entered for each point of interest and scans were made in the general area of the waypoint locations until the features were found. Figure 4.4 shows the HDS-8 head unit in the configuration used during these scans. The left half of the screen shows left and right side scan, the upper right shows down scan, while the lower right contains GPS and charting functions.

This display setup allows for simultaneous review of location, bearing, speed as well as a live view of the returns from the side scan and down scan sonar.

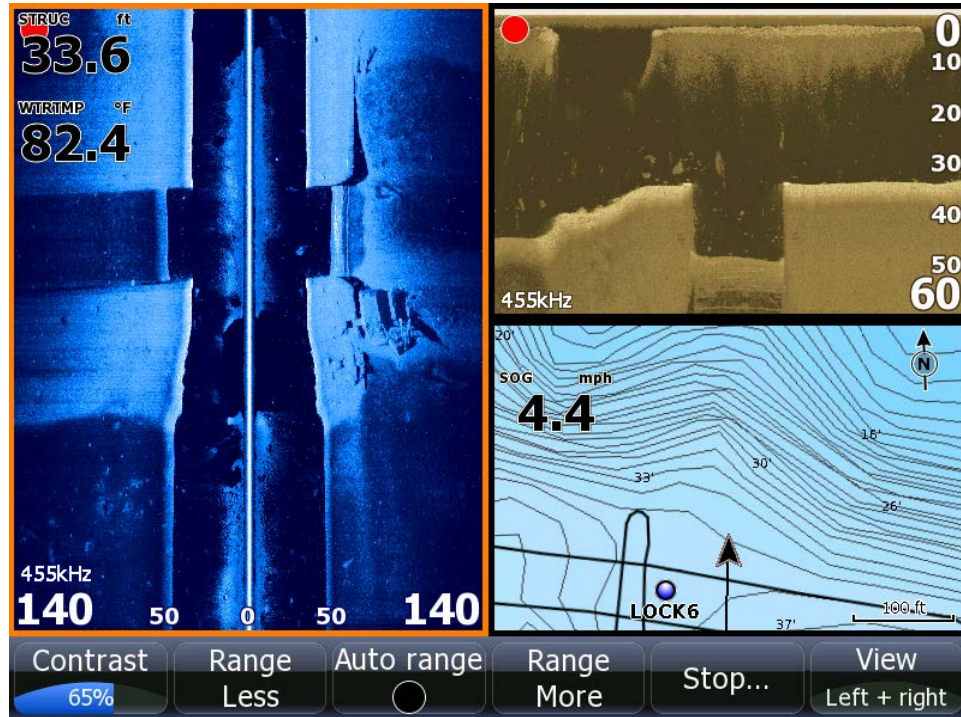


Figure 4.4 Screenshot taken from the HDS-8 unit during scanning of Lock 6 of the Muscle Shoals Canal showing side scan (left) down scan (upper-right) and charting (lower-right).

The locks are long and narrow, so to avoid possible distortion of the side scan results it was necessary to make several passes of each feature until the correct bearing and offset were found. The general direction of the features were found by orienting scans parallel to bluff walls. Finding the correct bearing produced scans that represent linear elements of features as straight lines without having to rely heavily on software

correction. Finding the correct offset was necessary to place features in optimal locations in the side scan sonar path. Scanning too far from the feature caused a loss of detail while scanning too close resulted in features being split between the right and left sonar paths. A speed of 4.5 miles per hour +/- 0.5mph was maintained during scans throughout the study. This was achieved by setting the throttle to 2400 rpm and adjusting the trim so that the motor was perpendicular to the surface of the water. This increased clearance between the transom and outboard to avoid interfering with transducer operation. The speed introduced little to no prop wash in the area of the transducer, was slow enough to achieve acceptable resolution, and was fast enough to maintain a true heading while reducing the effect of chop on the sonar returns.

Side scan and down scan returns were collected using the 455kHz setting. The lower frequency offers less resolution than the 800kHz scan rate; however at depths the features are located (35 to 60 feet), many 800kHz returns were too weak to make out sufficient detail. Lateral range suffered greatly at the higher frequency as well. Operating depths were well within published ranges, however poor water clarity and suspended sediments possibly caused the poor results at 800kHz. Bathymetry runs utilized the 50kHz setting on the broadband transducer as a precaution against similar interference.

Bathymetry was collected using broadband sonar in separate runs from the side scan surveys due to the multiple parallel and perpendicular passes needed to cover each area. Figure 4.5 shows the track lines from the separate parallel and perpendicular scans. Note the waypoints present on the screen capture, as they represent the corners of the lock chamber. During side scan runs, locations were marked on side scan results and their locations were automatically updated on the chart. Lock 7 was an ideal candidate for

collecting bathymetry with this setup, as most of the other locks are too close to bluff walls, making perpendicular scans impossible.

