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EFFECTS OF VARYING LAND USE ON HEADWATER STREAM FISH ASSEMBLAGES AND IN-STREAM HABITATS IN SOUTHWESTERN LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
In partial fulfillment of the
Requirements for the degree of
Master of Science

in

The School of Renewable Natural Resources

by
Alexandra Marie Fitzgerald
B.S., Virginia Polytechnic Institute and State University, 2010
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ABSTRACT

Although watershed land use effects on in-stream fish habitat and fish-macrohabitat associations have been widely studied in the past, low-gradient, coastal Louisiana streams have been poorly described in the literature. In this thesis, I report the results of a two-year study exploring relationships among regional land use, in-stream physical habitat, and headwater stream fish assemblages.

In chapter two, I examined land use, in-stream habitat variables, such as depth, flow, and substrate combined with three-pass electrofishing depletion estimates at thirteen 100-m stream sites. I used a combination of principal component analysis and structural equation modeling to determine if trends were present in the habitat, fish composition, and species trait data. I found that a species-based structural equation model was a better predictor of relationships among fish, land use, and in-stream habitat variables, when compared to species grouped by functional traits. In addition, it appears that the amount of agricultural land may not have as detrimental an effect on fishes in these coastal streams as reported for other aquatic systems and substrate type may be the most important manageable habitat parameter.

In chapter three, I measured various in-stream habitat variables (i.e.; dominant substrate, depth, flow) for two dominant macrohabitats (pools vs. glides). I collected fish from each macrohabitat via point-abundance electrofishing and compared these data with canonical correlation analysis (CCorA) to determine if trends were present in macrohabitat, fish composition, and species trait data. I found that species- and functional trait-based CCorAs were able to determine correlations with various macrohabitats and variables within macrohabitats.

Results indicate that species traits may be better measures of assemblage structure when macrohabitat-scale management, conservation, or restoration is the goal.

Although I expected land use to heavily influence in-stream habitat and fish assemblage composition, my research indicated that in-stream habitat was more influential than land use in determining species composition of Louisiana headwater stream fish assemblages. I also expected species- and trait-based models to successfully predict fish-macrohabitat associations. The findings of this study confirmed my predictions that multiple techniques for assessing fish-macrohabitat associations exist, although the most appropriate method may depend on specific management, restoration, or conservation goals.

CHAPTER 1: INTRODUCTION

In every respect, the valley rules the stream.
–H.B.N. Hynes (1975)

It has long been recognized the role the landscape plays in stream and river ecology and dynamics (Hynes 1975; Allan 2004). More recently, attention has focused on the effects of human activities on the landscape and, in turn, the streams and rivers embedded within landscapes. The conversion of lands for human activities have widespread and long-lasting effects including, but not limited to, altered flow regimes, changes in sedimentation, nutrient loading, and water chemistry, reduction in riparian vegetation, stream shading, and woody debris inputs, and increases in non-point source pollution (Angermeier and Karr 1984; Delong and Brusven 1993; Poff and Allan 1995; Walser and Bart 1999; Wang et al. 2001; Dolloff and Warren 2003). These changes to streams and the macro- and microhabitats that comprise their physical structure directly affect the ability of streams to support a diverse, native aquatic biota.

It is estimated that at least 70 percent of stream channel length in the United States is found in headwater streams (Leopold et al. 1964 in Lowe and Likens 2005). Meyer et al. (2007) argued that because their small catchments are easily influenced by surrounding conditions, headwater streams are one of the most varied of all lotic habitats. This tremendous habitat diversity is reflected in the ability of these small systems to support a variety of headwater-specialist species, riverine species requiring streams for particular life history stages, and terrestrial species with close ties to streams (Lowe and Likens 2005, Meyer et al. 2007). Headwater streams in the southeastern United States support a diverse array of freshwater fishes, many of which are endemic. Louisiana alone boasts 170 fish species (Douglas and Jordan 2002). Although varying land use plays a large role in habitat quality and, in turn, fish distribution, the

