EVALUATION OF A FEATURE EXTRACTION METHOD FOR USE IN RIVER PLANFORM ANALYSIS

By

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To Linda, my Mom

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Image segmentation was tested as a replacement method for manual digitization of river channels from aerial imagery. A simple t-test statistic was used to test the hypothesis that there would be no significant difference between the manual digitizing and image segmentation methods. High spatial resolution orthorectified 2008 imagery from the Florida Department of Transportation (FDOT) was used for comparison of the feature extraction methods.

After several test iterations were run to determine the optimal segmentation parameters, each image was processed and converted to a shapefile for import into ArcMap 10. Once imported into ArcMap, the main river channel extracted from the image segmentation was overlaid with the channel extracted via manual digitization to visually compare the differences between the two, and clipped into 44 different statistical units. The area of each channel was calculated within each statistical unit, and converted to a ratio. The manual digitization method was used as the control method, assumed to have zero variability, and all 44 units were assigned a representative ratio of 1. The image segmentation units were each converted into a ratio by dividing the area of the image segmentation by the area of the manually digitized channel.

The t-test statistical results of the first manual digitizing versus image segmentation comparison showed significant differences between the two techniques. The image

segmentation results with values farthest from 1 were quickly manually edited to be a better visual match to the river channel as seen in the imagery. New ratios were calculated and t-test statistic results of these ratios showed no significant difference between the two methods. This demonstrated that the image segmentation method is an appropriate substitute for the manual digitizing method, producing repeatable results quickly and with little manual intervention.

CHAPTER 1
INTRODUCTION: MAPPING RIVER WITH GIS AND IMAGE SEGMENTATION

This paper proposes a new method by which to extract river features from high spatial resolution imagery. This method reduces the subjectivity and time needed to prepare data for GIS-based river planform studies. Image segmentation is tested against manual digitizing to determine if there are significant differences in feature extraction results between the two. I apply image segmentation methods to a portion of the Lower Kissimmee River, Florida. This study area was chosen because it was already undergoing geomorphic studies as part of the Kissimmee River Restoration Project (KRRP) to restore a portion of the Kissimmee River to the original channel from an earlier channelization project. Methods for manually digitizing river features were proving time-consuming and inaccurate, and an image segmentation technique may result in more accurate results in less time.

Challenges with Mapping Rivers

Inherent Versus Operational Errors

Numerous challenges are encountered when attempting to map river features and various errors can occur. Many of these errors are operational, some are inherent. The issue of inherent and operational errors versus actual measurement of geomorphologic change was described by Downward *et al*. (1994). Inherent errors are produced during the actual survey, imagery, or cartographic production. Examples include improperly calibrated satellite sensors, poorly conducted surveys, an improperly applied projection, misrepresentation of features, or errors that result from file compression during storage. Operational errors occur in computer-based and GIS handling and manipulation by the user. It is important to be aware of the existence of either of these categories of error when conducting a GIS study. There may or may not be ways to correct inherent errors. However, operational errors can often be avoided, minimized, or corrected by the user during the study. There are three main types of operational errors to be wary of when conducting channel planform change studies: conversion errors, registration errors, and digitizing errors.

Conversion Errors. Image conversion causes degradation of the image resolution and occurs any time the original image is converted from analog to digital format (scanned) or georeferenced. Many historic images are available only in hard copy format and thus must be scanned into digital format. The quality of the scanner and the DPI (dots per inch) used, can produce mild to severe distortions and degradation of the image.

Registration Errors. When an image is georeferenced, the pixels are angled and shifted away from their original locations and must be resampled to assign their values. Any of the resampling methods used (nearest neighbor, bilinear interpolation, or cubic convolution) will cause image degradation.

Study areas such as the Kissimmee River (or any rural area in the United States) present a special challenge. There tends to be little topographic distortion due to the relatively flat terrain. However, there tend to be very few features to which the historic imagery can be georeferenced. What few buildings and roads are present in the historic imagery are often found to have been removed or significantly changed in more recent imagery. It is especially challenging when there is a large time gap between the historic and more recent imagery sets. The challenges with georeferencing historic images in the US differ from those in older, more established parts of the world. Many areas of the US did not and still do not have the relatively extensive permanent infrastructure development of older countries that can aid in georeferencing.

Digitizing Errors. Errors of varying magnitude are always introduced into a manually digitized data set. Downward *et al*. (1994) registered Ordinance Survey maps and assessed the root sum of squares of the residual easting and northing values to determine the error generated in the registration process. Digitizing errors were also measured through assessment of the variability in repeat digitizing. They concluded that errors in excess of 5 meters were more likely the result of actual differences in channel change than of digitizing errors. This rule of thumb is useful for studies of relatively large rivers but caution should be exercised in river channels where 5 meters would represent a significant proportion of the channel. In such cases, a 5 meter error will paint a drastically different picture of the channel than reality, resulting in misleading conclusions. Small errors from manually digitizing in smaller river channels can result in significant changes in the channel details that dramatically affect the outcome of analysis.

Spatial and Temporal Issues

Planform studies can face major challenges simply because of spatial and temporal unavailability of imagery and data (Downs and Gregory, 1995). There may also be a lack of data at appropriate time intervals or at moments when significant changes occur. Geomorphology happens over a very long time span and is punctuated with abrupt major events. Finding enough historical data or finding data that plainly shows the before and after stages of abrupt events can be the primary challenge for a study.

Spatial. Areal coverage can often be a challenge. Generally speaking, few historic aerial surveys were conducted specifically to record river conditions. In most cases, full coverage of the river system for any given time period does not exist. Similarly, the river may appear along the edges or corners of the photographs, as agricultural fields were often the primary focus of the survey. For all images excepting orthophotos, distortions along the edges of the photographs tend to be greater than at the center of the photograph, which may introduce some additional error into the study. Proper orthorectification can often eliminate most of this error, but it is a potential issue about which the researcher must be aware.

Temporal. Because the flights to obtain aerial photography of a specific region are often not flown in the interest of repeated fluvial morphology measurements, the images available may not have been taken at "ideal" times of the year for planform study. Frequently, the flight dates are at differing times of the year such that one image set was taken during high flows and another was taken during low flows. This presents numerous problems when attempting to compare active channel areas, sandbar areas, aquatic vegetation, and islands. Channel boundaries may be hard to distinguish, especially during overbank flows. Determination of river bank position and where exactly to draw the boundary is important to such studies. In the study by Downward *et al.* (1994), the Ordinance Survey maps were said to determine channel boundary by the "normal winter water level". Yang *et al*. (1999) defined it as the "soil vegetation limit". Others have defined it as the "active gravel area" (Winterbottom, 1995), which includes all areas of the river channel below the point of overbank flow, including sandbars and gravel bars. Still others delineate the boundary based on water line alone, excluding sandbars and gravel deposits (Gurnell, 1997; Mossa and McLean, 1997). Clearly, each interpretation could potentially yield very different results so it is important to define which method is used for study. In the case of delineation by water line, one could elect to test the errors that might result from this method by comparison with field-based cross-sectional surveys. VanSteeter and Pitlick (1998) found that differences in planform area based on water line delineated from an unrectified image set were negligible (3 percent) if discharge between time series was less than 30 percent. Their study was conducted on the upper Colorado River and it is important to note that variations in discharge will have a wide range of affects depending on the type of river system under study, its width, average and seasonal discharge, presence or absence of sand bars, etc. Likewise, this study was conducted on unrectified imagery, which can introduce significant spatial error. However, it does demonstrate one method that could be used to test for significant differences based on water level.

Another challenge is the available timeframe from aerial photography. Depending on the area of interest, a long enough photo record of the river channel in question may simply not exist. In this instance, the accumulation of change may not result in quantifiable differences that prove to be significantly different or larger than expected errors in the data (Gurnell, 1997), nor would there be a reasonable length of time to determine a lack of change such as in a stable river system.

A Matter of Scale

Scale is a subject that GIS analysts must address with each project. It is important to match the scale of the data to the needs of the project. One must find a balance between the appropriate level of detail and the purpose of the study. For example, if one is to conduct a study on climate conditions across several ecotones, very high spatial resolution data would be inappropriate. Likewise, if one is interested in measuring the change in fish habitats of a 100-meter section of stream, 30-meter grid cell data will be useless. But as is always the case, researchers are often forced to use whatever data is available for their project and "make it work". Knowing the scale of your research question and how it might affect the outcome of the study is important.

In river research, there are typically three levels of scale to consider. Areal cover percentages at the *catchment area* scale will incorporate the full extent of the natural feature or human activity but may over-emphasize the impact of features or activities which are remote from the river channel. The *river corridor* scale, conversely, risks underestimating the impact of remote factors. The *local* scale investigates whether channels respond primarily to local factors. (Downs and Priestnall, 1999)

The scale at which the data is represented is dependent upon the scale of the available imagery and the scale at which the data is captured (Lane, 2000). Images from different time periods and supplied by different agencies will tend to have a different scale. Thus, a direct comparison between the raw or unreferenced images is impossible. However, once imported into the GIS software and georeferenced, image base layers are set to the same scale, allowing direct measurements to be made, though image quality could still be variable depending on the spatial resolution.

Other Sources of Error and Issues to Consider

There are myriad other potential sources of error that could factor into a GIS-based study using aerial photography. Many of the errors discussed in this section are errors that become inherent to the photo. The creation or use of orthophotos corrects these factors but in the event orthophotos are not available, one must be aware of potential issues.

Pitch and roll of the airplane while recording the imagery can introduce distortion across the photograph. The nadir is the point directly below the plane. In the ideal image collection scenario, the nadir remains directly under the plane, at a perfect 90 degree angle to the ground. When conditions are turbulent, the plane will pitch or roll and the nadir will be off center. This will cause the photo to be taken at an oblique angle and large areas of the imagery will be distorted.

Improper edge matching of the photographs can also cause errors if the photographs become fuzzy towards the edges or otherwise distorted due to camera inaccuracies (Gurnell *et al.*, 1998). The distortion can cause features in the imagery to appear of improper size or placement, which will not allow for exact edge matching of the photographs. In this instance, any features that occur towards the outside of the photographs cannot be properly analyzed.

Vegetation along the river channel also presents a problem when delineating the river channel. Overhanging trees obscure the true location of the channel boundary, forcing the researcher to decide where to draw the delineation. Typically, the trees grow along the edge of the river bank so one can assume that a line drawn between one third to one half of the overhanging canopy width will properly represent the channel boundary (Winterbottom, 1995). Aquatic vegetation within the channel can make hand delineation difficult as well, making it hard to discern where the channel boundaries are.

There are other factors that don't necessarily cause errors, but they can present challenges to the researcher. Conducting a study over a large spatial area can present a challenge with data storage. If high spatial resolution images are used, there can be real issues with disk storage space, as this type of imagery takes up more disk space than do lower spatial resolution images. If lower spatial resolution images are used, disk storage issues may be avoided, but then much of the detail needed to properly delineate channel boundaries may be sacrificed.

Image Segmentation

Image segmentation (also known as 'per-segment" classification) is an unsupervised classification method that partitions an image into clusters of homogeneous pixels. It uses region growing algorithms to simplify an image into more meaningful categories appropriate for analysis. In an ecological modeling study conducted by Lobo *et al.* (1998), image segmentation was found to be superior to and produced more accurate classification than conventional ("per-pixel" classification) methods for extracting features from high spatial resolution aerial photos. This finding is promising for riverine studies. Ecological studies inherently focus on datasets that contain great variations in land cover types that must the teased apart and analyzed to determine correlations. Most river floodplains also have wide variations in geomorphologic features and land cover types, and mid to high spatial resolution (a measure of the smallest discernible spot on the ground) aerial photographs are becoming more commonplace. Thus the same features that present challenges when studying rivers are also excellent features to study with this method.

Automated extraction of river features from aerial imagery has been tested a small number of times. Winterbottom and Gilvear (1997) assessed the potential for mapping river forms in three dimensions using multispectral imagery and aerial photography. Bathymetric mapping with remote sensing is common in coastal environments but has not seen great use in fluvial systems. They concluded that using either multispectral imagery or black and white aerial photography to map river bathymetry showed promise, though the latter produced slightly less statistically significant results than the former. Still, this demonstrates that feature extraction based on reflectance values is also useful when using aerial photos rather than multispectral imagery.

Image segmentation methods have been applied to other water resources research using high spatial resolution imagery, such as the study conducted by Robertson and Chan (2009) that sought to estimate peak water flow in Zurich. They found that the results were comparable to hand-delineated classification schemes.

There are several advantages of using an automated feature extraction method rather than a manual method. One of the most important differences is the reduction in subjectivity that is inherent to manual digitizing methods (Lobo *et al.*, 1998). It can also, depending on the size of the study area and quality of the photos, save time while rendering high quality output but quickly classifying entire image sets from which specific features may be cut. The resulting classifications can be exported into other formats such as shapefiles that can be imported into a GIS, refined, and analyzed.

In this study, I determine the parameters to use for image segmentation of a high spatial resolution aerial photo set, compare it to a manually digitized layer taken from the same photo set, and outline how it improves results and where it falls short. This method presents a unique use of a combination of remote sensing and GIS technologies to analyze river planform and shows great promise for river channel, floodplain, and large ecosystem studies.

CHAPTER 2
ANALYSIS OF THE IMAGE SEGMENTATION FEATURE EXTRACTION METHOD FOR RIVER PLANFORM STUDIES

Introduction

Geomorphologic studies are a key component to understanding how river systems behave. However, collecting river metrics across a large system can be a challenge of space, time, and expense. Geographic information systems (GIS) and remote sensing (RS) techniques can open new possibilities for studying river systems on a large scale. In spite of GIS and RS software having existed for several decades, the use of this technology for river systems studies has been relatively limited. Compared to studies that include entire landscapes, studies focused solely on river systems present a unique challenge for study due to the spatial extent being constricted to within the channel boundaries. Landscape factors beyond the river channel such as geology and land use often greatly affect the river behavior, but are not always obvious or easy to measure. However, this challenge can also be met with the use of carefully conducted GIS and RS studies. Coupled with the more ready availability of aerial imagery, large scale river studies are now more easily constructed. Remote sensing techniques are useful for extracting data from aerial imagery for use in river system studies, especially planform studies. One particularly promising technique is known as image segmentation.

Image segmentation is an unsupervised classification technique that uses a "region growing" algorithm. Unlike traditional classification methods, image segmentation is based on pixel values and the relationships of those pixels to each other. Clusters of pixels are grouped together into "segments" based on similar reflectance values rather than disparate pixels being given the same classification. This avoids the need for post-process "cluster-busting", though it results in a need for manual reclassification of the segments. It also results in far more classification values (segments) than traditional classification. However, this method is well designed for high spatial resolution imagery where traditional classification would classify individual pixels rather than groups of pixels. It is also useful for studies interested in the variation and diversity across a landscape. Within the user interface, settings can be altered to increase or decreased the variation detected by the tool.

This project investigates a new technique for extracting river features for planform analysis. The objective of this research is to assess whether there is a significant difference between the results obtained from traditional manual digitizing methods used in most river planform analysis studies and the results obtained from image segmentation feature extraction method tested in this paper.

Literature Review

The Growing Need for GIS-Based Fluvial Studies

Rivers are a critical component of the environment and an important natural resource all over the world. They provide fresh drinking water, navigable waterways and a source of power generation for humans, and serve as habitat to a broad assortment of fish and invertebrate species. Each of these roles depends on the flow processes of the river, a characteristic upon which the river morphology wields control. Greater understanding of how river channels change in response to environmental variables will allow fluvial systems and conservation specialists to develop better management plans (Downs and Priestnall, 1999). Because of the inextricable link between river flow and channel morphology, interest has grown in the study of morphological processes and so has the need to obtain quality data more quickly and over larger areas than is possible with traditional measurement methods -such as the level and staff (Lane, 2000). Transect studies are helpful for small areas of the river that are easily accessible. However, they are not appropriate for large area studies and study sites that are remote, and are widely regarded as “time-consuming and spatially restrictive” (Winterbottom and Gilvear, 1997).

Advantages of GIS-Based Studies

Field measurements will always be an important part of fluvial morphology but visualizing and quantifying channel morphology can be aided by the use of aerial photography, which offers rapid and reliable measurement (Lane, 2000). There are also certain situations when remote sensing and geographic information systems (GIS) techniques are the only feasible options. Such cases include studies of historic conditions, very remote areas, and large study areas (Walsh *et al*., 1998). Large-scale phenomena such as large floods are better studied using GIS-based methods that allow large scale assessment; traditional methods often cannot capture the full impact of the event (Winterbottom, 1995). Likewise, the upstream and downstream impacts are not as easily or readily measured with field methods.

Utilizing a GIS-based approach to study river planform has many basic advantages over traditional manual methods of map tracing and overlay, including ease of generation, storage and manipulation of digital information, planimetric error correction, multiple map overlay, calculation of quantitative data, and subsequent export of data for quantitative analysis (Downward *et al*., 1994). Many of these tasks are greatly simplified and thus more efficient, allowing for greater productivity and potentially more accurate scientific analysis. GIS are capable of handling the demands of large datasets needed for modeling fluvial systems and the use of GIS for manipulating these datasets is on the increase (Priestnall and Downs, 1996). Many fluvial studies have relied on GIS for analysis, but there is a still realized need for greater integration of GIS-based research to enhance riverine studies (Priestnall and Downs, 1996; Butler and Walsh, 1998; Walsh *et al*., 1998; Lane, 2000). Whenever possible, field measurements and GIS and remote sensing methods should be used in tandem to produce the best quality data and be better able to draw appropriate conclusions in the research (Walsh *et al*., 1998).