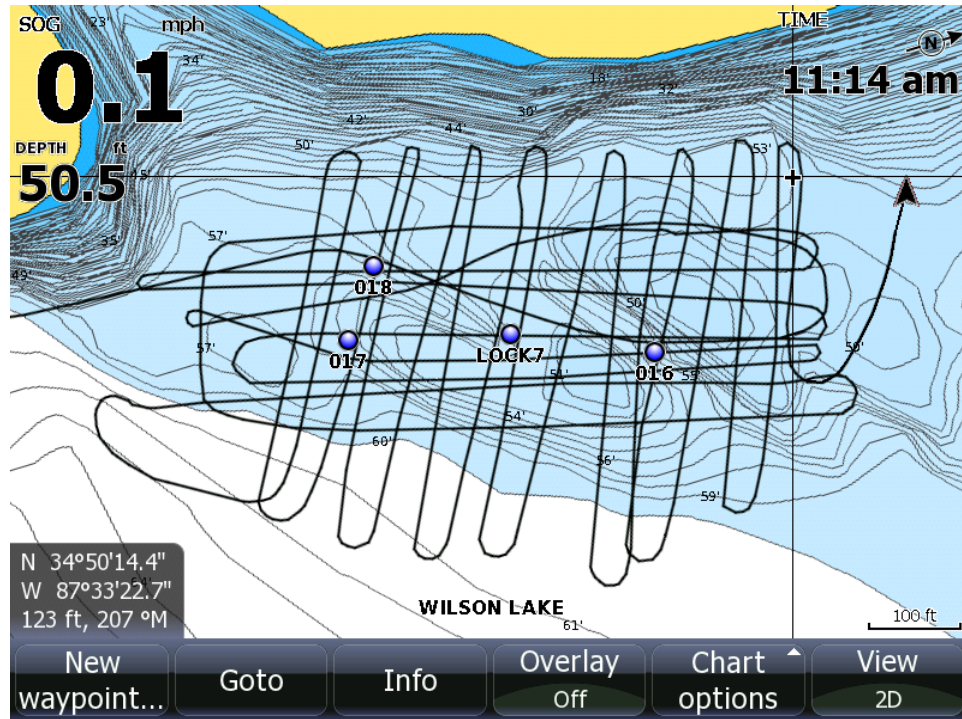


Figure 4.5 Screenshot of track lines during bathymetry scanning of Lock 7 of the Muscle Shoals Canal

Data Processing

In keeping with the theme of utilizing commercially available and affordable products for scientific study, commercial software was used to produce bathymetry, georeference side scan sonar data, and export sonar imagery into image tiles for use in web maps. The bulk of the processing was performed with DrDepth 5.0.8, while preliminary analysis and organization were performed with Lowrance Sonar Viewer 2.1.2

(Figure 4.6). DrDepth software was purchased at a reasonable cost, while the Sonar Viewer software is available as freeware from Lowrance.

Diligence in the scanning phase produced sonar results that needed little path correction, though any corrections made within DrDepth are transparent to the user once transducer offset is entered in to the settings. As the GPS receiver and transducer are mounted in different locations, DrDepth allows for X and Y offsets between the two to be entered and accounted for in processing. This can be particularly helpful when scans are comprised of multiple tracks running opposite directions, in which case the offset would be compounded.

DrDepth has the ability to export georeferenced imagery from sonar data along with a corresponding .kml file for use in Google Earth, Google Maps API, or ArcGIS Online. Lowrance .sl2 files, which contain all 3 sonar bands with positional data, were imported into the software. Broadband sonar appears as a path with depth data that can be interpolated into custom bathymetry, the accuracy of which depends heavily on structure and spacing of track lines for each run. Corresponding side scan imagery can then be overlaid into its correct position or over custom bathymetry. Slight contrast and sensitivity adjustments were made to side scan returns to enhance the visibility of features prior to being exported to image tiles.