native ichthyofauna found in low-order headwater streams, such as those found in southwestern Louisiana, has been reported to be highly resilient to natural and anthropogenic changes in environmental conditions, which allows rapid recovery of species assemblages after disturbance (Reice et al., 1990; Winemiller and Rose 1992; Williams et al. 2003; Williams et al. 2007). However, additional studies focusing on the effects of land use and environmental variation on stream habitat quality and biotic integrity need to be completed for this region. Felley (1992) identified multiple areas of research for Gulf coastal streams, including the effects of low-water/high-water cycles, channelization, removal of woody debris, and land use on stream fish abundance and assemblage structure. With these research needs in mind, I focused my research on fish-habitat interactions in headwater streams in southwestern Louisiana.

The overall goal of this study was to explore relationships among regional land use, in-stream physical habitat, and headwater stream fish assemblages. The bulk of this thesis focused on comparing streams across two spatially isolated drainages (Chapter 2). My specific objectives were to assess: 1) the relative effect of land use on in-stream habitat and fish assemblage composition; and 2) whether taxonomic or functional categorization of fish assemblages was more appropriate for determining the effects of land use and in-stream habitat on native fishes. A smaller project (Chapter 3) explored headwater stream fish microhabitat usage in three neighboring, relatively undisturbed streams in the Kisatchie National Forest of southwestern Louisiana. The main objective of this study was to determine if the distribution of fishes varies among microhabitats, and the variables that influence those distributional trends. By evaluating the relative contribution of in-stream habitat and land use to the taxonomic and functional structure of resident fish assemblages managers will be better prepared to implement

management and restoration plans that reduce land use impacts on unique and understudied low-gradient streams in the western Gulf of Mexico Coastal Plain.

BIBLIOGRAPHY

Allan, J.D. 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. Annual Review of Ecology and Systematics 35:257-284.

Angermeier, P.L. and J.R. Karr. 1984. Relationships Between Woody Debris and Fish Habitat in a Small Warmwater Stream. Transactions of the American Fisheries Society 113: 716-726.

Delong, M.D. and M.A. Brusven. 1993. Storage, transport, and decomposition of particulate organic matter in an agriculturally impacted stream. Hydrobiologia 262:77-88.

Dolloff, C.A. and M.L. Warren, Jr. 2003. Fish relationships with large wood in small streams. Pages 179-194 *in* Gregory, S.V., K.L. Boyer, and A.M. Gurnell, editors. The ecology and management of wood in world rivers. American Fisheries Society, Symposium 37, Bethesda, Maryland.

Douglas, N.H. and R.J. Jordan. 2002. Louisiana's inland fishes: A quarter century of change. Southeastern Fishes Council Proceedings 43:1-10.

Felley, J.D. 1992. Medium-low-gradient streams of the Gulf coastal plain. Pages 233-270 *in* C.T. Hackney, S.M. Adams, and W.H. Martin, editors. Biodiversity of the Southeastern United States. Aquatic Communities. John Wiley & Sons, Inc., New York, New York.

Hynes, H.B.N. 1975. The stream and its valley. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 19:1-15.

Lowe, W.H. and G.E. Likens. 2005. Moving headwater streams to the head of the class. BioScience 55:196-197.

Meyer, J.L., D.L. Strayer, J.B. Wallace, S.L. Eggert, G.S. Helfman, and N.E. Leonard. 2007. The Contribution of Headwater Streams to Biodiversity in River Networks. Journal of the American Water Resources Association 43: 86-103.

Poff, N.L. and D.J. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrologic variability. Ecology 76:606–27.

Reice, S.R., R.C. Wissmar, and R.J. Naiman. 1990. Disturbance regimes, resilience, and recovery of animal communities and habitats in lotic ecosystems. Environmental Management 14:647-659.

Walser, C.A. and H.L. Bart. 1999. Influence of agriculture on in-stream habitat and fish community structure in Piedmont watersheds of the Chattahoochee River System. Ecology of Freshwater Fish 8:237–46

Wang, L., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environmental Management 28:255-266.