Downs and Gregory (1995) called for a consistent method with which to investigate complex geomorphologic systems. GIS-based analysis of aerial photographs can shed light on many of the active processes while forming the basis for repeatable study methods and results. Aerial photographs can simultaneously show engineering controls, surrounding land use, morphologic changes in the river over time, and many other features across the entire basin that might not be as clear otherwise. The photos literally paint a picture of the system from which we can directly measure a mixture of controls and impacts. Photos also allow integration of time variables quite easily, given the use of more than one photo series.

Many studies concerned with measuring channel change which were reviewed for this project used satellite data and digital elevation models (DEMs) with low resolution. These datasets commonly have grid cells 30 x 30 meters in size. While this may be acceptable for larger rivers, the image resolution is far too low for smaller rivers. Detailed channel measurements and feature extraction is simply not possible without medium or high spatial resolution imagery. Modern aerial photographs render good to excellent quality images of channel boundaries and floodplain forms from which detailed features may be extracted.

Aerial images are relatively easy and affordable to obtain. Depending on availability, they also allow a look back into the past and the conduct of analyses in morphologic change over time. They allow fluvial studies to be "scaled up" and allow potential incorporation of a broader set of influential parameters while increasing flexibility and reducing tedious manual calculations (Downs and Priestnall, 1999). Additionally, correlations between landforms and channel morphology that have been made through field work can be extrapolated via aerial imagery analyzed in a GIS. For example, Schumm (1960) reported a correlation between the silt-clay of river channel sediments to channel form. Given this information, one could utilize aerial photos in combination with mapped soil data to make inferences about a river channel's sediment makeup, erosional properties, or past and future lateral movements. Likewise, useful products may be derived from aerial photography for the analysis of fluvial properties such as river centerlines for the study of channel asymmetry (Knighton, 1981). Aerial photos also contain information (via visual displays of the landscape) that is useful in the interpretation of channel processes that may be stored digitally and analyzed spatially in a way not possible without the use of GIS (Gurnell, 1997). Map results derived from combined GIS and RS techniques may show little difference from the results obtained via simple air photo interpretation and in situ sampling. However, the combined technique may allow easier and more complete quantification, and is easier and faster to update (Walsh *et al.*, 1998). GIS can shed light on spatial patterns and parameters that are impractical to calculate manually, and that may not be as obvious without a spatial perspective (Downs and Priestnall, 1999).

Previous GIS-Based Studies on River Planform

As alluded to in the previous section, some of the most important derivable river morphology parameters that can be obtained through GIS-based analysis are channel length, sinuosity, planform position, and channel width. Most of river morphology work completed using aerial photographs may be classified as the specific determination of channel attributes such as channel banks, sandbar presence, and channel width (Lane, 2000). For this study, I was primarily interested in papers addressing changes in planform position and width. The method I test is most directly applicable to the study of these parameters, though other parameters may be subsequently generated from the data layers created using the method I test.

Lewin and Manton (1975) mapped the entire river channel and floodplain of three Welsh rivers in one of the first examples using aerial photographs for fluvial research. They also mapped planform change overlays for four time series in a highly active portion of the River Tywi.

In 1984, Graf demonstrated a probabilistic method using river channel renderings derived from aerial photograph, map, and engineering survey overlays to test erosion prediction on Rillito Creek, Arizona. This was one of the first attempts to do more than simply describe the history of morphologic change along a river. Other studies were subsequently carried out based on this method. An erosion probability map was constructed for the Rivers Tay and Tummel in Scotland as part of doctoral dissertation by Winterbottom (1995) using Graf's method, with inclusion of additional erosion data to improve results. In this work, aerial photographs converted to Boolean layers indicating active channel areas (defined as areas of water or unvegetated gravel bars) were classified by distance from the river channel. Next, Boolean multiplication resulted in a layer indicating the succession of erosion along the river channel. Color aerial photographs were used as results from the use of black and white imagery were promising but poor. In 2000, Winterbottom and Gilvear conducted a study on the River Tummel that incorporated additional variables to refine Graf's method. Variables such as bank morphology, sediment type, and vegetation presence on bank erosion rates were incorporated into the study. It is important to note that the Rivers Tummel and Tay in Scotland are very different types of rivers than is Rillito Creek. For example, the River Tummel is an 80-meter wide wandering gravel-bed river, a good test for the applicability of Graf's method. Graf also applied his method to the Salt River of Arizona in 2000 to map historic channel position, the effects of urban development on the channel, various functional surfaces (low and high flow channels, islands, engineered surfaces, etc.), and subsequently, future locational probability of the river channel that could be utilized in restoration efforts.

Downward *et al*. (1994) sought to demonstrate the variety of analysis techniques that could be easily conducted using GIS because of its data manipulation capabilities. Using historic data to test their methods on the Rivers Towy and Dee, they described three useful methodologies and also discussed the potential for errors using GIS methods. The three methods examined were vector overlay, area map overlay, and historic map overlay.

Vector overlay is one of the most commonly used techniques, and is akin to the manual overlay method used pre-GIS. In this method, linear representations of the river boundaries for each time step are overlain. In Area Map Overlay (now commonly referred to as raster overlay), rasterized grid cell representations of the landscape are overlain, showing the presence or absence of river channel at each time step. A third method called Historic Map Overlay utilizes the raster overlay methodology depicting channel presence, but also assigns a weight to each grid cell based on the number of years between each time step. The first two techniques (especially vector analysis) are frequently used in river planform change analysis, while the third is far less common.

Issues of anthropogenic disturbance and the resulting effects it has on rivers is a common theme found in many of these publications. In 1995, Marston *et al*. used a series of maps and aerial photographs to study the conversion of the Ain River (France) from a meandering to single thread channel and subsequent floodplain changes. Construction of a reservoir and lateral embankments, coupled with shortening of the river and vegetation encroachment resulted in stabilization and entrenchment of the channel. By overlaying the manually digitized floodplain vegetation and channel boundaries they were able to determine that the channel was indeed restricted, and vegetative succession to a more upland composition had occurred.

In 1997, Gurnell followed up on a publication by Gurnell *et al*. (1994) that studied planform change along the River Dee, this time incorporating aerial photographs analyzed within a GIS. In this paper, the extra step was taken to classify the predominant bank cover and digitize exposed depositional bars. Results indicated consistent spatial and temporal reduction in stream width, from upstream to downstream and from historic to current time periods. Vegetation and depositional changes that correlated with narrowing channel width were also observed. Overall, this paper provides an example of how GIS-derived river data can be used to explore channel changes in the context of fluvial and landscape processes.

Also in 1997, Mossa and McLean described the effects of floodplain and in-channel mining activities on channel planform on the Amite River, Louisiana. This study is unique in the use of a compilation of USGS topographic maps to delineate river channel and aerial photographs to determine mining locations. A full aerial image set was not available for analysis, but the mine locations were determined and digitized into a GIS with river polygon layers to perform an area-based assessment of channel change versus floodplain cover. Positive correlations were determined to exist between significant channel change and the presence of mining activity. Additional studies of the effects of mining in river channels were produced, such as that by Santo and Sanchez in 2002. They used stereoscopy from aerial photographs to classify landcover and delineate channel boundaries, then scanned these into a GIS for analysis. Findings indicate that mining did have a strong impact on the river morphology and riparian vegetation, regardless of whether the mining occurred in the channel or on the floodplain.

In 1998, the studies along the River Dee were once again expanded by Gurnell *et al*. to test the use of GIS on analyzing the interactions of hydrological and morphological processes with the ecology of riparian zones. Specifically, the progressive changes of a berm and its vegetative cover using maps and aerial photographs was analyzed using overlay techniques made common in the previous studies. Additionally, water level frequency distributions and a digital elevation model were used to map seasonal changes on the berm. This paper effectively demonstrated the utility of meshing historic and modern data within a GIS to analyze the interactions of hydrologic and ecologic functions of a riparian zone.

VanSteeter and Pitlick (1998) combined channel morphology, streamflow, and sediment load to study endangered fish habitats on the Upper Colorado River. They used aerial photographs and GIS to produce map overlays, and also measured the total potential error produced from digitizing various features from unrectified images. By and large, the errors were negligible but a total potential error from main river channel measure was found to be as high as 8 percent (assuming the errors were additive). Overall, they found the main channel and side channel to have significantly reduced area, less heterogeneity throughout the reaches, and a subsequent loss in potential fish habitat.

Leys and Werritty (1999) used ERDAS ER Mapper to georeference and analyze change between historic time steps for the Cleekhimin Burn in Scotland. ER Mapper allows the analysis of landscape change among several layers while eliminating the need to manually digitize the river bank lines. While this might limit data errors mainly to the georeferencing process, no intermediate files are generated during the analysis, and thus the data cannot be isolated or exported to a different GIS package for additional analysis and mapping. This is a disadvantage when one might want to overlay other spatial layers with the bank line or change data to conduct additional analysis of river processes.

Yang *et al.* (1999) produced a rather straight forward study using Landsat satellite imagery and manual digitization to analyze channel migration of the Yellow River Delta in

China. One notable difference in their study however, was the assignment of positive numbers to northward channel migration and assignment of negative numbers to southward channel migration. This system could be applied generally to assign areal values to the left and right sides of channels that ran in multiple directions throughout their course.

Ham and Church (2000) estimated the erosional and depositional volumes of bed material for five time series along the Chilliwack River in British Columbia. In using aerial photos and GIS, they sought to lengthen the observational time periods and widen spatial sampling to determine the true nature of sediment transport rates that cannot be attained by in situ sampling alone. They used five process-based categories (stable, erosion, deposition, stripping, and recovery) to assign values to areal features. Volumes were measured by multiplying areal changes by bed material depth for each of 15 morphologically-based study reaches. They cited differences in water level between some photo series as having a significant impact on their results.

Another example of using GIS to extend the researcher's view back through time was a study of migration rates of the lower Mississippi prior to anthropogenic influences. In this study, Hudson and Kesel (2000) digitized hydrographic surveys from the late 1800s and early 1900s to assess historic meander-bend migration with respect to meander-bend curvature.

Winterbottom published another study of the Rivers Tummel and Tay in 2000 to analyze channel changes over the short and long term (less than 25 years, and between 25 and 250 years, respectively) and relate these changes to climatic and anthropogenic influences. This study extended from previous works (Winterbottom, 1995; Winterbottom and Gilvear, 2000) and only loosely compared the historical record of flood events and engineering projects to the changes in the river.

Also in 2000, Gilvear *et al*. published a study assessing planform and meander development on the Luangwa River, a sand-bed tropical meandering tributary of the Zambezi River. As had been done in their other studies, channel planform was manually digitized from historic air photos and overlays demonstrate the highly meandering nature of this river. They also utilized metrics taken from these overlays as the basis for testing a GIS-based kinetic model for of meander development.

In 2001, Karwan *et al*. combined the use of GIS and remote sensing to analyze the effects of land cover change on river channel morphology (stream width and sinuosity). They manually classified the land cover and manually digitized the river channel transects from multiple dates of Landsat and black and white aerial photos, respectively. Areas and time periods that had experienced deforestation and development also saw the greatest amounts of channel change.

Graf undertook a major study in 2006 to compare regulated and unregulated reaches of rivers upon which major dams had been constructed. 36 dams were included in the study for a total of 72 river reaches. Needless to say, the geomorphologic measures of this many reaches over such a broad geographic scale would not have been possible without the use of GIS. Mapped functional surfaces (high and low flow channel, islands, engineered surfaces, etc.) of each reach were compared to determine general trends in dammed rivers. Results indicated that the active area of functional surfaces was less in regulated reaches than in unregulated reaches. At the very least, this impact would have serious negative consequences for the system ecology.

The combined use of GIS and aerial photographs has proven very useful for analysis of morphological measures. However, in spite of the work that has been done, compared to other areas of study such as hydrology, there is still relatively little GIS-based research conducted on river channel change (Downs and Priestnall, 1999). Many studies employ only very basic GIS methodologies, underutilizing the real power of GIS-based research. Many of the methods are still carried out with tedious and subjective manual inputs. Refined methodology, new techniques, and more integrative approaches remain untested. Great potential lies in the combined power of GIS and remote sensing software to semi-automate the production of intermediate mapping products such as channel boundary delineation. This research seeks to continue filling in the gap by testing new methods for river feature extraction.

Study Area

The Kissimmee Basin encompasses 5,866 square kilometers in south-central Florida (Figure 2-1). It is a low gradient watershed, sloping southward from an elevation of 15.5 meters to 4.6 meters (Koebel, 1995). The lower basin is 1,731 square kilometers, extends between Lake Kissimmee and Lake Okeechobee, and contains the Kissimmee River and tributaries. The Kissimmee River runs between Polk and Osceola counties, as well as Highlands and Okeechobee counties. Nearly equal-length wet and dry seasons characterize the humid sub-tropical climate of the basin. Annual average rainfall is 121 centimeters for the upper basin and 114 centimeters for the lower basin (Bousquin *et al*., 2005).

Historically, the meandering Kissimmee River had an extensive floodplain area and a widely fluctuating hydrologic regime. Prior to channelization, the river meandered 166 kilometers. The floodplain, which is up to three kilometers wide in some portions of the basin, would generally be inundated for lengths of time from four to eleven months each year. This produced a diverse thriving floodplain ecosystem of connected wetlands and tremendous diversity.

In the 1920s and 1940s, major hurricane events caused massive flooding, loss of life, loss of property, and millions of dollars in damages. Thus, Congress authorized the Central and South Florida Flood Control Project in 1954. The Kissimmee River was channelized into what is known as the C-38 canal, 9 meters deep and between 27 and 91 meters wide, and contained six water control structures. After the channelization and installation of water control structure was complete in 1971, the river length was reduced to 90 kilometers and all flow and seasonal inundation was eliminated from the natural channel. The channelization project effectively controlled flooding but did so at great expense to the entire ecosystem. Important wetlands were lost, water quality became degraded, and dramatic declines in bird, fish and other animal populations were realized (Bousquin *et al*., 2005). Even before the project was completed, the devastation to the ecosystem could be seen and efforts were forwarded to enable restoration of the system.

The Kissimmee River Restoration Project (KRRP) began in 1999 and a large portion of the backfilling and restoration was completed in 2001. Final completion is expected in 2014. The project will reconnect over 70 kilometers of the historic channel, restore over 150 square kilometers of floodplain, and reestablish inundation periods that support the species diversity of the floodplain and wetland as seen prior to channelization (Bousquin *et al*., 2005). This project is unique for its goal of reestablishing ecosystem integrity rather than simply focusing on single-species habitat improvement.

Several studies are being conducted by the South Florida Water Management District (SFWMD), including research on the progress of fisheries, vegetation, hydrology, and geomorphology for post-restoration evaluation purposes. SFWMD and the University of Florida partnered to conduct the field and lab-based set of geomorphologic studies. The research presented here was inspired by work performed during these studies, though is not a direct part of those studies. It addresses a recognized need for developments in river-specific GIS analysis methods.

Methods

Data Acquisition

Spatial data were manually digitized and extracted from a 2008 set of MrSID format aerial orthophotos downloaded from the Florida Department of Transportation (FDOT) website. This photo set was chosen because it created a clear, complete image of the restored Kissimmee River. Also, the images were already calibrated and georeferenced, removing this extra step from the process. As an orthophoto set, I assumed that corrections for distortion had already been made and minimized such that there would not be significant additional inherent error in the image set. At a resolution of 0.02 square meters per pixel, it is also typical of the high spatial resolution imagery that is becoming more commonly available and is perfect for testing feature extraction methods.

The imagery was acquired by FDOT on March 27, 2008. Two USGS water gages are in this study area; Lorida is located on the northern end of the restored portion of the Kissimmee River and Basinger is located on the southern end (Figure 2-2). On the flight date, the mean gage height at Lorida was 3.77 meters and the mean gage height at Basinger read 3.18 meters (North American Datum of 1927). The gage heights in March of 2008 were higher than average monthly gage heights for March since 1994 (based on mean gage height of the Lorida gage). Backwater pools were present on the floodplain and many secondary channels were fully connected across the floodplain. This presented challenges both for digitizing and feature extraction which will be discussed below.

Geospatial Operations

ESRI ArcGIS 10 (ESRI, 2010) software was used to manually digitize the channel boundary (Figure 2-3). Digitizing was performed at a scale of 1:1,000 in order to capture a high level of detail. For consistency, one GIS Technician digitized the river channel and was instructed to follow visible in-channel water boundaries. Small backwater areas connected to the main river channel were included, exposed sandbars and secondary channels were excluded. Overhanging vegetation was split to include approximately one-third of the vegetation in the digitized channel boundary. One-third is the portion presumed to be overhanging the water, while two-thirds is presumed to be over land.