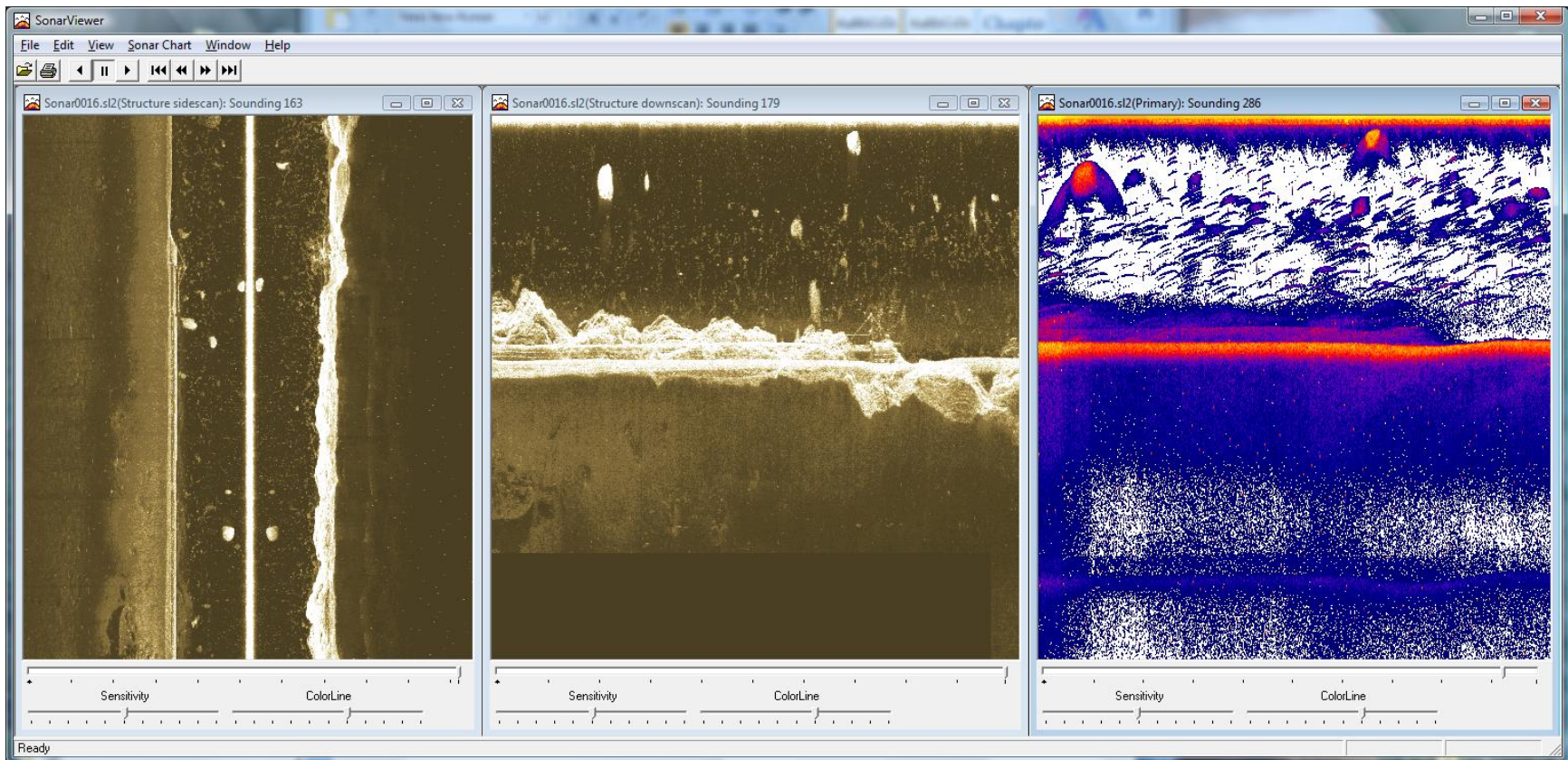


Figure 4.6 Three sonar bands as shown in Lowrance Sonar Viewer 2.1.2

(A) Side scan. (B) Down scan. (C) Broadband.

FINDINGS

Image Analysis

Figure 4.7 shows a side scan sonar and historical photograph comparison for Lock 6. Several features of the lock and surrounding structures can be identified from sonar returns alone, while others are better identified with the aid of historical photography. Individual limestone blocks that make up lock walls (Figure 4.7A) can be clearly seen in sonar returns at the mouth of the lock while gate support structures can only be identified by noticing the sonar shadow they cast on the floor of the lock (Figure 4.7B). As is the case with aerial photography interpretation, sonar returns can sometimes be better identified by analyzing the shadows cast by features. Shadows result when an object blocks the path of the sonar beam and there is no return for an area. Features such as lock gates (Figure 4.7C) are sizable enough to be easily recognizable without consulting photography, while smaller features such as the mooring posts (Figure 4.7D) may be overlooked entirely without the aid of historical images. Additional features (Figure 4.7E, F, G) can be identified in sonar imagery with the aid of pre-flood photographs.

Figure 4.8 shows how historical photography can help to validate sonar results. The bend in the wall leading into the chamber at Lock 7 (Figure 4.8A) first appears to be an error in the sonar return, as it would be assumed that the feature should be perfectly linear. However, the photograph clearly validates the shape of the wall as being bowed. It is possible to identify features in photography by using sonar as well. The square feature (Figure 4.8B) can be seen in the sonar image, but could be overlooked entirely in the photograph without knowing it was there and thereby noticing the reflection in the water.

The stand of trees seen in the photograph (Figure 4.8C) can clearly be seen in the sonar image, both as direct returns and as sonar shadows. Shadows help with determining the height of standing timber, which could be calculated with basic photogrammetry skills and verified with broadband sonar.

Figure 4.9 shows another example of using historical images to understand sonar returns. The Shoal Creek Aqueduct remains intact, and the channel is mostly smooth with the exception of one section that shows some protruding linear elements running parallel to one another (Figure 4.9A). A quick glance at the image on the postcard reveals that the bottom of the aqueduct channel was comprised of metal ribs. This suggests heavy sedimentation in the aqueduct. Further investigation into the sonar image suggests that the sediment is bulged up on the south edge of the aqueduct channel, note how the shading of the sediment suggests a downhill slope toward the exposed ribs. A cross section taken with down scan sonar (Figure 4.10) confirms this uneven sediment buildup.

An undated newspaper clipping was introduced prior to the beginning of data collection that gave an account of a salvage diver spending ten years trying to locate a locomotive believed to have been left behind near Lock 6 (Stansell, n.d. 1995?). While the number of dives and actual time in the water is unknown, ten years is a long time to locate an artifact in 35 feet of water when a general location is known. Using the same general information about the location of the lost locomotive, it was found in under one hour. The location was then saved as a waypoint using the charting capabilities of the Lowrance unit. The speed at which this sonar equipment can scan an area and save exact positional information could aid salvage divers, rescue operations, research studies, or any host of scenarios where finding underwater objects in a timely manner is important.