Williams, L.R., T.H. Bonner, M.G. Williams, C.S. Williams, and T. Leavy. 2003. A survey of fishes and macroinvertebrates inhabiting streams of Peason Ridge Wildlife Management Area (Ft. Polk, US Army, Louisiana). Habitat associations and population structure for fishes inhabiting headwater steams of west-central Louisiana. Unpublished manuscript.

Williams, L.R., J.D. Hudson, III, M.G. Williams, V. Campbell-Arval, and T.H. Bonner. 2007. Evaluation of a stream system after clearcut logging disturbance in the gulf coastal plain. Journal of Freshwater Ecology 22:119-133.

Winemiller, K.O., and Rose, K.A. 1992. Patterns of life-history diversification in North American fishes: implications for population regulation. Canadian Journal of Fisheries and Aquatic Sciences 49:2196–2218.

CHAPTER 2: RELATIVE INFLUENCE OF LAND COVER TYPE AND IN-STREAM HABITAT ON SOUTHWESTERN LOUISIANA COASTAL STREAM FISH ASSEMBLAGES

2.1 INTRODUCTION

Headwater streams of the southeastern United States have received comparatively little research and management compared to headwater cold- and coolwater streams in the northern and western areas of the United States (Larimore 1981; Stevens 2004). Many of these warmwater streams have historically supported important recreational fisheries, but in recent decades have been severely impacted by in-stream, riparian, and watershed alterations that have impacted in-stream habitat and fish assemblage composition (Carver 1975; Ebert et al. 1991; Jackson 1991; Felley 1992). Because it is widely recognized that management strategies and sampling techniques developed for lotic coldwater and coolwater fishes and their habitats are inappropriate for warmwater systems (e.g., Ebert et al. 1991; Rabeni and Jacobsen 1999; Williams et al. 2004; Rabeni et al. 2009; Price and Peterson 2010), quantitative research into fish-habitat relationships in altered warmwater systems is needed.

Although numerous studies have demonstrated a direct and influential effect of land use on in-stream habitat (e.g., Vondracek et al. 2005; Wiejters et al. 2009), other studies indicate the role of land use, although important, may have less impact on the structure of stream fish assemblages than physical stream habitat characteristics or other local variables such as stream sinuosity and riparian characteristics (Wang et al. 1997; Wang et al. 2006; Diana et al. 2006). In addition, conclusions regarding environmental effects on fish assemblage structure can depend on whether analyses are based on taxonomic or functional approaches to fish assemblage characterization, particularly in southern, warmwater streams (Hoeinghaus et al. 2007).

Coastal streams in Louisiana provide a unique opportunity to examine relationships between fish assemblage structure, habitat, and land use, as well as, the appropriate assessment approach (e.g., taxonomic or functional groupings) for examining these relationships. These streams are characterized by low gradients, moderate to high discharge, low turbulence, low dissolved oxygen, sand/silt substrates, large amounts of woody debris, and watersheds that are isolated by saltwater (Robinson 1986; Conner and Suttkus 1986; Felley 1992; Ice and Sugden 2003; Brown and Matthews 2006). They are also home to a diverse array of fishes that are adapted to seasonal extremes in temperature and low dissolved oxygen levels (Douglas 1974; Conner and Suttkus 1986; McAllister et al. 1986; Douglas and Jordan 2002). In addition, most of these streams have been increasingly impacted in recent decades by a diversity of anthropogenic disturbances including agriculture, forestry, and urban/infrastructural development.

The goal of this study was to explore relationships among regional land use, in-stream physical habitat, and the assemblage structure and abundance of headwater stream fishes in the southwestern Louisiana coastal plain. Specifically, I wanted to assess: 1) the relative effect of land use, based on land cover type, on in-stream habitat and fish assemblage composition and structure; and 2) whether taxonomic or functional fish groups are more appropriate for determining the effects of differences in land cover types and in-stream habitat on resident fishes. Results of this study will help managers implement management and restoration plans that reduce land use impacts in these coastal plain systems.