ERDAS Imagine 2011 (Intergraph Corporation, 2011) was used to perform the image segmentation. Within the ERDAS Imagine image segmentation user interface, there are several parameters that can be set to alter the outcome of the feature extraction. The parameters of concern for this study include threshold, minimum value difference (MVD), and variance. These parameters represent three-dimensional Euclidean distances of RGB (red, green, blue true color) values on a scale of 0-255 (8-bit integer), which have no units. The threshold sets the difference between the reflectance value of a pixel and its neighbors above which the software will create a segment edge. Setting the threshold higher will decrease the number of edges and thus the number of segments. MVD measures the minimum difference between pixel reflectance values, above which pixels will be included in a different segment. An increase in the minimum MVD results in a decrease in number of segments. The variance setting determines the variation among pixels and thus the heterogeneity of each segment. An increase in the variance setting results in a decrease in the total number of segments. Numerous iterations were run to find the optimal combination of these three settings. The combination resulting in the best visual delineation of the river channel for this imagery set was a threshold value of 10, an MVD value of 10, and a variance setting of 3.5 (Figure 2-4). Another setting that was adjusted to obtain good output was the minimum number of pixels. This determines the minimum number of pixels for each segment. In this study, the delineation of the river depended on the previous three settings. But the minimum number of pixels setting was used to keep the file size to a minimum while still allowing an acceptable level of detail. For this study, a setting of 50 proved best. An increase in the minimum value decreased to total number of segments and cause segments of otherwise quite variable reflectance values to be merged together. All of these settings were all chosen with the needs of "typical" planform change analyses in mind, while also keeping the file size as small as possible so that the image could be easily handled by the network and transferred from one geospatial software to another.   Finally, I used All Layers, which uses all layers of multiband images and intersects the results. I set the measure to Euclidean Distance so that cells would be assigned to segments based on closest proximity. (ERDAS, 2011)

Image segmentation was run on individual images rather than mosaicking the images together, largely due to constraints of the network and software. The resulting files were very large so it proved best to handle each singularly. This only produced a couple of areas with minor edge matching issues, which would be avoided if the images could be mosaicked. Even when running the images individually, the entire process took 16 minutes on average, far less time than manual digitizing which can take several hours to complete per image. This process might take more or less time depending on the capabilities of the hardware used.

After segmentation, each image was converted into shapefile format within ERDAS Imagine and imported into ESRI ArcMap 10. The large river segments that were delineated by the image segmentation were reclassified into "river channel" via simple manual selection. Any small segments isolated inside the main river channel were selected and merged into the river channel. I then merged all the reclassified segments into one large river channel segment to represent the image segmented result for the entire river. This portion of the process took about an hour for the entire river. Again, depending on the capabilities of the hardware a user can simultaneously run image segmentations, file exportations, and perform the necessary steps for reclassifications, substantially cutting down the time and man hours needed for the project. I was able to complete in a few days more work than my GIS technician was able to complete in several months working 10 hours per week.

In this project, I was only concerned about comparing the results of the main river channels produced, so secondary channels and extensive floodplain backwaters were excluded. Figure 2-5 shows an overlay of the manually digitized results with image segmentation results.

For my first analysis, I wanted to compare the relatively "raw" results of running the image segmentation tool so I did a minimal amount of manual post processing, only reclassifying the largest segments that were the obvious river segments and smaller segments that occurred completely within the large river segments. Areas that resulted in individual segments separate from the main channel, but adjacent to the channel boundary and vegetation were left intact. These areas represented features that caused different reflectance values, and the errors they produce will be discussed in the results.

A new series of polygons were created to partition the river channel into equally sized statistical sampling units that were oriented with the channel direction at any given location. The contiguous boxes were snapped together to prevent gaps and overlapping slivers. Many studies use analysis blocks of 1 km^2 in size (e.g., Downward *et al.* 1994, Mossa and McLean 1997). In this study, an analysis block size of 0.25 km^2 was used to ensure the appropriate statistical sample size. The river polygons were cut according to the boundaries of each box to create 44 samples, each containing manually digitized and segmented channels (Figure 2-6). Areas of the segmentation that fell outside of the digitized channel were considered "overestimated" segments, and areas of segmentation that fell inside of the digitized channel were considered "underestimated" segments. Once the river was cut, it was a simple matter to calculate the area of each river channel within the statistical units.

Analysis and Results

Calibration and georeferencing of the image set was assumed to have been performed correctly such that the inherent errors of the data set would not add significant error to the analysis. The manually digitized river channel was used as the control, assumed to be correct and taken as the base against which the feature extraction method is assessed. This was done because manually digitizing river channels is the most often used method for river planform and is generally accepted as an accurate method for analysis.

To avoid differences in area among the statistical units, the channel areas were converted into ratios (Table 2-1). The manually digitized channel areas were all set to a ratio of 1 with a mean of 1 and an assumed standard deviation of 0. Ratios of the channel area resulting from image segmentation were calculated and resulted in a mean of 0.95 with a standard deviation of 0.10. By and large, it appears that the image segmentation resulted in an underestimation of the river channel area as compared to the manually digitized channel. However, to test whether or not the difference is significant, a one-sample two-tailed t-test was conducted on the image segmentation results (Table 2-2). The null hypothesis is that the image segmentation sample mean will equal 1, the sample mean of the manual method. The absolute value of the t-test result was 3.70. T-critical for a one-sample two-tailed t-test (α=0.05) and 43 degrees of freedom is 2.0167. Thus, the river channel resulting from image segmentation is significantly different from the manually digitized channel and did in fact significantly underestimate the channel area.

Figure 2-7 shows the ratio results of the image segmentation channel by statistical reach. There are several reaches that are clearly return a ratio much lower than 1 and reduce the overall mean of the image segmentation results. I decided to perform additional manual segment reclassification to see if a small amount of additional work could improve the results. In ArcMap, I edited the original image segmentation results, merging to the main river channel polygon any segments that I wanted to include as part of the main channel. This process took less than 20 minutes for each sector that was reclassified.

The reaches for which I performed additional reclassification are shown in Figures 2-7 and 2-8 with bars in the diagonal pattern. These areas has a ratio of 0.85 or less (a value of at least a 0.15 difference from 1), an arbitrary threshold I selected in order to determine which reaches to alter. There were no overestimated reaches that were greater than 1.15. For the values that were less than 0.85, I reclassified the underestimated segments that clearly fell within the river channel.

Figure 2-8 shows the results from the image segmentation rework on reaches 3, 8, 12, 14, 36, 41, and 42. The ratios were much closer to 1, some going slightly above. The resulting mean was 0.98 with a standard deviation of 0.06, which still indicates that the dataset is underestimated compared to the manually digitized dataset, but overall with less deviation (Table 2-2). The absolute value of the t-statistic for the new data was 1.73, which fits within the t-critical value of 2.0167, meaning that the new dataset is not significantly different from the manually digitized dataset.

Discussion

The measurement of river channel planform can be made more efficiently and accurately with the aid of aerial photographs and GIS (Lane, 2000). Extensive measurement of large scale events are easily studied in GIS, and the use of aerial photographs allows a comparison of historic conditions as well (Winterbottom, 1995). Generation of quantitative data is greatly simplified using GIS (Downward, *et al.*, 1994), a characteristic that proved important for calculation of the numbers used to analyze comparisons between the manual digitizing and image segmentation methods in this study. The use of semi-automated methods such as image segmentation further simplifies and makes more efficient the extraction of river features from aerial imagery. This is in contrast to the less efficient and often less visually accurate manual digitizing method used in many previous river planform studies. But neither image segmentation nor manual digitizing is without its potential flaws and peculiar characteristics, the features of which warrant further discussion because of the influence these features had on the outcome of the study.

Underestimation and Overestimation

One of the major outcomes of the initial run of the image segmentation was significant underestimation or overestimation of the channel area as compared to the manually digitized output. The way image segmentation works, there will likely never be an instance when the image segmentation and the manually digitized channel are perfectly aligned. The image segmentation classifies the image on a per-pixel basis, which results in the channel boundary showing numerous crenulations as it traces the edges of riparian vegetation on a pixel-by-pixel basis. When a human digitizes the channel boundary, the result will be a much more fluid line that may fall more inside or outside of the channel boundary, depending on how the technician chooses to digitize the channel and the scale at which the feature is digitized. Regardless of whether the image segmentation is performed on high or low spatial resolution imagery, the line that is produced will either fall inside or outside of the manually digitized line, thus producing an underestimate or an overestimate, respectively. In this particular study, underestimation proved to be more common that overestimation (Figure 2-7). I set the parameters to give more detailed results rather than more generalized results. Because of the settings I used, any variations within the river channel (riffles, sills, sandbars, etc.) were classified into separate segments and were not classified as river channel. The result was an overall narrower river channel than that achieved with manual digitizing. To overcome this issue, I simply performed a small amount of manual reclassification on the worst reaches, visually selecting the segments to include in the delineated river channel. The result was a river channel that better matched the manually digitized channel, and that was often a better visual match to the imagery than the manually digitized channel.

There are several features of this imagery that causes the under- or overestimation errors. Several of the reaches ranging from 21-35 show an overestimation of channel area for the image segmentation method. One example of the overestimation was caused by backwater areas along the edges of the river channel that would not normally be digitized as part of the “active channel boundary” (Figure 2-8). Some of this may have been cause by the time at which this particular imagery was flown. It was flown at a time of relatively high flow in the Kissimmee system, so areas with low banks became areas of overflow and backwater, whereas in other photo series from a different time these backwater areas may not have been present.

Another cause of overestimation error was shadows along the margins of the river channel, between the water and vegetation areas (Figure 2-9). The shadows caused segments to be created that included areas of both water and vegetation. Similar to backwater areas, side channels were included in the image segmentation as part of the main river channel where they had seamless connectivity (Figure 2-10). This is one example where manual digitization is advantageous because you can create the division between channels while digitizing. However, it is a very simple matter to cut the river polygon produced by image segmentation and separate the channels in post-processing.

The reaches that show an underestimation contain any of a variety of features that cause enough variation in the spectral signature that the software created separate segments. Riffles caused large areas of underestimation in some reaches (Figure 2-11). The riffles cause the surface of the water to be disturbed, resulting in a very different reflectance value than the surrounding water. Because of the parameter settings for this project, the software partitioned the riffle into its own segment. Submerged sandbars and sand sills also resulted in enough of a difference in reflectance values to cause areas of underestimation (Figure 2-12). Overhanging vegetation also caused underestimation (Figure 2-13). This occurs because the image segmentation tool delineates a line around the vegetation as it classifies those pixels into a different segment than the water pixels. The GIS technician instead draws a line through the vegetation to delineate where the channel is actually located. Thus, the image segmentation underestimated the channel boundary. Similarly, shadows cast by tall overhanging vegetation and a low sun angle were classified into a segment separate from the river channel while the GIS technician simply drew a line through the shadows (Figure 2-14). Clouds were present in one image, also causing an underestimation because the stark contrast between the cloud and the water resulted in the cloud being formed into a segment right in the river pathway (Figure 2-15).

The reaches for which I performed manual reclassification each contained several features that caused significant underestimation. Reach 3 had a large submerged sand sill present (Figure 2-16), Reach 8 had shallow sandbars, shadows and backwater areas (Figure 2-17), Reach 12 had large riffles, submerged sandbars and backwater areas (Figure 2-18), Reach 14 had riffles and sandbars (Figure 2-19), Reach 36 had riffles and backwater areas (Figure 2-20), Reach 41 had riffles (Figure 2-21), and Reach 42 had riffles and overhanging vegetation (Figure 2-22). The features for which correction will need to be made will vary with each project based on the type and quality of imagery used, the resolution of the imagery used, and the type of river under study.

Manual Digitizing Method

Some of the over- and underestimation errors can also be attributed to inconsistencies in how the GIS technician digitized the river. Even though the instructions given were intended to produce consistent results, day to day decisions made by the technician and the subjective nature of manual digitization resulted in some discrepancies that caused additional error between the two methods. For the most part, the manually digitized line was rarely very far inside or outside of the river channel as seen in the imagery. The digitized lines showed a trend of occurring slightly inside of the actual channel boundary, but overall the digitizing was quite accurate. I have seen other projects in which the manually digitized line was not as accurate and I feel this data set was very high quality. But there were a couple of noticeable mistakes made that may or may not affect the outcome of an analysis. First, when digitizing across the mouths of tributaries entering the main river, the line was not always as accurate as it could be (Figure 2-23). These areas are very subjective and difficult to delineate so these areas will always be problematic. Another feature I noticed was the overgeneralization of channel features (Figure 2-24). In several instances, the digitized lines could have been far smoother, portraying a somewhat more realistic display of the river channel.

The quality of the manual digitizing is a crucial yet subjective part of many of the previous studies conducted on river planform. Certainly if several different technicians were tasked with digitizing the same river channel, each would have a slightly different result. However, image segmentation will produce the same results each time it is run, given the exact same parameter settings. This removes much of the subjectivity and error that might result during manual digitizing.

Time Advantages

In testing this method, one of the most notable differences between the image segmentation and manual digitizing was the amount of time it took to complete each. Even though there were several steps involved in performing the image segmentation, the combined time for the entire process was far less than for manually digitizing. The manual digitization was completed by a trained technician who worked for approximately 160 hours to complete the project. This included time needed to refine the digitizing technique and scale, as well as errors that resulted in lost edits (sudden ArcMap shutdowns), and any rework that needed to be completed. This time would likely be very similar regardless of experience level. Once the scale and process for handling troublesome features (sandbars, shadows, etc), the work is very straight forward and easy. In comparison, all processes associated with completing the image segmentation, converting the files into shapefile format, and the additional edits performed took a total of approximately 35 hours. The biggest time constraint was the processing capability of the machines on which the study was conducted. Had better machines with faster processing capability been available, and had I the ability to run all the processes locally instead of across a network, I may have been able to complete this portion of the study in even less time. The processes required to perform the analysis (creation of statistical unit grid, calculation of areas, etc) are the same for both sets of data so are not factored into the individual time calculations.

Conclusions

Manual methods do allow for on-the-fly decision making and manipulation of data in a way that cannot be readily programmed. One key example includes the discerning of water from shadow and water surface features such as riffles and submerged features. However manual methods of feature extraction are tedious (Downs and Priestnall, 1999) and subjective. Image segmentation was investigated as a potential replacement method for manual digitization in the delineation of river channels for planform study. It is an automated unsupervised classification tool for feature extraction from aerial imagery. An assessment was performed to determine the significance of the difference in results between the image segmentation and the manual digitization. Manual digitization is most widely used method by which to extract river channel boundaries and in this study, it was assumed to be the absolute and correct result with a statistical variance of 0. The initial outcome of the image segmentation produced results that were significantly different from the manually digitized dataset. The reaches that had the most outliers were manually edited to create a better visual match to the river channel boundary seen in the imagery. This quick adjustment resulted in a new dataset that was not significantly different from the manually digitized set, thus showing that this feature extraction method is suitable for use in river planform studies based on aerial photographs. The method also proved to be faster than manually digitizing and is repeatable with potentially more accurate overall results. There needs to be greater development of the use of GIS in river system studies (Priestnall and Downs, 1996; Butler and Walsh, 1998; Walsh *et al*., 1998; Lane, 2000), and this study presents a method that shows much promise.

Table 2-1. Channel areas and ratio calculations for manually digitized channel, the first iteration of the image segmentation, and the second iteration of the image segmentation improvements.

Reach	Total Area of Manually Digitized Channel (m^2)	Total Area of Image Segmentation Channel (m^2)	Total Area of Edited Image Segmentation Channel (m^2)	Ratio of Image Segmentation Channel	Ratio of Edited Image Segmentation Channel
1	26639.75	25013.73	25013.73	0.94	0.94
2	8789.04	8342.76	8342.76	0.95	0.95
3	11984.26	8211.06	12210.41	0.69	1.02
4	25860.36	23904.36	23904.36	0.92	0.92
5	17724.62	16220.93	16220.93	0.92	0.92
6	16620.13	14889.56	14889.56	0.90	0.90
7	13605.75	12139.73	12139.73	0.89	0.89
8	17047.36	14227.31	17088.02	0.83	1.00
9	19230.21	17433.93	17433.93	0.91	0.91
10	15766.69	14422.55	14422.55	0.91	0.91
11	26188.73	24548.38	24548.38	0.94	0.94
12	14412.92	11185.53	14675.58	0.78	1.02
13	21789.64	18844.35	18844.35	0.86	0.86
14	11515.50	9118.63	12011.94	0.79	1.04
15	11460.29	10244.34	10244.34	0.89	0.89
16	12279.79	11674.87	11674.87	0.95	0.95
17	11813.05	10946.30	10946.30	0.93	0.93
18	11725.15	11432.82	11432.82	0.98	0.98
19	14074.05	14159.73	14159.73	1.01	1.01
20	18283.62	16506.49	16506.49	0.90	0.90
21	13440.31	14008.26	14008.26	1.04	1.04
22	21935.53	23788.35	23788.35	1.08	1.08
23	16350.07	17702.24	17702.24	1.08	1.08
24	27066.53	25746.45	25746.45	0.95	0.95
25	13221.73	14770.61	14770.61	1.12	1.12
26	17372.66	18600.86	18600.86	1.07	1.07
27	16465.11	16779.11	16779.11	1.02	1.02
28	14733.60	15889.40	15889.40	1.08	1.08
29	13323.79	14362.90	14362.90	1.08	1.08
30	13475.33	14037.41	14037.41	1.04	1.04
31	14167.12	14697.16	14697.16	1.04	1.04
32	23999.12	24122.50	24122.50	1.01	1.01
33	25407.17	26053.26	26053.26	1.03	1.03
34	19381.85	18893.26	18893.26	0.97	0.97

Table 2-1. Continued.