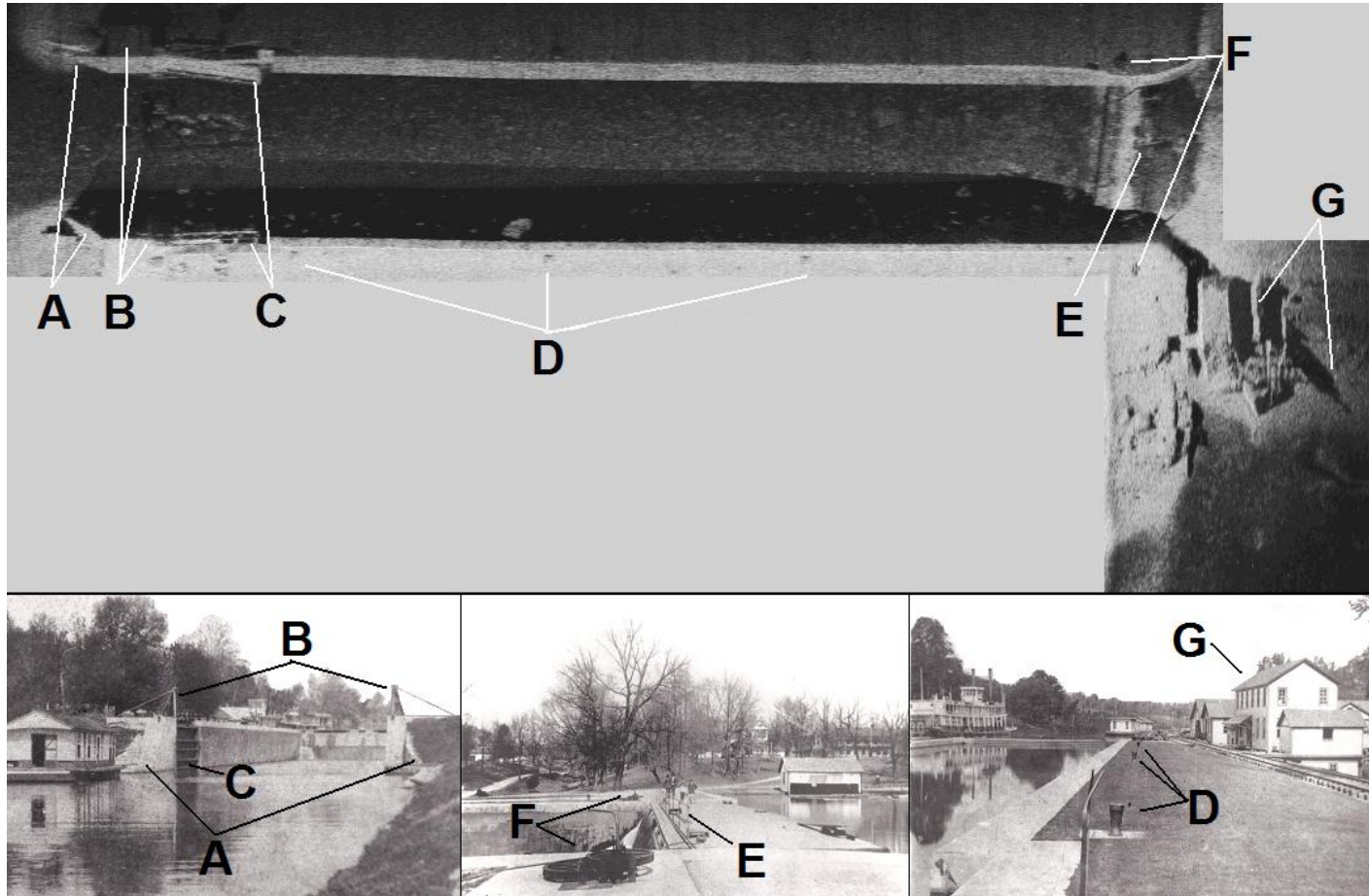


Figure 4.7 Side scan sonar and historical photograph comparison for Lock 6 of the Muscle Shoals Canal. (A) Limestone blocks. (B) Gate support structures. (C) Gates. (D) Mooring posts. (E) Railing. (F) Large gears. (G) Buildings. McDonald Collection Photographs, Archives/Special Collections, Collier Library, University of North Alabama, Florence, Alabama.