2.2 METHODS

2.2.1 Site Description

Sites were located in streams within the Mermentau and Calcasieu River watersheds in southwestern Louisiana, within the U.S. Environmental Protection Agency Level III Western Gulf Coastal Plain and Southern Coastal Plain ecoregions, respectively (Daigle et al. 2006). The Mermentau River basin drains approximately 10,100 km^2 and is predominantly agricultural land cover with an emphasis in rice/crawfish cultivation. The Calcasieu River basin drains approximately 10,500 km^2, is predominantly forested, managed as mature longleaf pine (*Pinus palustris*) plantations (Williams et al. 2007), as well as, critical habitat for the red-cockaded woodpecker (*Picoides borealis*). Average monthly temperatures in southwestern Louisiana range from 10.2°C in January to 27.9°C in July, with an annual average temperature of 19.9 °C. Total annual rainfall for the region averages 139 cm.

I established 13 study sites in 1st to 3rd order streams in the Calcasieu (N=6) and Mermentau (N=7) River watersheds based on accessibility, lack of upstream structures (dams, sills, etc.), ability to retain adequate water levels throughout the drier summer season. No additional streams in these watersheds met these criteria because of widespread anthropogenic modification and frequent summer dewatering. Each sample site consisted of a 100-m stream reach containing a variety of macrohabitats, substrate, and woody debris that was representative of habitat conditions in that stream (Kruskal and Mosteller 1979).