Reach	Total Area of Manually Digitized Channel (m^2)	Total Area of Image Segmentation Channel (m^2)	Total Area of Edited Image Segmentation Channel (m^2)	Ratio of Image Segmentation Channel	Ratio of Edited Image Segmentation Channel
35	34622.53	35118.11	35118.11	1.01	1.01
36	12109.77	10078.43	12726.36	0.83	1.05
37	19194.61	19161.45	19161.45	1.00	1.00
38	26494.73	26047.37	26047.37	0.98	0.98
39	16776.83	15847.14	15847.14	0.94	0.94
40	18117.14	16713.32	16713.32	0.92	0.92
41	15650.74	11324.31	15719.93	0.72	1.00
42	14843.01	12027.88	14582.79	0.81	0.98
43	23431.28	21945.76	21945.76	0.94	0.94
44	14985.90	14210.03	14210.03	0.95	0.95

Table 2-2. Mean, standard deviation, t-statistic, and t-distribution ($p<0.05$; DF = 43)

	Mean	Standard Deviatio n	t-statistic	t-distribution
Image Segmentation 1	0.95	0.098	-3.70	3.03E-04
Image Segmentation 2	0.98	0.063	-1.73	4.50E-02

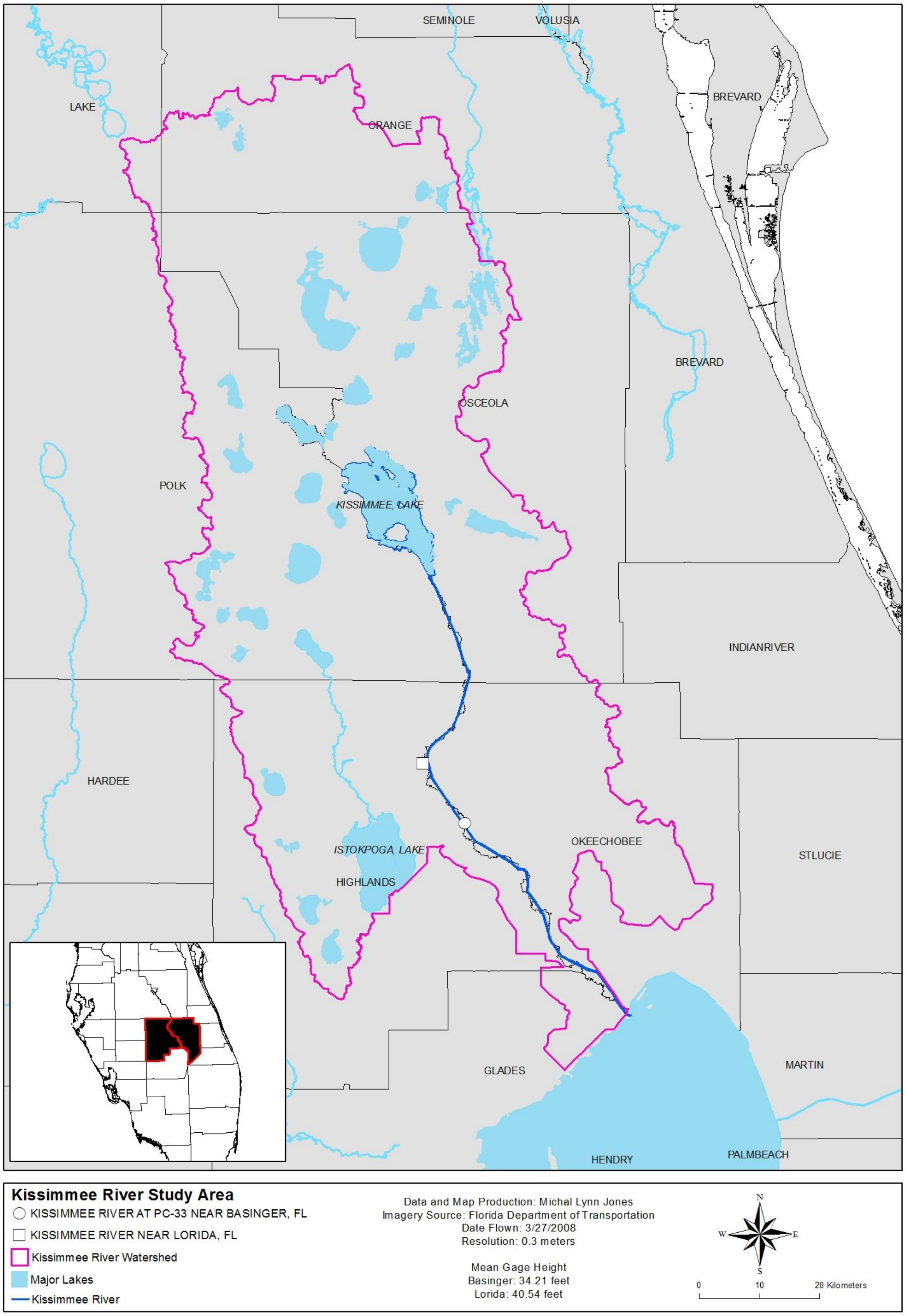

Figure 2-1. Kissimmee River study area showing the Kissimmee Watershed outline, Lorida and Basinger gages, and prominent water bodies.

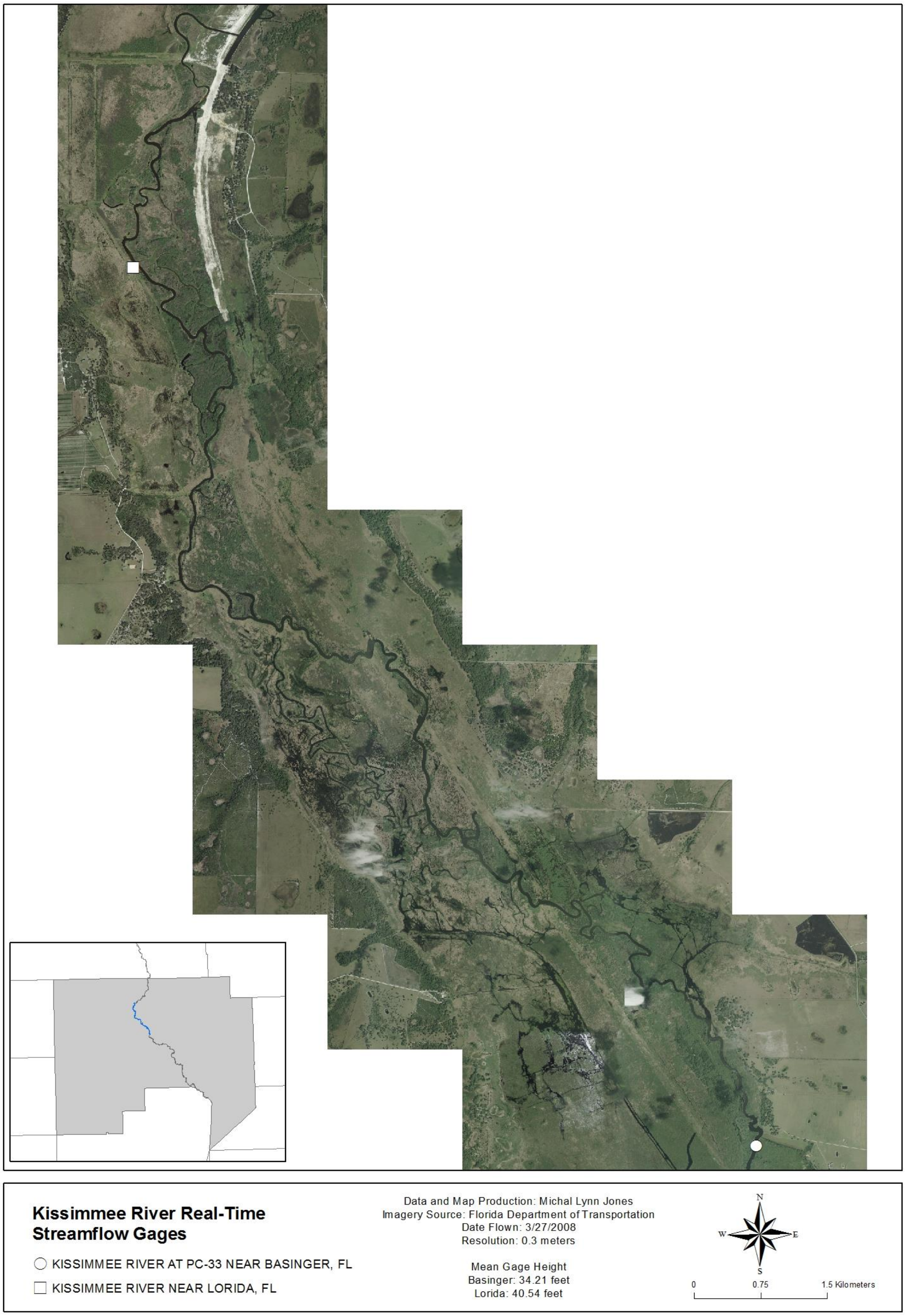

Figure 2-2. Kissimmee River study area imagery and stream gages.

Figure 2-3. Example of manually digitized river channel.

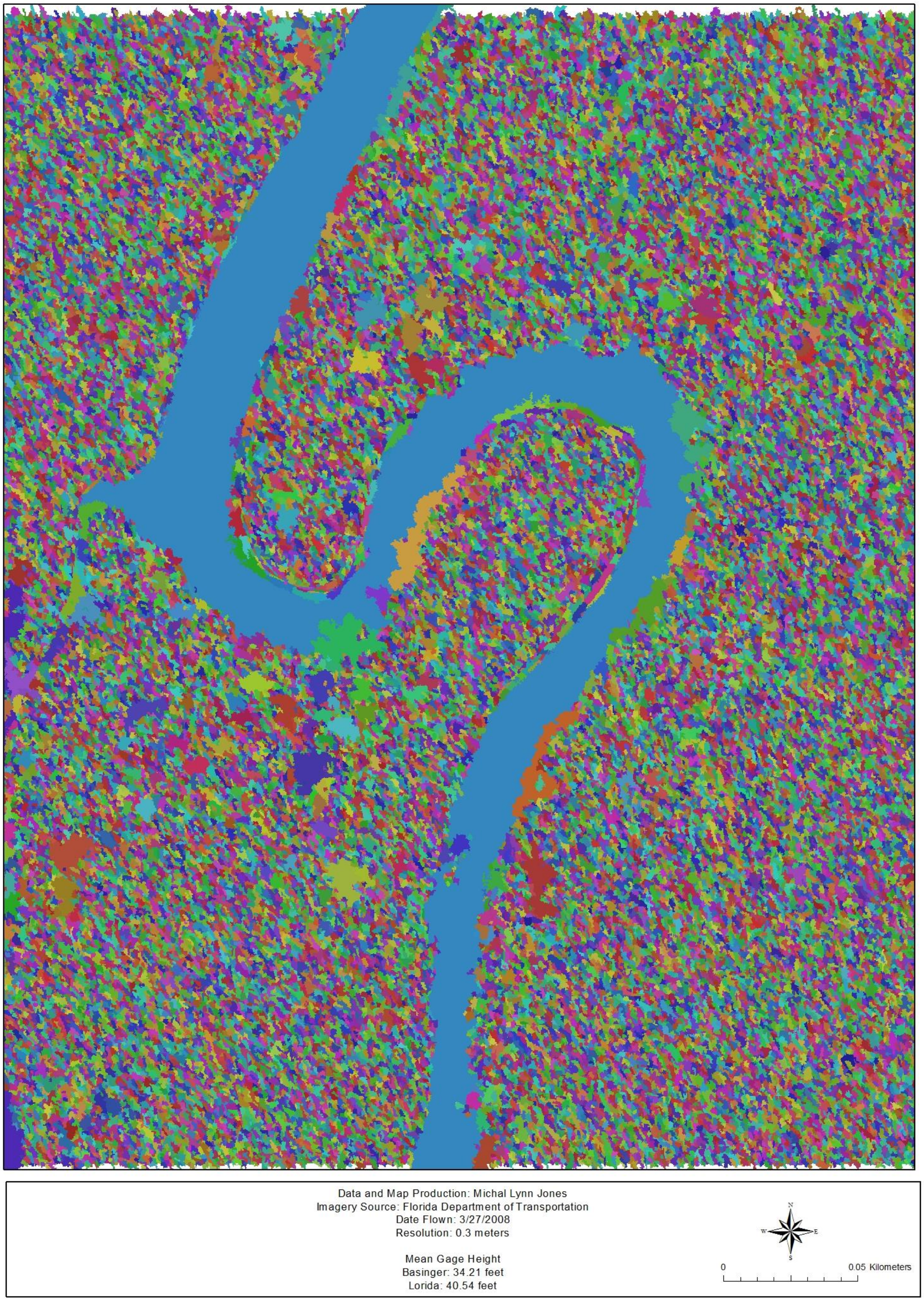

Figure 2-4. Unprocessed results of optimal image segmentation parameters with main river channel shown in blue. Each patch of color represents a unique segment.

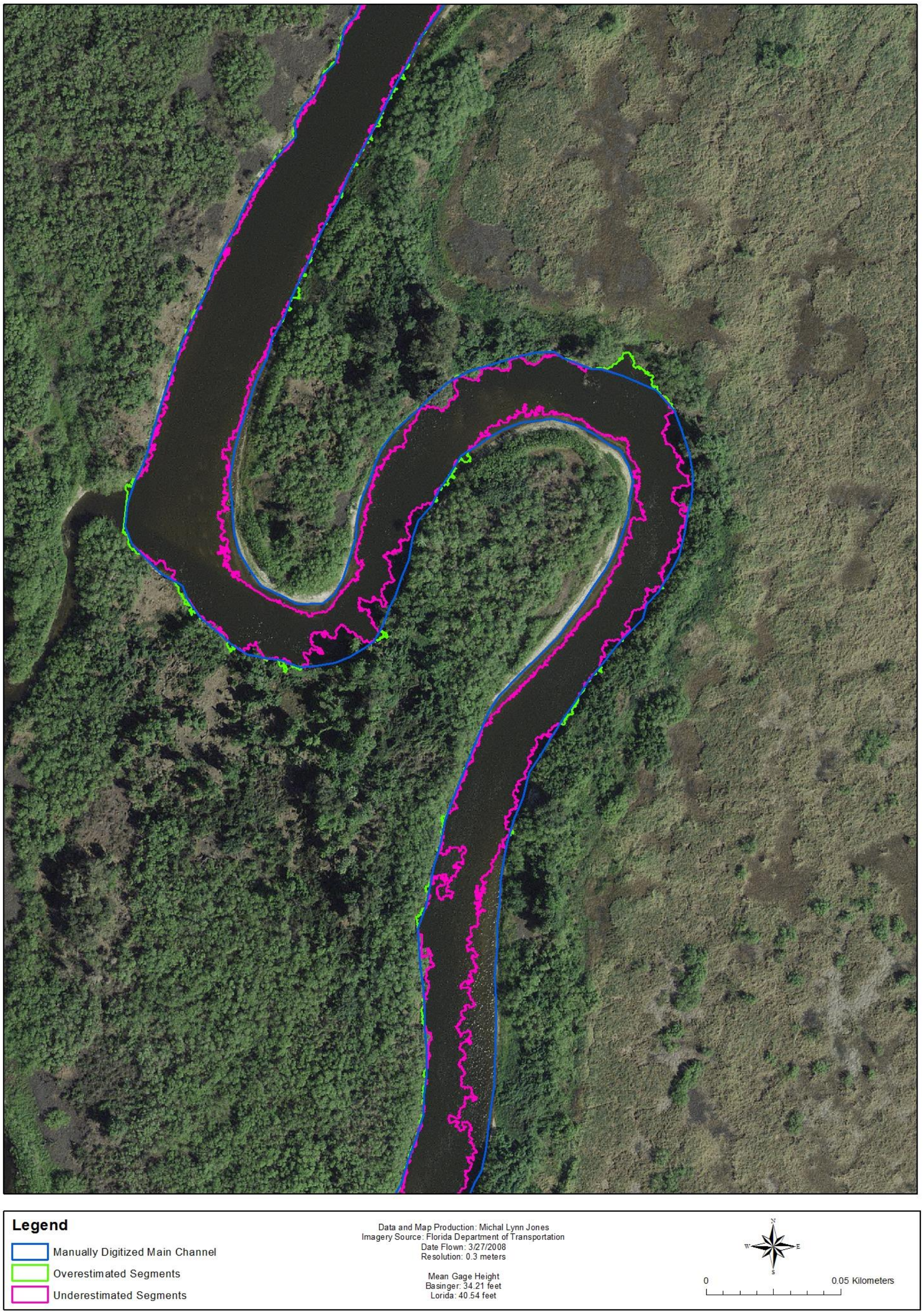

Figure 2-5. Example overlay of manually digitized channel and image segmentation results. The pink represents areas of underestimation while green represents areas of overestimation.