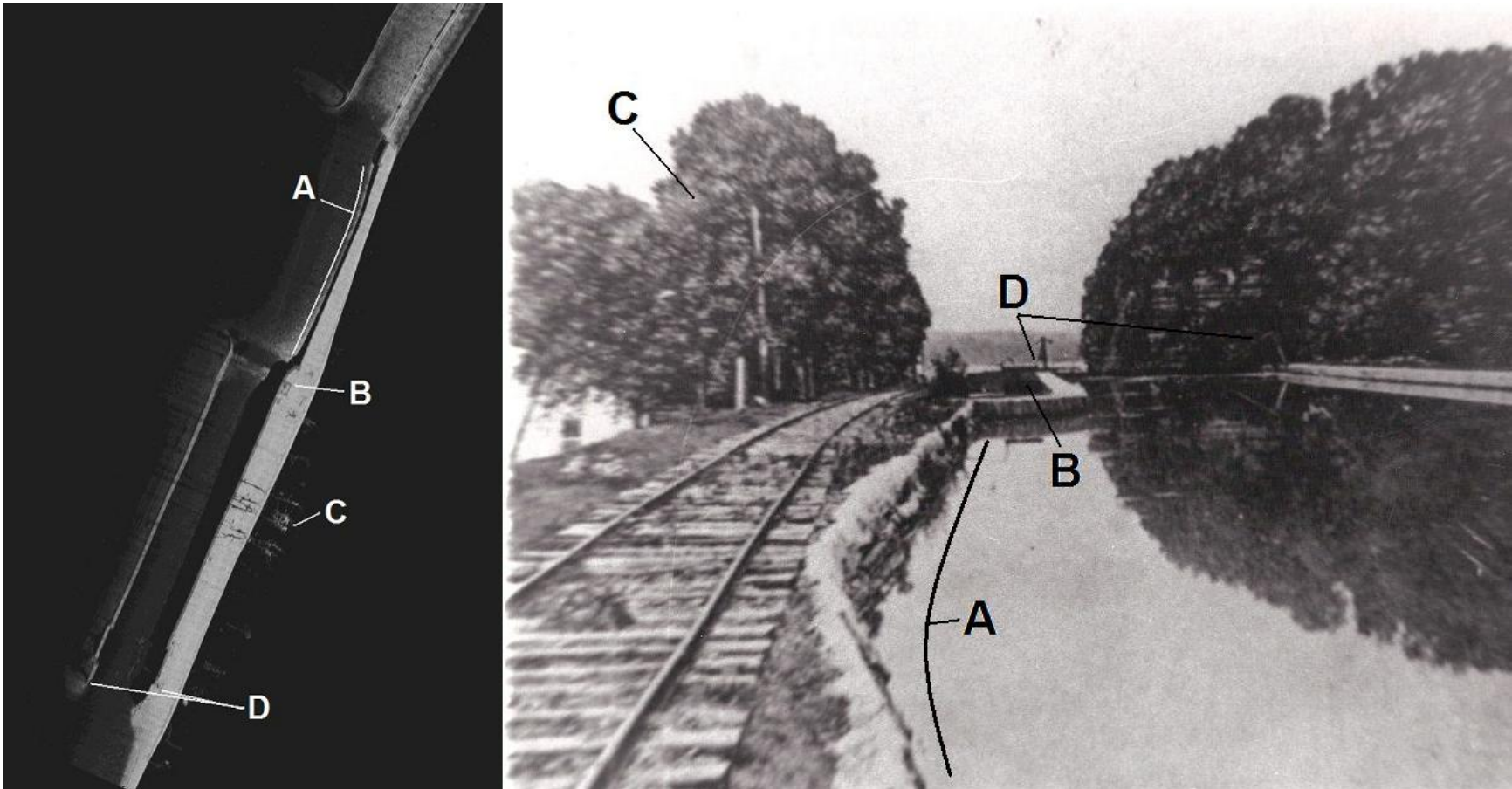


Figure 4.8 Side scan sonar and historical photograph comparison for Lock 7 of the Muscle Shoals Canal. (A) Curved wall north of lock chamber. (B) Square object (C) Trees. (D) Gate support structures. McDonald Collection Photographs, Archives/Special Collections, Collier Library, University of North Alabama, Florence, Alabama.