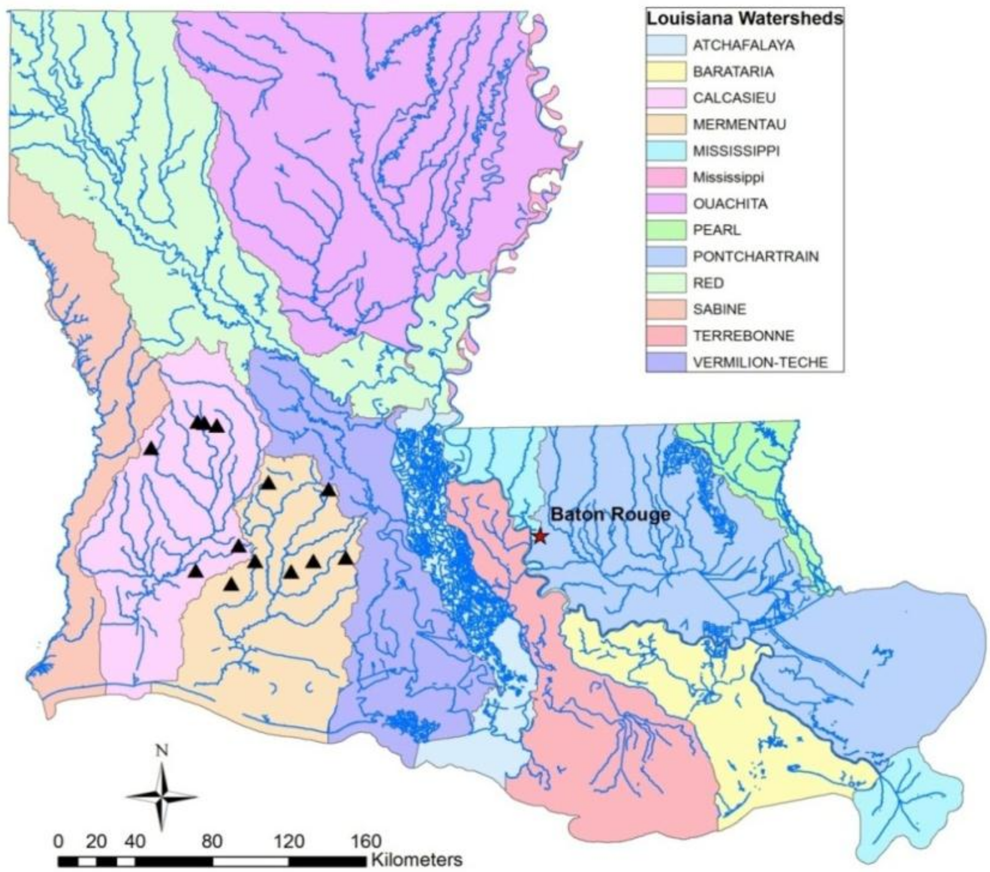


Figure 2.1: Locations of the 13 study sites in the Calcasieu and Mermentau River basins sampled in late spring 2011 and 2012 in southwestern Louisiana.

2.2.2 Field Sampling

Fish sampling- I sampled fish at each site with a Halltech HT-2000 or Smith Root LR-24 DC backpack electrofishing unit. Selected stream sites were visited once each during the summers of 2011 and 2012 (13 streams x 2 summers = 26 total sampling efforts). Block nets were placed at the upstream and downstream ends of each 100-m stream section to prevent fish escape during electrofishing surveys (Price and Peterson 2010). Each survey consisted of a three-pass removal in an effort to collect all fishes present (Meyer and High 2011). All fish were identified to species and released at original place of capture, excluding individuals kept as voucher specimens, and those that could not be identified on site. Unidentified individuals were placed in

an ice slurry and returned to the laboratory for further identification. Power-on time was recorded in order to estimate catch-per-unit-effort (CPUE; fish per minute) at each site. Fish were collected under valid state collection permits and Institutional Animal Care and Use Committee (IACUC) protocols.

Habitat- Following fish collection, habitat measurements were recorded at 30 points along a series of 10 diagonal transects modified from the representative reach extrapolation technique (RRET; Williams et al. 2004). Depth (m), flow (cm/sec, Sontek Flowtracker Handheld ADV) and substrate were recorded at 25%, 50%, and 75% along the transect. Substrate was visually categorized as coarse gravel, fine gravel, sand, silt/clay/muck, and hardpan. I collected two samples of substrate at each site with a 500-ml jar for a more quantitative assessment. These samples were dried to constant mass at 60°C and weighed prior to sifting through a modified Wentworth scale to determine substrate particle size composition (Wentworth 1922). Percent canopy cover was measured in the middle of each transect with a concave reflective densiometer. Wetted width (m) was measured at the start of each transect, whereas transect length (m) was measured at alternating transects. To quantify in-stream structure, I recorded large woody debris (>10 cm diameter, >1.5 m length) that intersected alternating transects and estimated fine woody debris with a stick count within a 0.5-m radius of each sample point.

Water Quality- I recorded water temperature (°C), dissolved oxygen concentration (DO; mg/L), pH, turbidity (NTU) and specific conductance (µS/cm) at each site with a hand held YSI 650 (YSI, Inc., Yellow Springs, OH). In addition, water samples were taken at each stream, placed on ice, brought back to the laboratory, and analyzed for biochemical oxygen demand (BOD). Duplicate BOD samples were assessed over a 20-day period following Standard Method 5210 (American Public Health Association 2005).

2.2.3 Land Use Analysis

Watersheds upstream of study sites were delineated with a digital elevation model (DEM) in ArcGIS (ERSI ArcMap 9.3). Stream information was obtained from the National Hydrography Dataset (NHD) 1:24,000 provided by the United States Geologic Survey (http://datagateway.nrcs.usda.gov/GDGOrder.aspx). I obtained land cover data from the Louisiana 2006 Land Cover Data accessed from National Oceanic and Atmospheric Administration (NOAA) Ocean Service, Coastal Services Center website (http://www.csc.noaa.gov/crs/lca) and subsequently reclassified categories as urban, agriculture, forested, water, palustrine, or estuarine, which I verified during site visits. Percent land cover was determined for each upstream catchment by converting raster pixels (30x30-m resolution) to square kilometers and calculating total area within each land cover type.