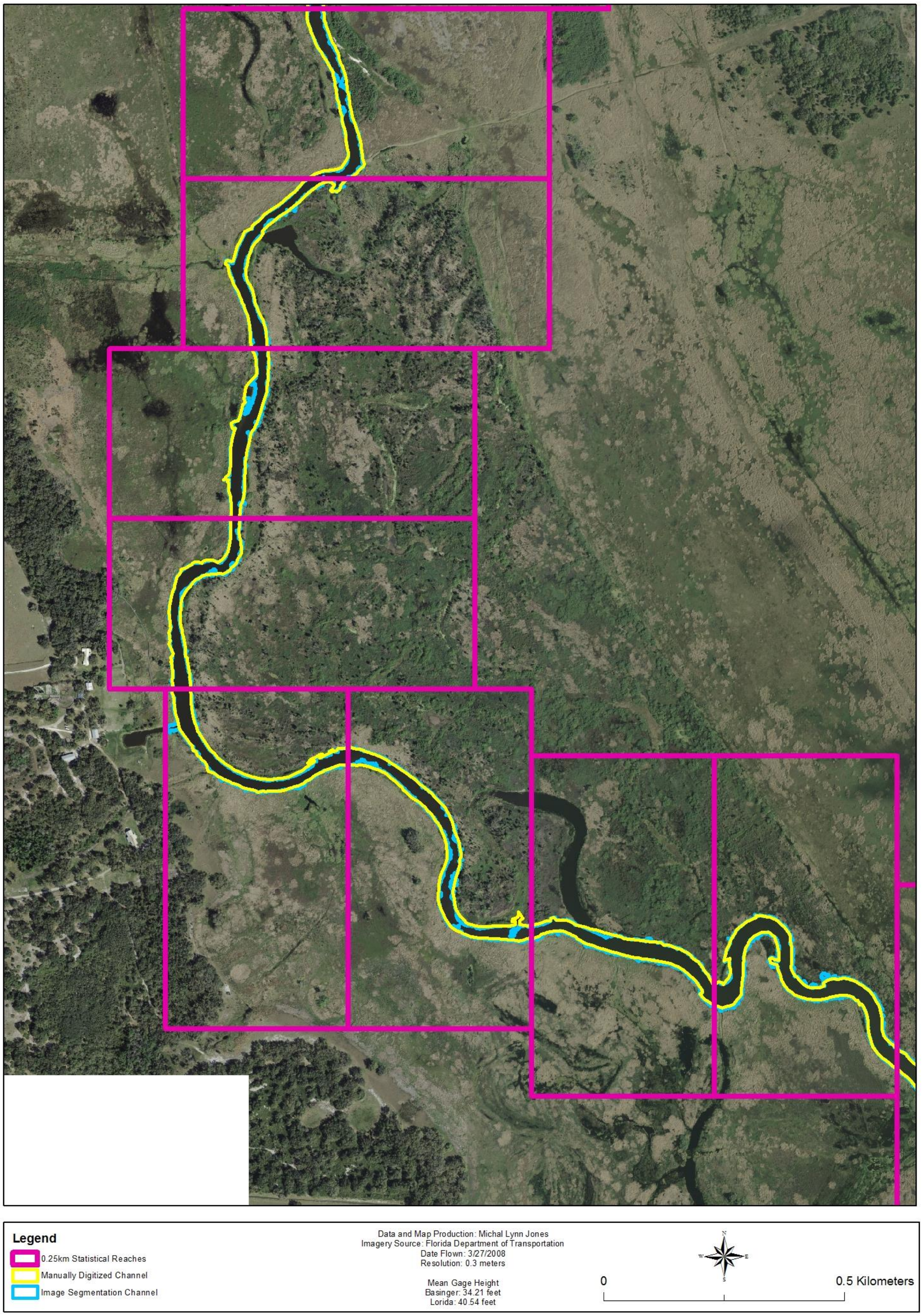

Figure 2-6. Example of a Statistical Analysis Block showing an overlay of the manually digitized channel and the image segmentation result

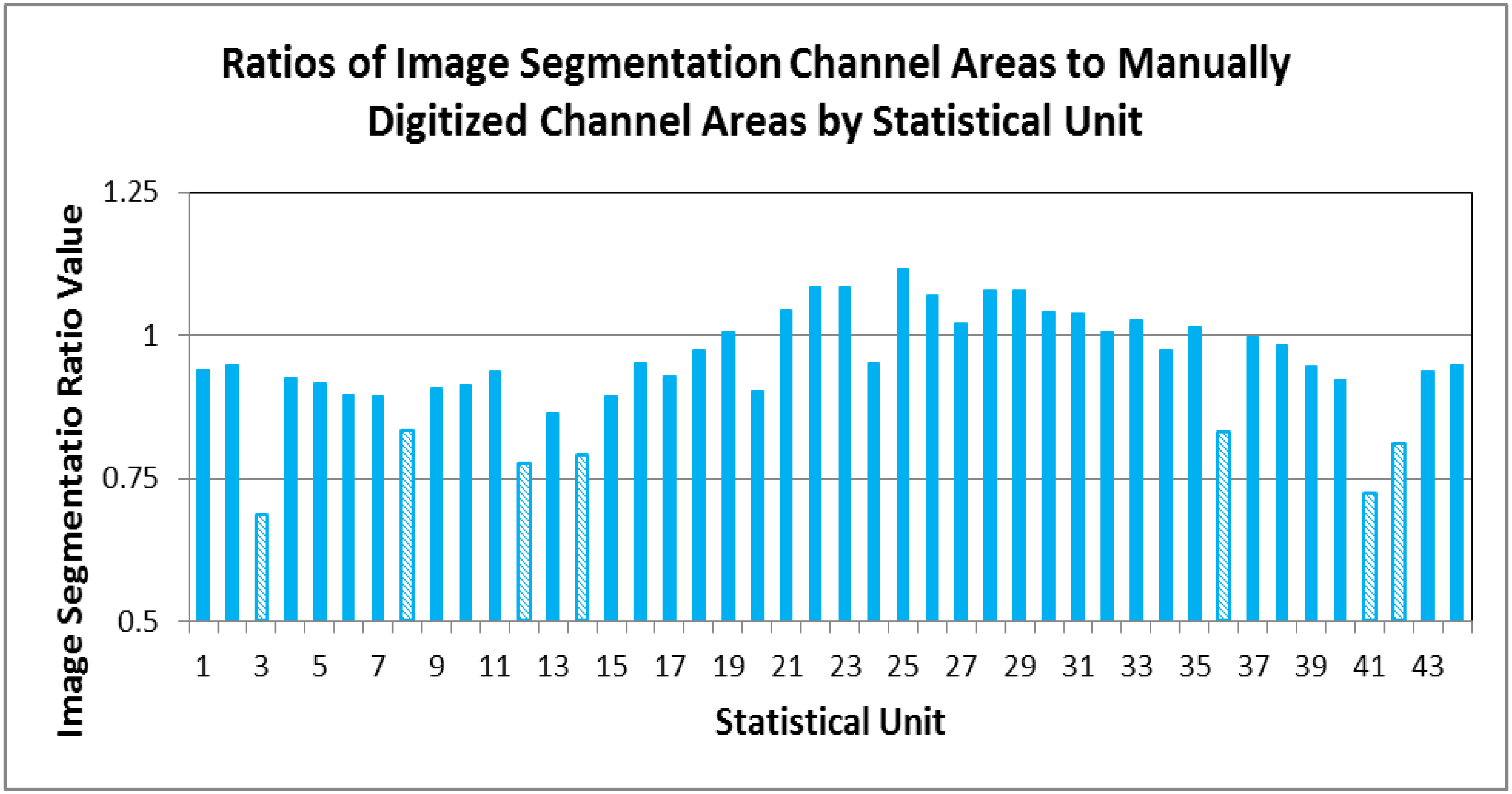

Figure 2-7. Chart of image segmentation ratios using the first iteration data. The dataset mean t is 0.95, the t-statistic is 3.70. Data points with diagonal pattern indicate reaches that underwent additional reclassification to test the ability to improve results.

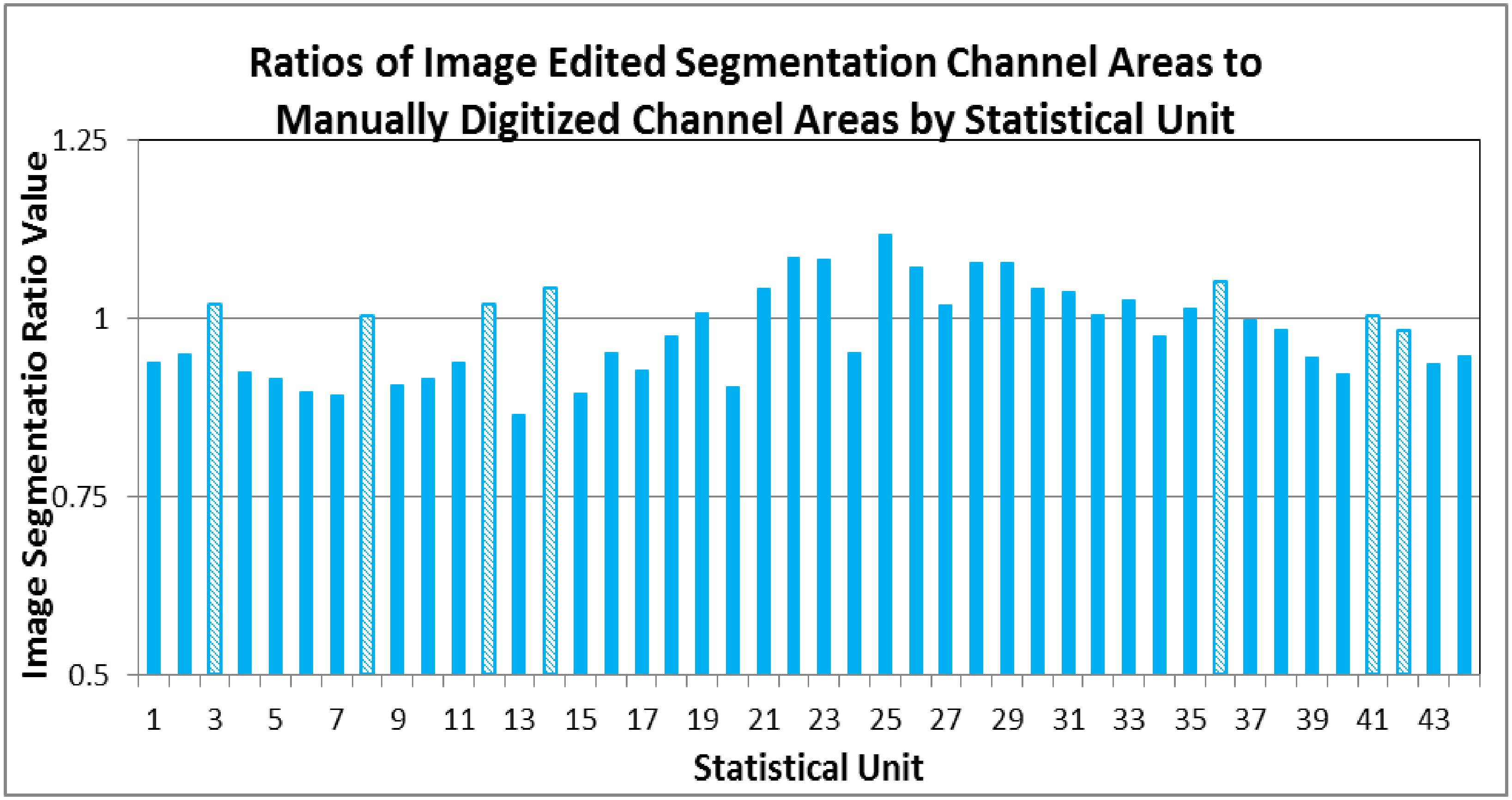

Figure 2-8. Chart of image segmentation ratios showing the second iteration data. The dataset mean is 0.98, the t-statistic is -1.73. Data points with diagonal pattern indicate the results of reaches that underwent additional reclassification.

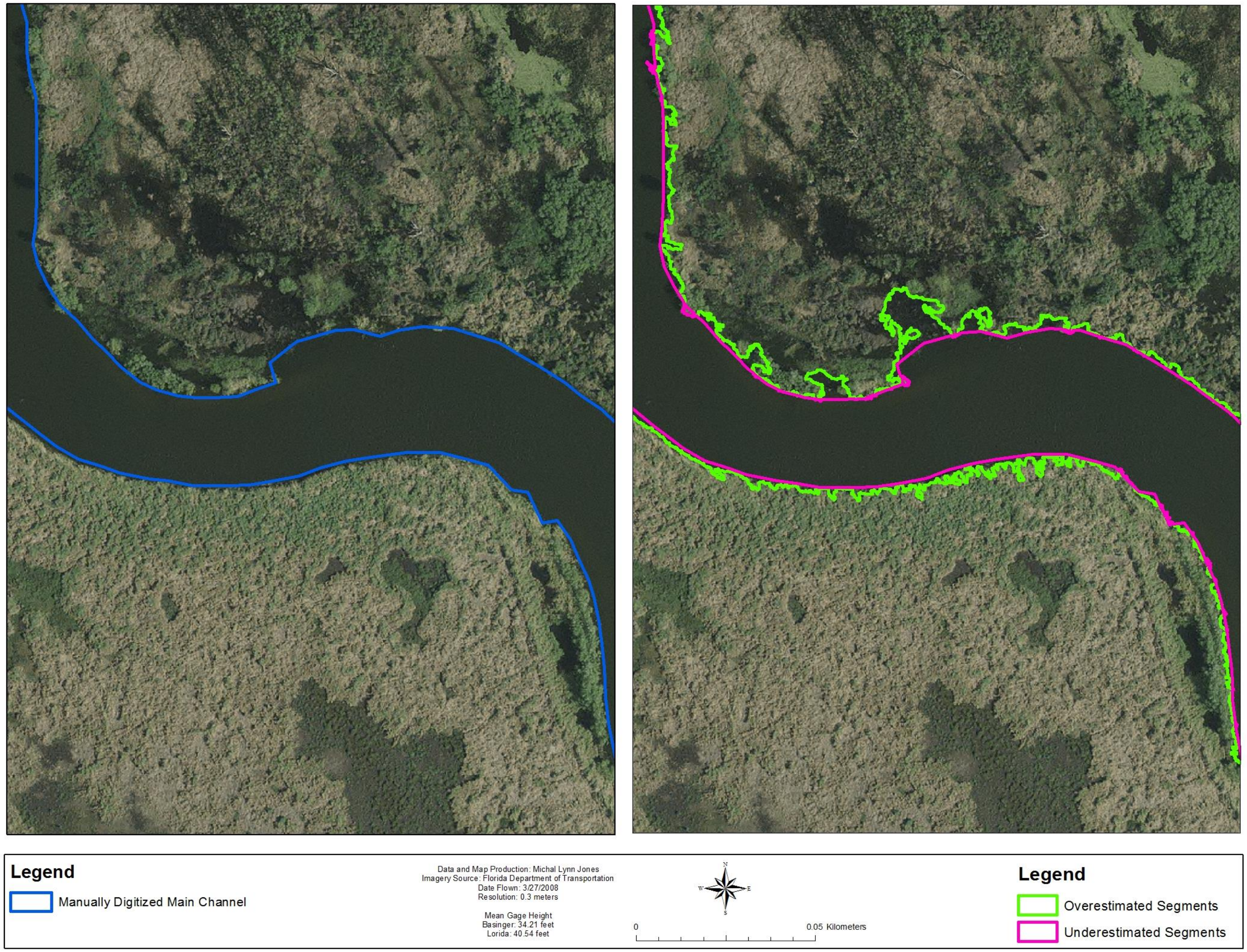

Figure 2-9. Comparison of manual digitizing method and image segmentation showing the overestimation errors cause by backwater areas and shadows along the river margins.

Figure 2-10. Comparison of manual digitizing method and image segmentation showing the overestimation errors caused by the presence of a secondary channel. Any water seamlessly connected to the main river channel will be classified as such and must be seperated in post-processing.

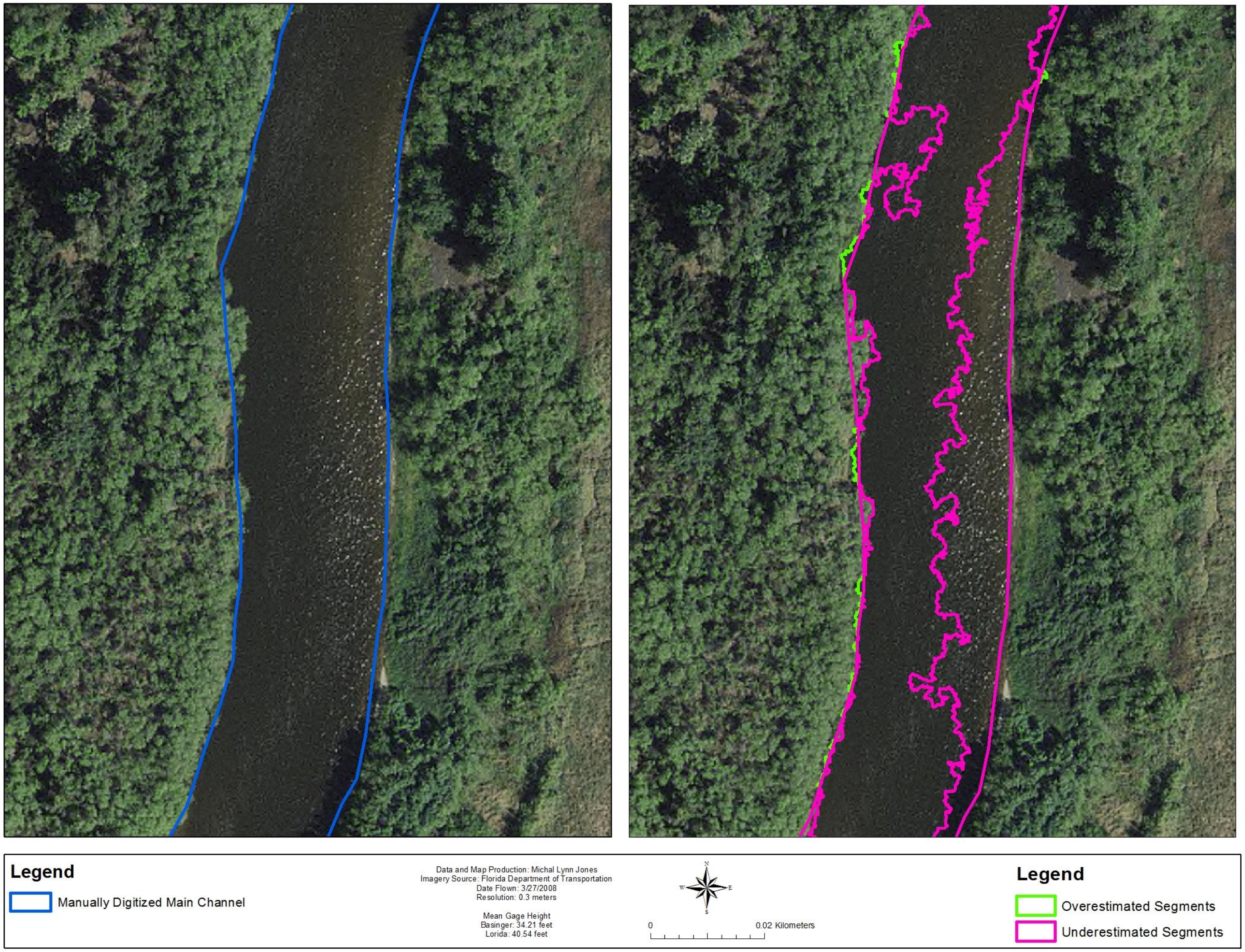

Figure 2-11. Comparison of manual digitizing method and image segmentation showing how riffles cause underestimation errors.