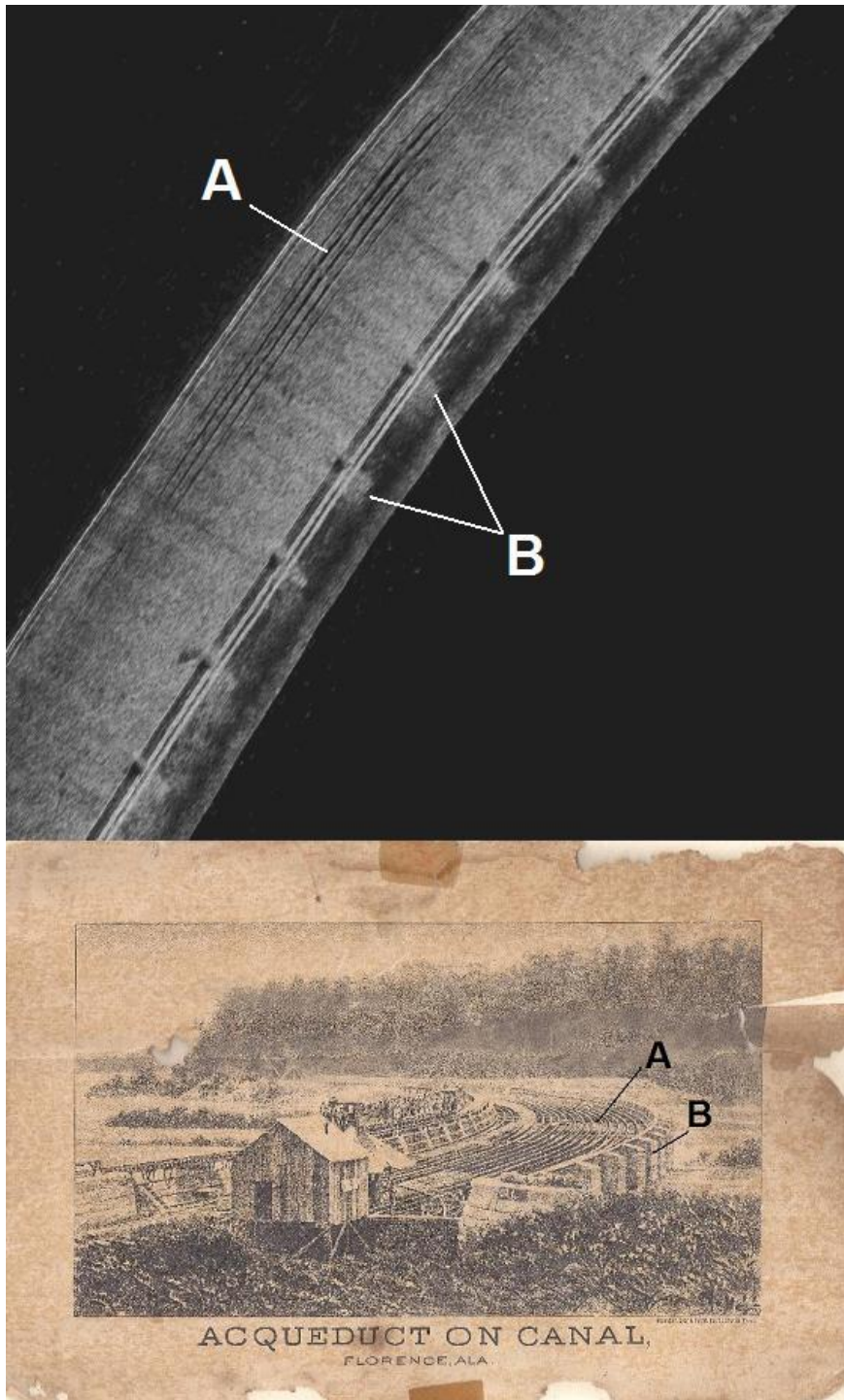


Figure 4.9 Side scan sonar and historical image comparison for Shoal Creek Aqueduct. (A) Metal ribs. (B) Stone pillars. McDonald Collection Photographs, Archives/Special Collections, Collier Library, University of North Alabama, Florence, Alabama.

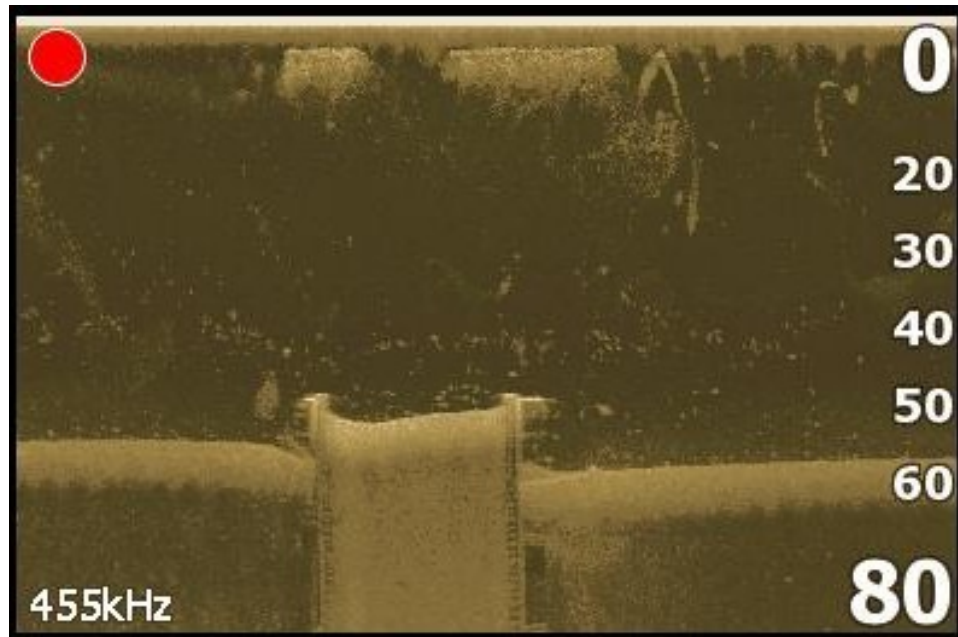


Figure 4.10 Screenshot of down scan sonar returns showing the cross section of the Shoal Creek Aqueduct.

Bathymetry

Bathymetry data were collected in the hopes that creating a 3-dimensional surface on which sonar imagery could be overlain would aid in the interpretation of features on the lake bed. In practice, the results were not accurate enough to produce usable results. Three dimensional bathymetry created for Lock 7 (Figure 4.11) gives a general idea of the contours, however, details such as vertical lock walls were completely lost to interpolation and as such were not conducive to image overlay. Though more advanced processing available in other software packages could yield better results with the same equipment, none were available for testing. Once familiar with analyzing sonar imagery, it becomes unnecessary to present features in three dimensions to fully

understand what is in a scene. Much like analyzing aerial photography, shadows, shading, textures and patterns become visual clues to interpreting sonar imagery.