2.2.4 Statistical Analysis

Because concerns have been raised about the efficiency of detecting and netting fishes in warmwater streams (Hayer and Irwin 2008; Price and Peterson 2010), I estimated detection probabilities for fish species with likelihood-based models employing a logit link function (PROGRAM MARK Vers. 6.1, White and Burnham 1999) following Mackenzie et al. (2002, 2006) and Gu and Swihart (2004). For each species, I estimated detection probabilities for each pass across all sampled streams. Fish species groupings were determined with principal component analysis based on the correlation matrix of species abundances (PCA; Hirst and Jackson 2007; PROC FACTOR, SAS vers. 9.3, SAS Institute, Inc., Cary, N.C.). Following Jackson (1993) and Franklin et al. (1995), I selected principal components with a scree plot (Cattell's Test; Cattell 1966) and by comparing eigenvalues to randomly generated eigenvalues

(parallel analysis or Horn's Test; Horn 1965). Fish species used to interpret the principal components had minimum correlation of 0.5 (Stevens 2002).

The principal components based on fish abundances, along with physical habitat, water quality, and land use variables, were used in a structural equation model (SEM; Pugesek 2003; Grace 2006; PROC CALIS, SAS vers. 9.3, SAS Institute, Inc., Cary, N.C.) to determine the influence of land use and habitat on fish abundance (Figure 2.2). The SEM allowed simultaneous modeling of complex interactions and parameter estimation among land use, habitat, and the fish assemblage, each of which is difficult to measure by conventional means. SEMs combine the strengths of multiple regression, multivariate analysis of variance, and factor analysis (Hayduck 1987; Hoyle and Gregory 1994; Hoyle 1995; Gough and Grace 1999; Grace 2006). Unlike performing individual univariate models for each relationship (e.g., land use influences on habitat) that incorrectly assume and estimate independent error terms (Grace 2006), my SEM approach better estimates variance by indicating the path of analysis, with each subsequent step incorporating the error of the previous step, and still allows the estimation of individual parameters in the model. I constructed three latent, or underlying variables, to represent land use, habitat, water quality, and the fish assemblage. These latent variables were described by land cover percentages and field measurements. Ideally, each species would be allowed to uniquely correlate with the fish community latent variable (Pugesek 2003; Grace 2006). However, because of degree of freedom limitations, I used four principal components to describe the overall fish assemblage latent variable. Use of latent variables, rather than direct measures, allowed for quantification of the variance associated with habitat, land use, water quality, and the fish assemblage not explained by direct field or GIS measurements (Pugesek 2003; Grace 2006), thus suggesting the real relative influence of each latent variable on the fish community without

the underestimation bias from unmeasured variables. Goodness of fit for the SEMs was assessed by root mean square error approximation (RMSEA), the Bentler-Bonnet Non-Normed Fit Index (NNFI), the Comparative Fit Index (CFI), and Consistent AIC (CAIC). Although RMSEA is generally considered more informative, I put greater emphasis on interpretation of NNFI, CFI, and CAIC because these indices are less sensitive to sample size (Marsh et al. 1988; Hu and Bentler 1995; Fan et al. 1999; Tomer and Pugesek 2003).