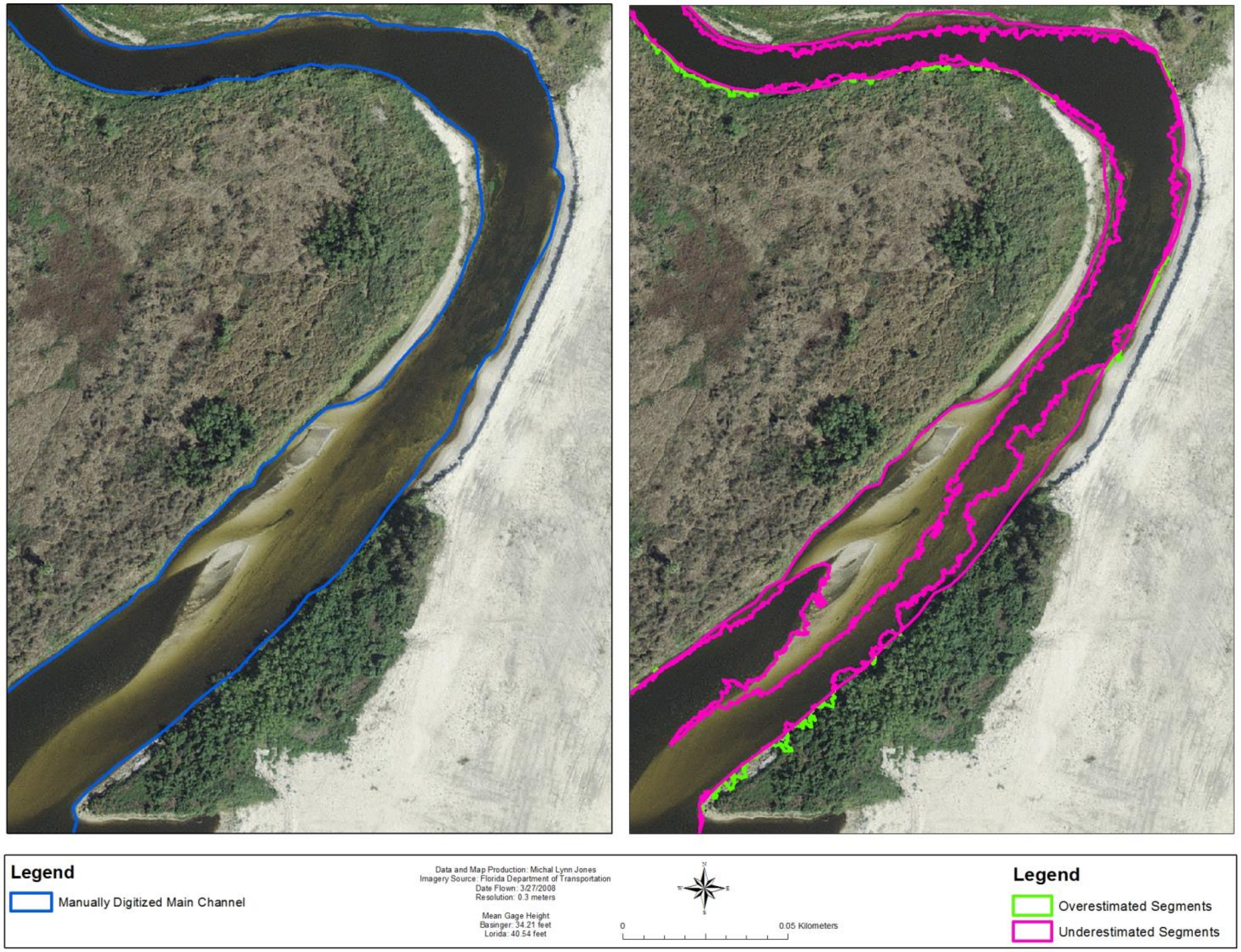

Figure 2-12. Comparison of manual digitizing method and image segmentation showing sandbar and sand sill related underestimation errors. This particular area had recently undergone backfill as part of the restoration effort and clearly the new sand was eroding into the channel.

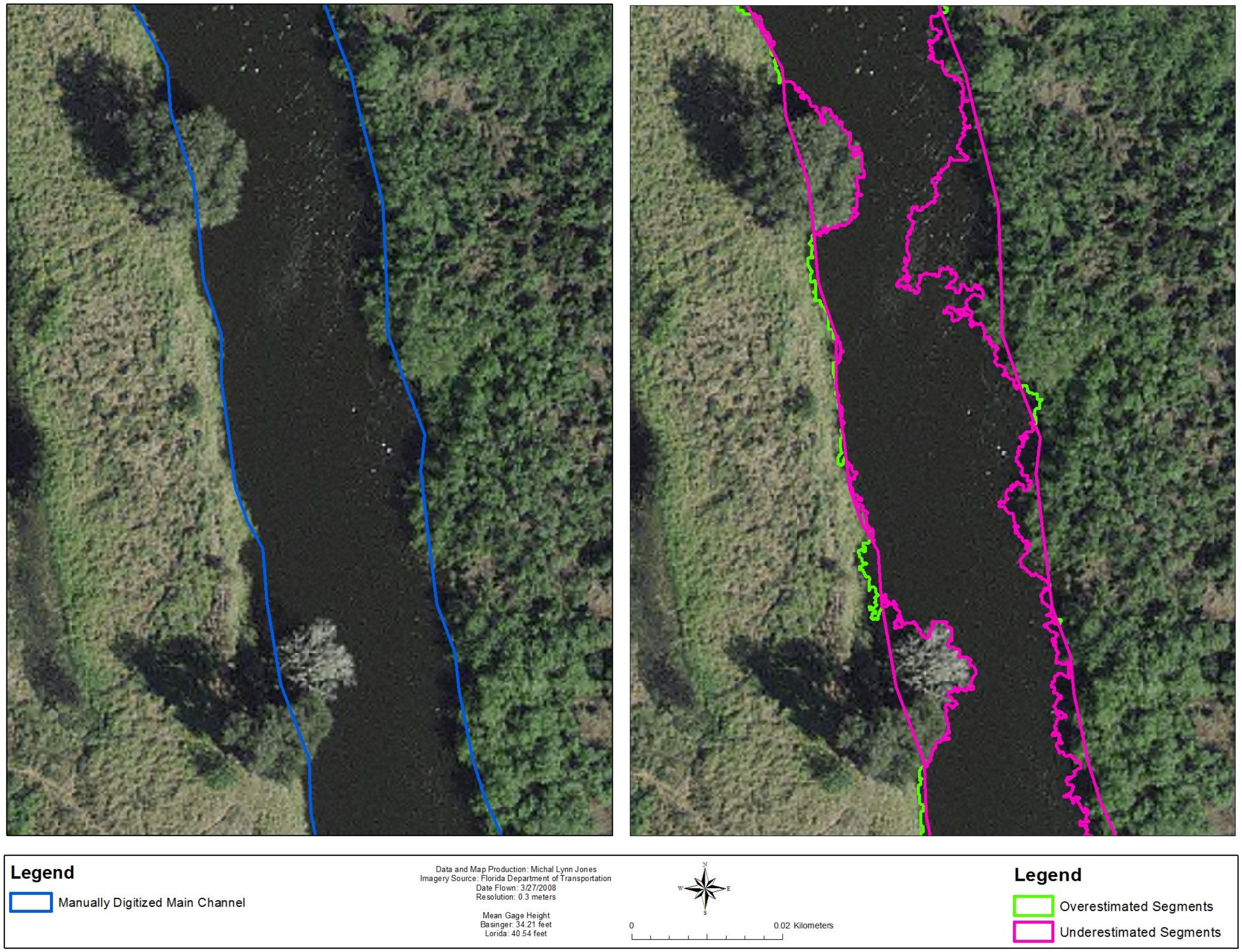

Figure 2-13. Comparison of manual digitizing method and image segmentation showing how overhanging vegetation causes underestimation errors. A riffle error is also present.

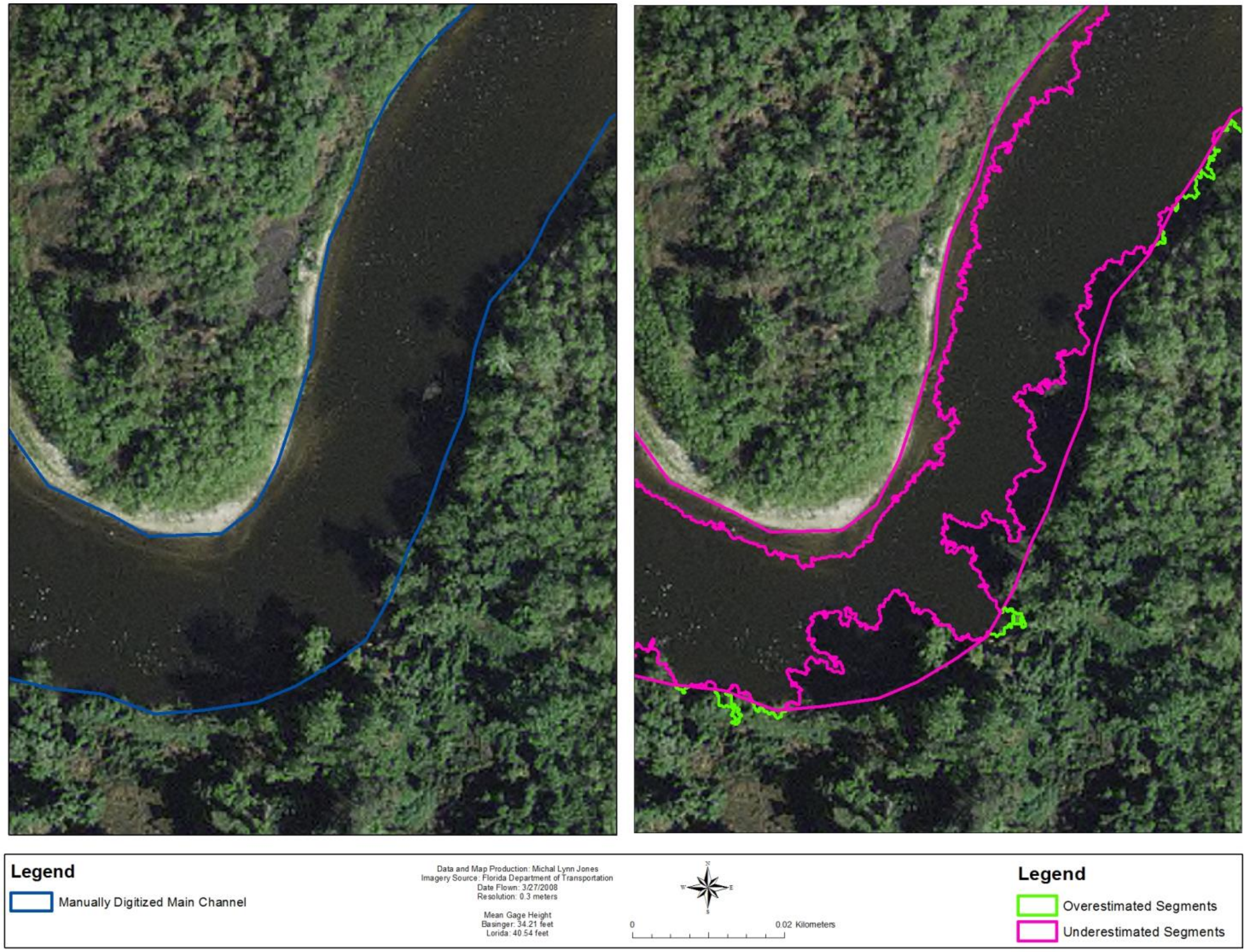

Figure 2-14. Comparison of manual digitizing method and image segmentation showing how shadows cast by the combination of tall overhanging vegetation and a low sun angle cause underestimation errors. Also note the presence of a submerged sanbar causing additional underestiamtion error.

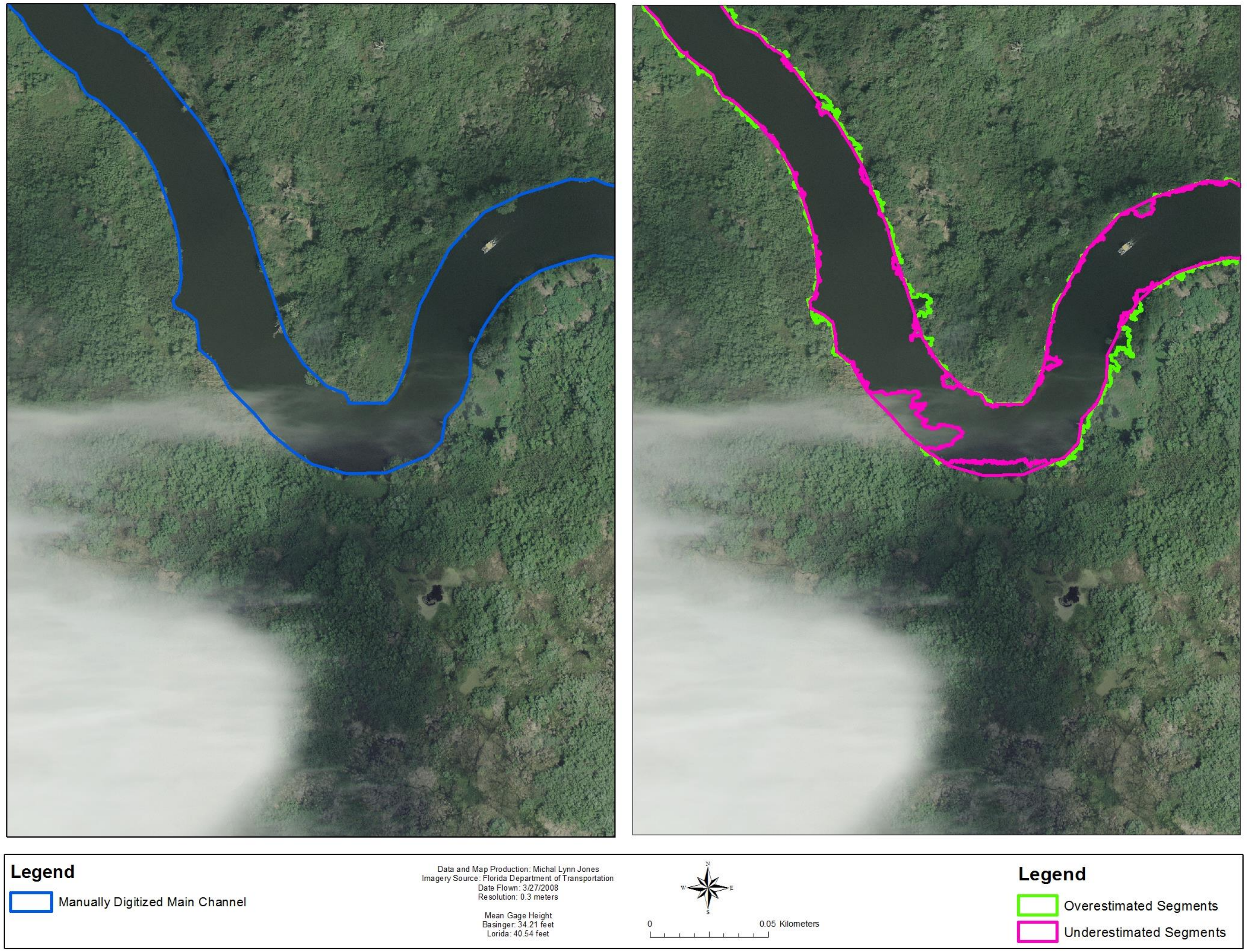

Figure 2-15. Comparison of manual digitizing method and image segmentation showing the underestimation error caused by cloud cover in the imagery.