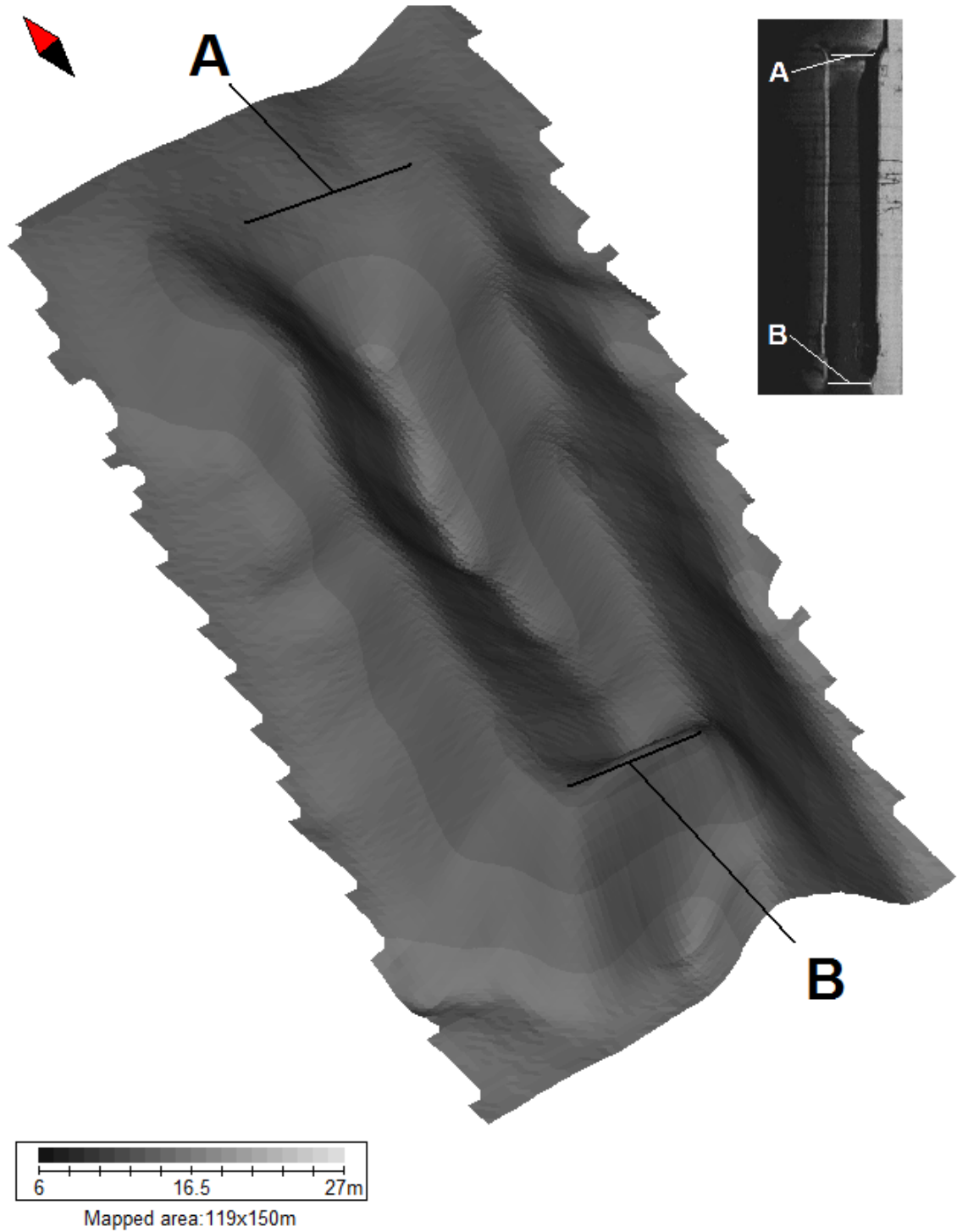


Figure 4.11 Three dimensional bathymetry of Lock 7 of the Muscle Shoals Canal

Geovisualization

Georeferenced imagery created with DrDepth software was displayed in Google Maps via Google Maps APIv3. A photo slideshow accompanied the map which contained historical photography and down scan imagery that were not well suited to display on the map. This was done in an attempt to present unfamiliar content in a context that has become familiar to many people. Imagery was presented to several non-technical users with no image interpretation experience, and the overwhelming response was that they needed some type of annotation to know what they were looking at. The labeled pairs of side scan imagery and historical photography seen in Figures 4.7, 4.8 and 4.9 were the result of this feedback. Users reported a much better understanding of the sonar imagery when presented in this fashion, and were then able to consult the mapped imagery with a better understanding.

Limitations

Due to the transom mounted transducer, results obtained from the sonar used in this study are subject to distortion caused by vessel movements from wind, waves, load shifts, or any other influence on the pitch and attitude of the vessel. In choppy water, the transducer rides up and down with the waves causing the distance between the transducer and the lake bed to change. This results in a bottom that looks artificially bumpy and distorted (Figure 4.12). Another drawback is limited depth range, particularly in murky water. Any scans beyond 35 feet required use of the coarser 455kHz frequency for side scan and down scan imaging to produce acceptable returns. With deeper features, there is no way to get the transducer closer to the bottom as is possible with towable systems.