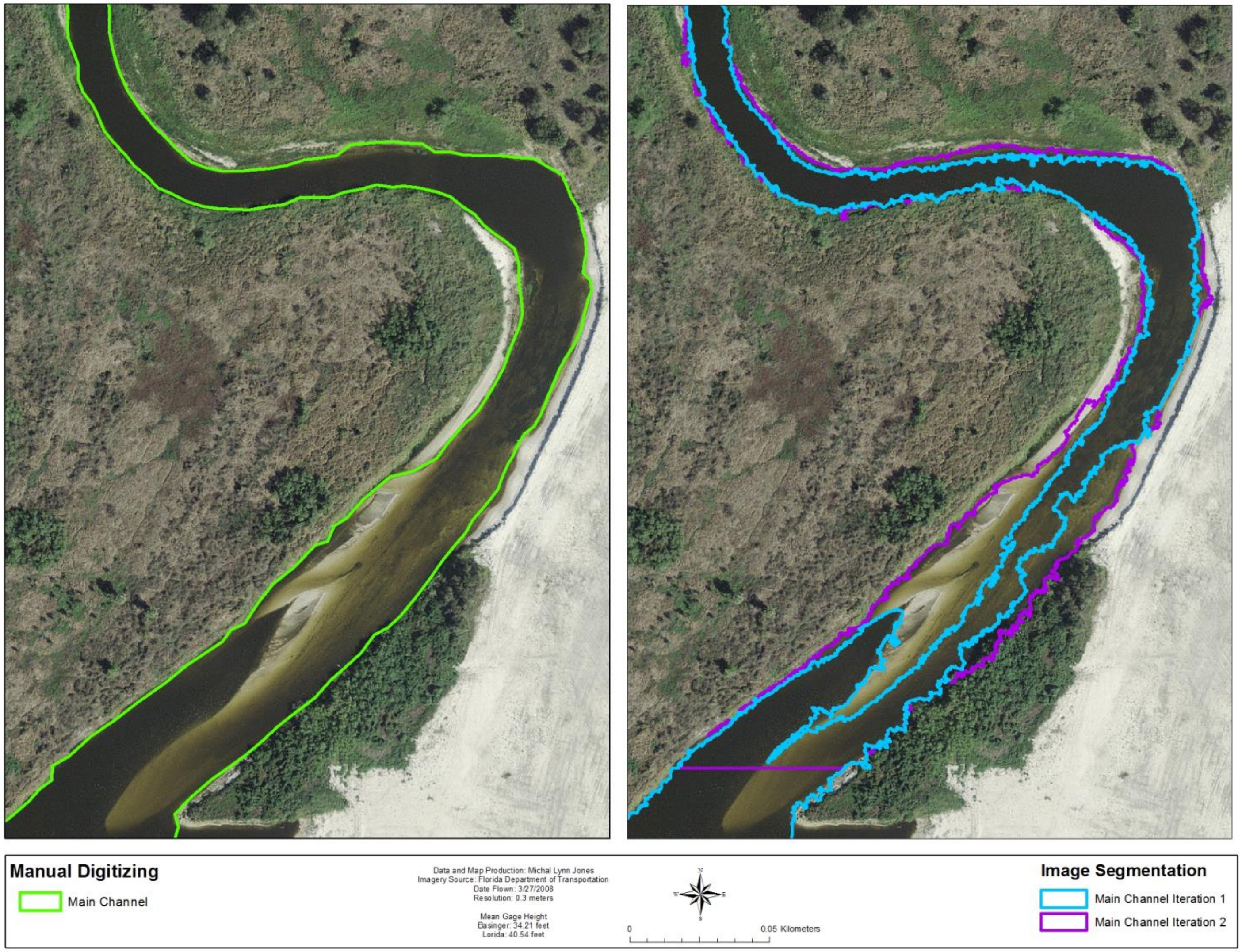

Figure 2-16. Reach 3, with a ratio of 0.69, is an area of significant underestimation. In this image you can see where the sand backfill is eroding and washing into the river, causing an area of very different reflectance from the regular river channel. Post-edits resulted in a ratio of 1.02.

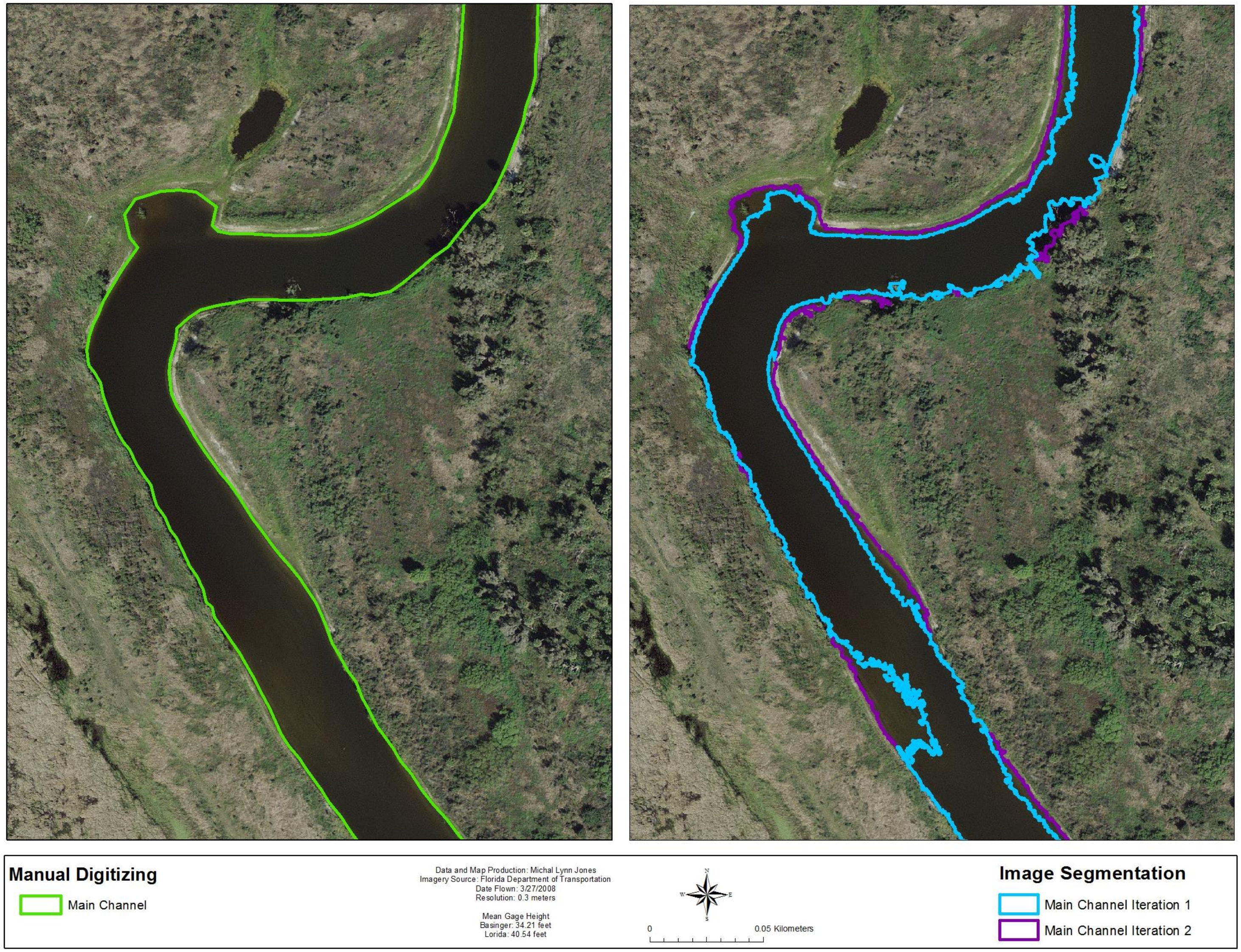

Figure 2-17. Reach 8, with a ratio of 0.83, it is an area of significant underestimation. In this area, sandbars, sand sills, a shallow backwater area, and overhanging vegetation resulted in a smaller channel area. Post-edits resulted in a ratio of 1.00.

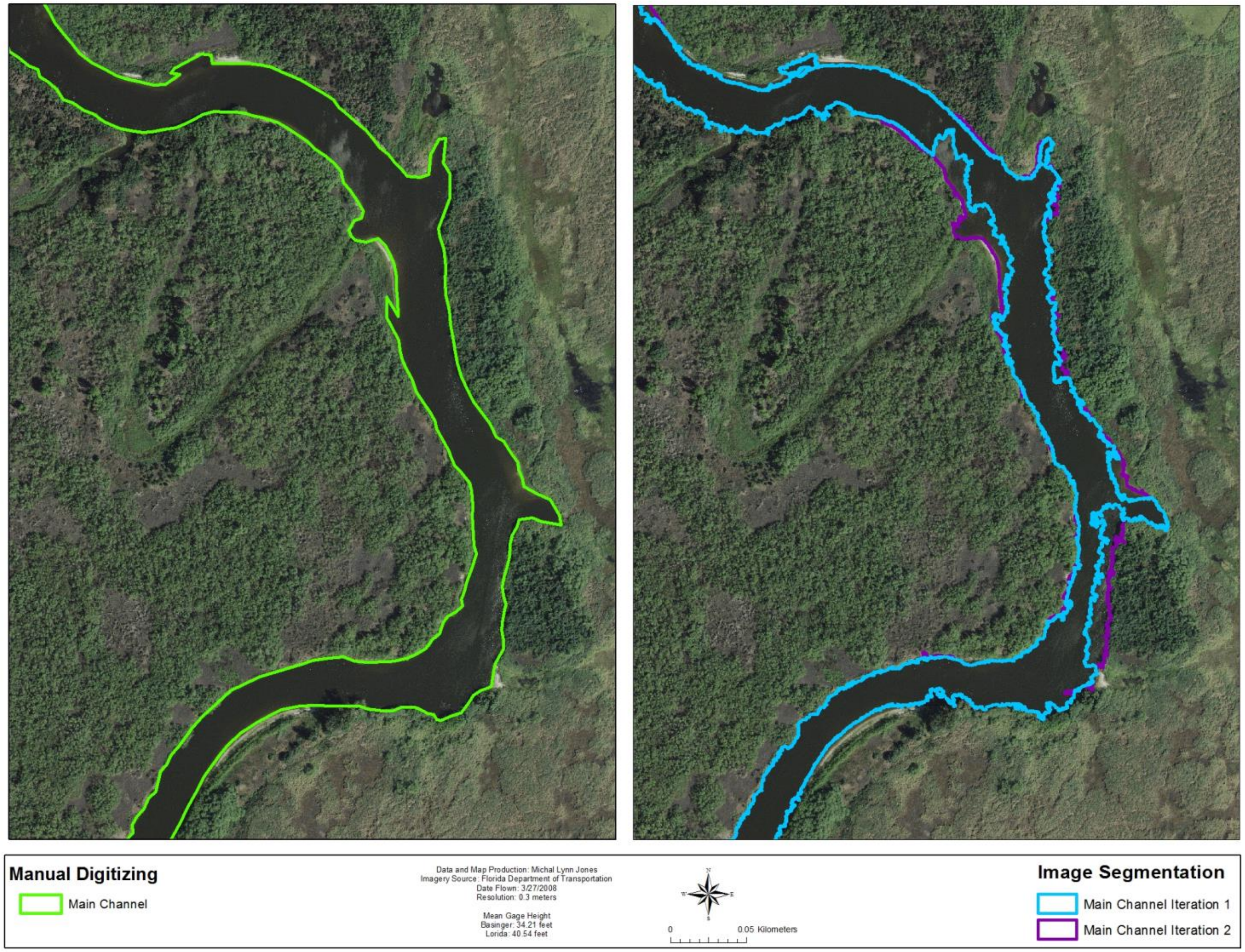

Figure 2-18. Reach 12, with an index of 0.78, is an area of significant underestimation. In this area, sandbars, riffles, shadows, and overhanging vegetation caused segments to be separated from the river, resulting in an overall smaller channel area. Post-edits resulted in a ratio of 1.02.

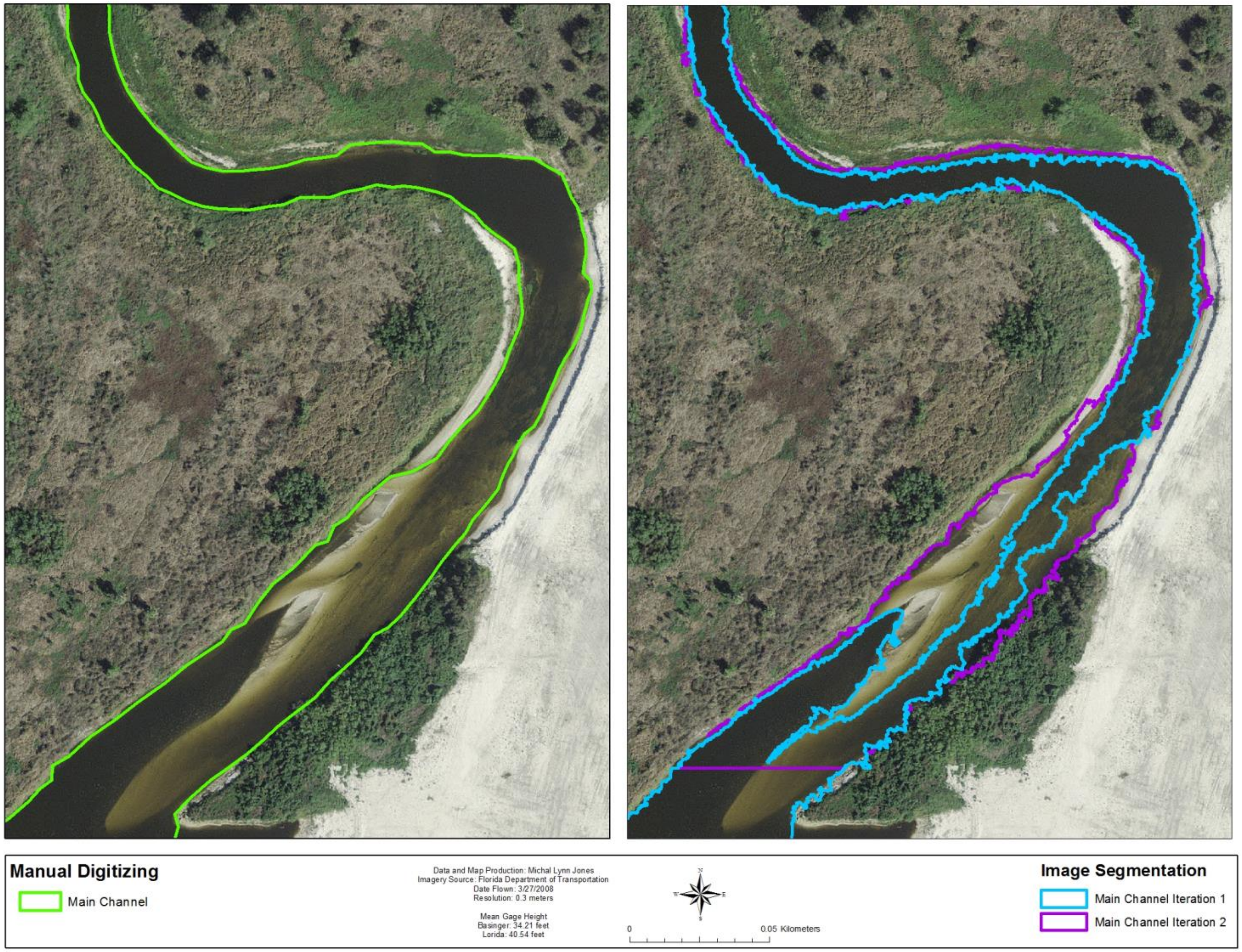

Figure 2-19. Reach 14, with a ratio of 0.79, is an area of significant underestimation. In this area, sandbars, riffles, and shadows resulted in segments that were not included in the river channel. Also note that the way the image segmentation works, it effectively excluded the secondary channel. Post-edits resulted in a ratio of 1.04.

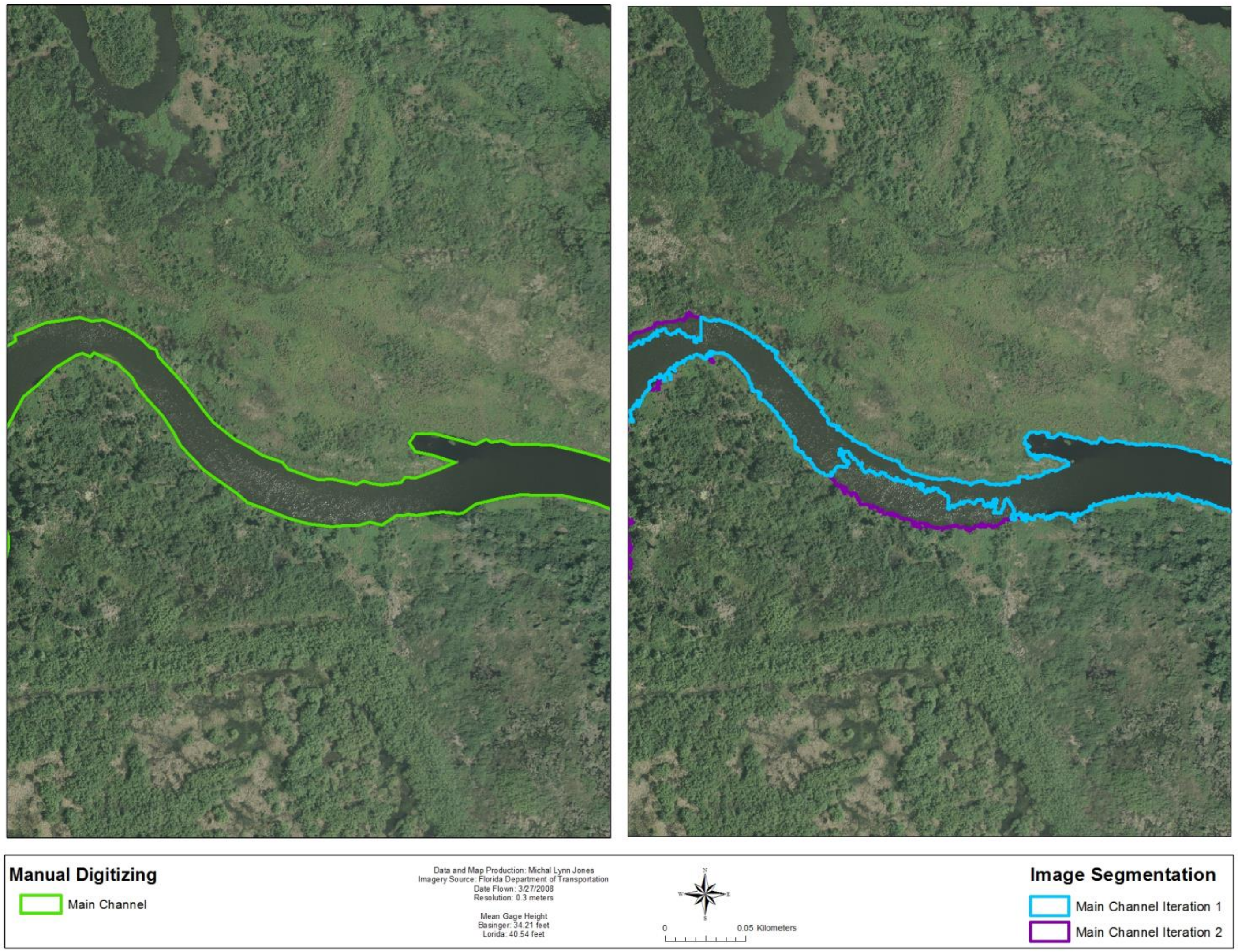

Figure 2-20. Reach 36, with a ratio of 0.83, is an area of significant underestimation. In this area, riffles resulted in an overall narrower river channel segment. There is also an area of image seams, which caused the straight line. Post-edits resulted in a ratio of 1.05.

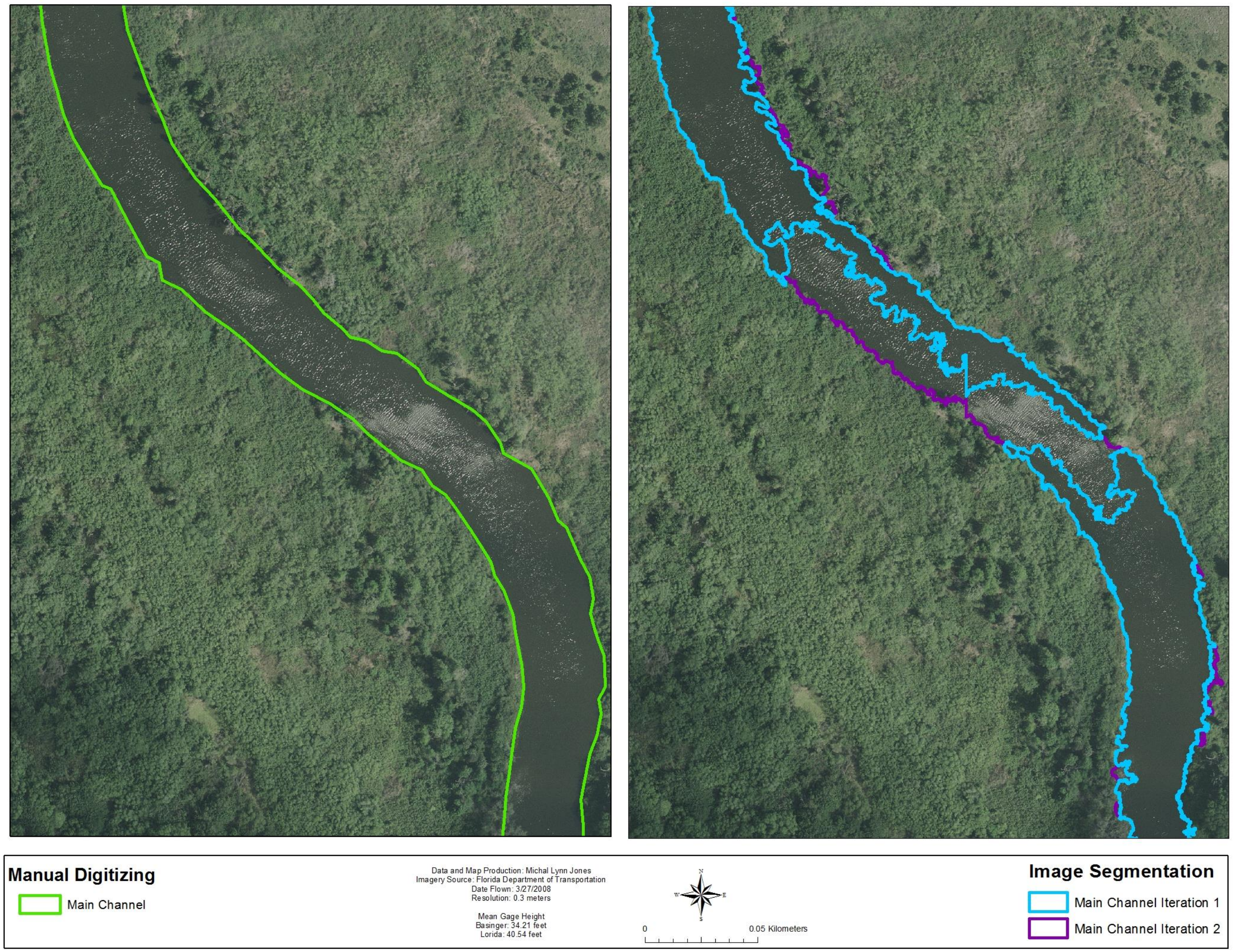

Figure 2-21. Results of Reach 41, an area of significant underestimation and a ratio of 0.72. In this area, riffles resulted in a complete break in the river channel segment. Post-edits resulted in a ratio of 1.00.

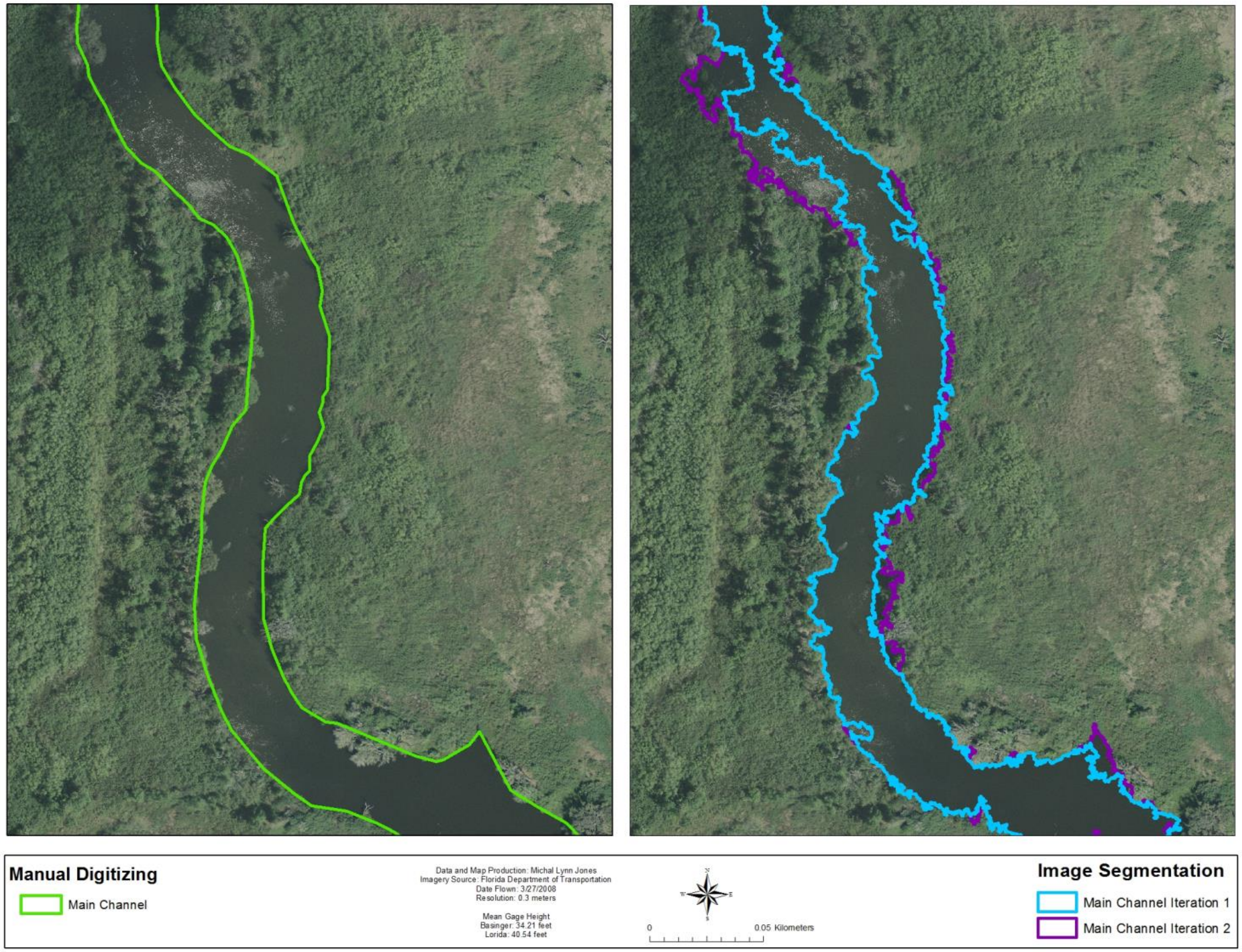

Figure 2-22. Reach 42, with a ratio of 0.81, is an area of significant underestimation. In this area, riffles and overhanging vegetation resulted in an overall narrower river channel segment. Post-edits resulted in a ratio of 0.98

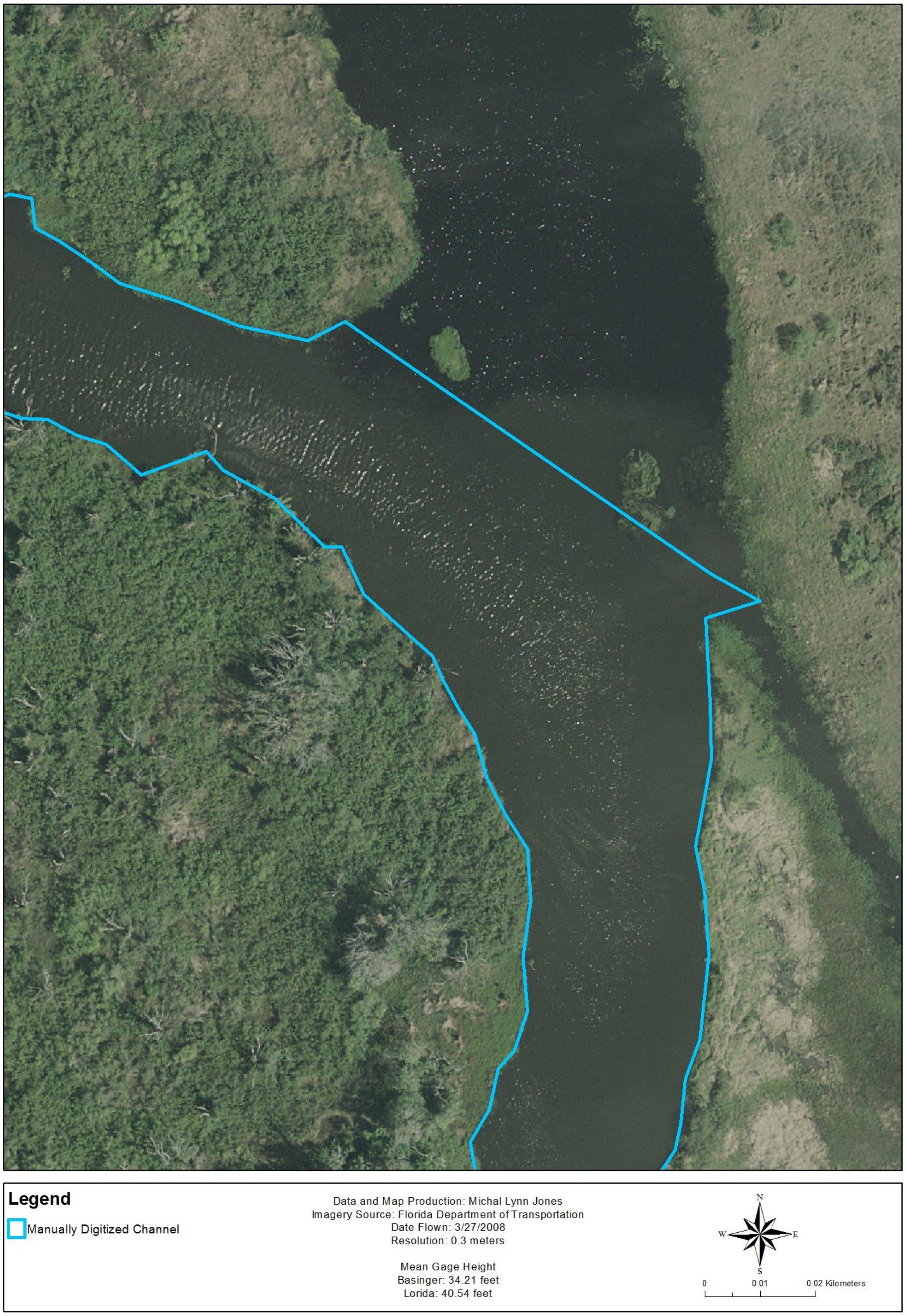

Figure 2-23. This image shows the subjectivity of digitizing across the mouth of tributaries and side channels, and the resulting potential for error.

Figure 2-24. This image shows how manually digitized lines can be jagged and sharp if the technician does not choose to make them smooth, which results in a less realistic display of the river channel and potential errors in analysis.

CHAPTER 3
FINAL CONCLUSIONS: USING IMAGE SEGMENTATION, DISCOVERIES, AND FUTURE RESEARCH

This study sprang from a need to find a better way to extract river channel features. Manually digitized renderings of the Kissimmee River had been created for another study. These shapefiles were created for several time series and had taken months of work. Upon examination however, the work was of very poor quality and not suitable for analysis. Thus, I was interested in assessing a method that would both save time and produce high quality, repeatable results specifically for river planform analysis. Image classification methods have been used extensively for land cover classification and change analysis and several types of feature extraction methods exist for a variety of spatial analysis purposes. However, I had not yet seen their application specifically to river planform study. Image segmentation seemed to be a promising method.

Image segmentation is a type of unsupervised classification that uses a region growing algorithm to lump pixels into individual segments. This differs from traditional classification methods that clump disparate pixels into the same categories. Because of the way it works, image segmentation is excellent for use in capturing the variability across landscapes, such as those found in extensive floodplain systems. It is also an excellent tool for extracting very specific features because the user can set parameters to control how finely or coarsely the pixels are segmented. Finding the exact setting that works best for any particular project will require some experimentation. It is highly recommended that the analyst run several test iterations using different combinations of parameters to find the optimal settings for any particular study. In this study, 35 iterations were attempted to fine-tune the parameter settings and select the optimal settings. Once these parameters were chosen, I was able to run all the images with the same parameters and obtained very similar results. One could also mosaic an image set and process the large image in one session. This is recommended if system resources allow as this will result in seamless segmentation across the entire study area.

Discoveries

In performing the test iterations of this tool, I made some discoveries about how it may be used to study floodplain features other than just the river. Certain settings caused the main river channel and vegetation covered overflow areas to be clumped together. Even though only the vegetation was visually obvious, the reflectance values indicated the presence of water. Thus, image segmentation could be useful in studying floodplain connectivity even if the presence of water isn't obvious. This could be useful to floodplain ecologists interested in organismal utilization of floodplain habitats as water rises and recedes. Results could be compared against digital elevation data to determine the plausibility of the results. Similarly, during flood events in which the presence of water is obvious, image segmentation could be used to determine flood extent. This could be useful to municipal planners in such activities as assessing overall flood damage, rise and fall timing of the flood event, and determining future flood risk.

Future Research

Image segmentation is an optimal tool for high spatial resolution imagery since it works more or less like an image degradation tool by lumping pixels together. This study did not test the use of the tool on black and white imagery, nor on low quality or low resolution imagery. This is the logical next step for future research because of the need to use imagery from a variety of time periods and sources, each with differing quality and resolution in the assessment of historical river conditions. After determining the usability with different imagery types, further assessment of the method can be completed, comparing the results of a manually digitized time series to the results of a time series extracted solely with image segmentation.

Final Conclusions

This study used image segmentation to produce repeatable results with no significant variation from the widely accepted manual digitizing method. It is a suitable if not better substitute for manual digitizing using high spatial resolution images that is less time consuming and thus potentially less costly to perform.

It must be noted that the delineation of a river channel can be subjective and when taken from an aerial image, it is completely based on visual cues. Thus, the most important aspect of the study can be whether or not the extracted channel feature “looks right”. However, given that the image segmentation extracts data based on reflectance values, given the appropriate parameters, the resulting channel delineation may be assumed correct with minimal error.

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BIOGRAPHICAL SKETCH

Michal Jones was born in Tulsa, Oklahoma, where she attended elementary school. She attended junior high school in Durango, Colorado, where her family moved in 1987. Moving back to Tulsa in 2000, she attended Union High School, which prepared her to study at Oklahoma State University (OSU). Following her love of animals and nature, particularly fish ecology and river systems, she subsequently obtained a Bachelor of Science degree in Zoology. During her time at OSU, she had the opportunity to work with many graduate students and professors conducting field and geographic information systems (GIS) research on the ecology of streams and rivers. After graduation from college, she sought and obtained employment in a variety of freshwater stream and river research projects involving mussels, fish, and GIS. Interested in moving to Florida to pursue a Master of Science degree, she obtained employment in the Florida Museum of Natural History's Florida Program for Shark Research. In 2006 she was hired to conduct field work on a large joint project with the Florida Fish and Wildlife Conservation Commission and the UF Department of Fisheries and Aquatic Sciences, tracking and mapping fish movements on the Apalachicola River for several months. After returning from the field, she enrolled in the Department of Geography to study fluvial morphology, GIS, and remote sensing. As a graduate student she worked for the Department of Fisheries and Aquatic Sciences, the UF GeoPlan Center, the United States Geological Survey as a STEP employee, St. John's River Water Management District, the South Florida Water Management District, and the Department of Agricultural and Biological Sciences. She also obtained a tuition assistance package from the UF GeoPlan Center and several teaching assistantships in the Geography Department for the hydrology, GIS, and Air Photo Interpretation classes. As of this writing, she works for SAIC, Inc. in Orlando, Florida, performing GIS analysis work on government contract projects.