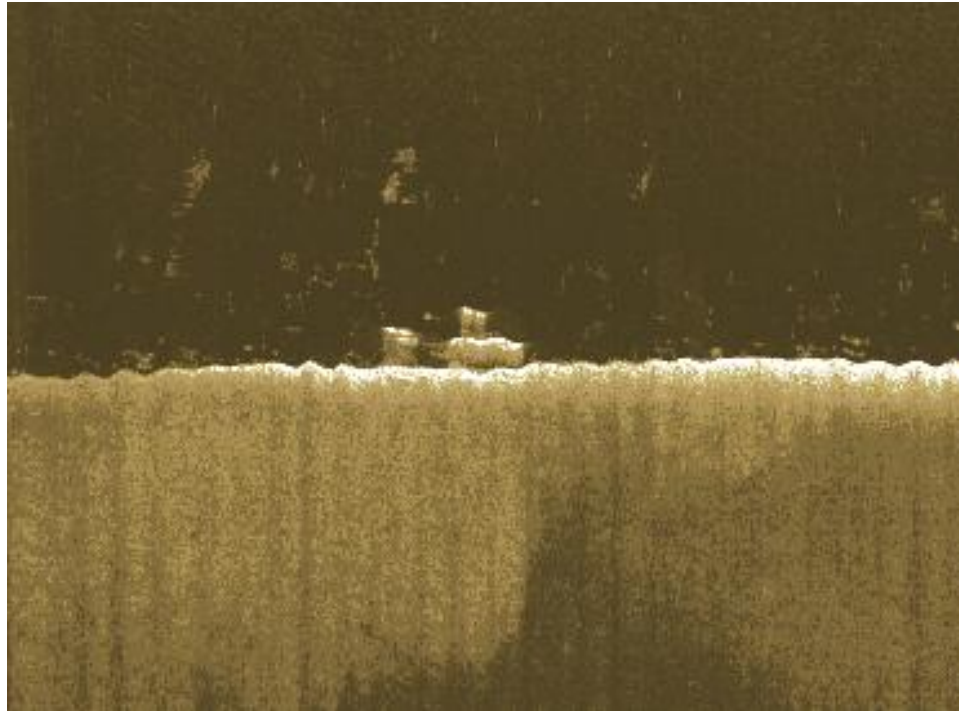


Figure 4.12 Down scan sonar image of locomotive showing distortion from scanning in choppy water

CONCLUSIONS

In this study, consumer grade sonar equipment and inexpensive commercially available software were used to conduct a survey of submerged remains of the Muscle Shoals Canal using side scan, down scan and broadband sonar. The sonar returns gathered provide clear imagery of the canal system as it sits today, helping to write the latest chapter in the history of a culturally and historically significant landmark in North Alabama. Many features were instantly recognizable, while others were identified with the use of historical photography and image interpretation techniques. Imagery was

presented to non technical users through web maps and annotated photographs to increase interest and awareness of the condition of the canal system.

Results show that the consumer grade sonar used in this study is capable of providing usable data in the interest of historic preservation. Canal structures can be identified and georeferenced for further study by diving, or the sonar could be used as a low cost preliminary study in order to justify the use of high end sonar systems. The low cost and efficiency of consumer grade sonar units has potential to open doors to future research and exploration of our underwater treasures.

While a partial inventory was created in order to show the capabilities of consumer grade sonar units, much work remains to be done to create a complete inventory of the Muscle Shoals Canal. Such an inventory could lead to increased interest in the history of the structure, history of the region, and heightened awareness of the countless heritage sites that lay hidden beneath rivers and lakes.

Output from the sonar equipment used in this study is likely of a high enough quality and resolution to serve as the sole source of data for many inventories; however, should a more detailed survey be required, preliminary results from consumer grade units could be used in justifying the need to conduct a survey with high end sonar equipment. Collaboration with divers and underwater photographers would add another dimension to historical inventories as well. The low cost equipment and methods used in this study are meant to encourage exploration by local historical organizations and smaller universities, promoting similar inventories of underwater historical sites that were previously thought to be out of reach financially. Future work could involve the testing of similarly priced side scan sonar units in various scenarios. With such low cost and readily available

systems, even blind exploration of underwater landscapes becomes a reasonable endeavor.

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Chapter 5

CONCLUSIONS

In this study, low cost and readily available consumer grade sonar equipment and software were used to conduct a survey of the submerged remains of the Muscle Shoals Canal in Northwest Alabama using side scan, down scan and broadband sonar. The sonar returns gathered provide clear imagery of the canal system as it sits today, helping to write the latest chapter in the history of a culturally and historically significant landmark in North Alabama. Many features were instantly recognizable, while others were identified with the use of historical photography and image interpretation techniques. Imagery was presented to non technical users through web maps and annotated photographs to increase interest and awareness of the condition of the canal system.

The results show that the consumer grade sonar used in this study is capable of producing imagery suitable for the creation of resource inventories of underwater historical sites. Canal structures can be identified and georeferenced for further study by diving, or the sonar could be used as a low cost preliminary study in order to justify the use of high end sonar systems. The low cost and efficiency of consumer grade sonar units has the potential to open the doors to future research and exploration of our underwater treasures.

While a partial inventory was created in order to show the capabilities of consumer grade sonar units, much work remains to be done in order to create a complete inventory of the Muscle Shoals Canal. Such an inventory could lead to increased interest in history of the structure, history of the region, and a heightened awareness of countless heritage sites that lay hidden beneath rivers and lakes.

Output from the sonar equipment used in this study is likely of a high enough quality and resolution to serve as the sole source of data for many inventories, however should a more detailed survey be required, the preliminary results from the consumer grade units could be used in justifying the need to conduct a survey with high end sonar equipment. Collaboration with divers and underwater photographers would add another dimension to historical inventories as well. The low cost equipment and methods used in this study are meant to encourage exploration by local historical organizations and smaller universities, promoting similar inventories of underwater historical sites that were previously thought to be out of reach financially. With such a low cost and readily available system, even blind exploration of underwater landscapes becomes a reasonable endeavor.

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