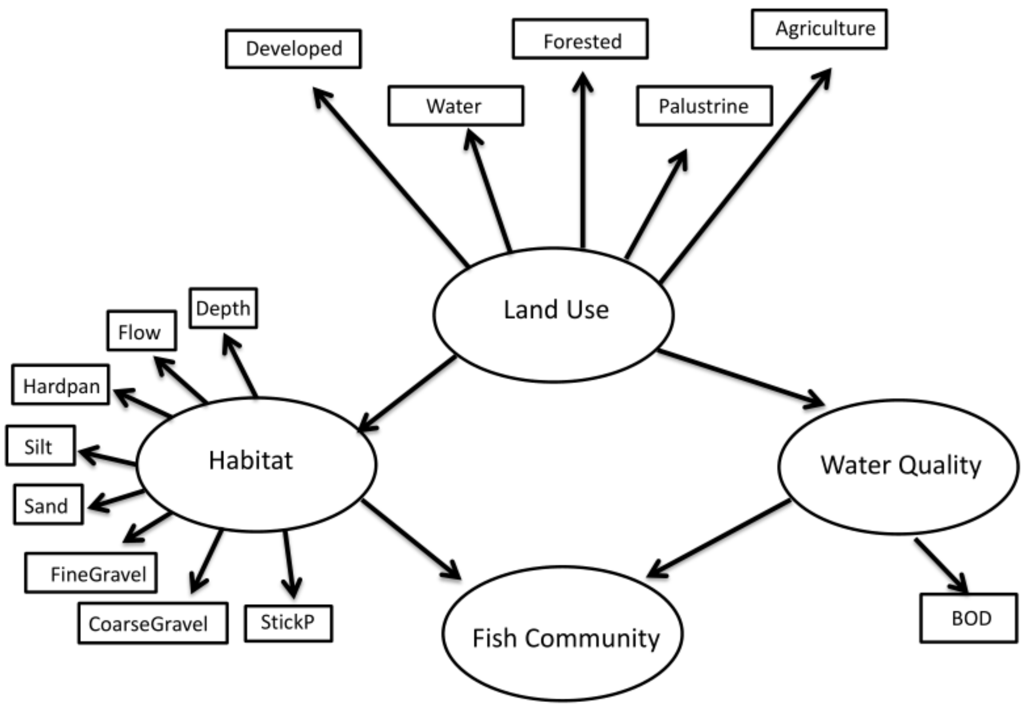


Figure 2.2: Structural equation model representing the latent variables habitat, land use, water quality, and fish community and the direct measurements used to describe these variables**.**

I also constructed three additional SEMs examining these relationships based on species functional traits, including feeding modes (piscivore, invertivore, omnivore, or detritivore), feeding locations (benthic feeder, water column filterer, plants and plant surface feeder, water surface feeder, water column predator), and spawning modes (cavity spawner, nest spawner, nest associate, broadcast spawner, live bearer, plant spawner, or non- nest building substrate spawner)

to determine if habitat associations were more evident based on these species groupings. Functional trait-based analyses provide additional means of examining land use-habitat-fish interactions based on life history characteristics rather than species. Traits for each species were determined from literature specific to fishes of the region (Ross 2002; Thomas et al. 2007). I considered the species-based SEM as the baseline for interpretation of all SEMs, because this model had the greatest flexibility for finding a best fitting structure. The utility of the functional assessments was assessed by comparing goodness of fit statistics of the three species-trait SEMs to the baseline species SEM.

2.3 RESULTS

2.3.1 Fishes

Fish and habitat data were collected over 26 sampling events between 2011 and 2012 (Table 2.1). Samples yielded 3,276 individuals representing 45 species, which ranged from 8 species is West Bayou Grand Marais to 23 species in Big Brushy Creek. Species detection probabilities were generally very high regardless of stream sampled (Table 2.2). Fishes with very low detection probabilities were uncommon in the study. Therefore, based on the high detection probabilities for most species, the progressive decline in detection probabilities that one would expect if depletion was occurring, the rarity of fishes with low detection probabilities, and their minimal impacts on subsequent analyses, I did not believe there was sufficient evidence to adjust abundance estimates based on detection differences among the streams.

Table 2.1: Complete list of all species sampled, total collected, and percent of total abundance for all sample sites in Louisiana during 2011 and 2012 sample seasons.

Species	Common Name	Total Collected	% Total Abundance
Gambusia affinis	western mosquitofish	976	29.79
Lepomis megalotis	longear sunfish	608	18.56
Lepomis cyanellus	green sunfish	428	13.06
Lepomis macrochirus	bluegill	164	5.01
Lythrurus umbratilis	redfin shiner	144	4.40
Fundulus olivaceus	blackspotted topminnow	122	3.72
Lepomis humilis	orangespotted sunfish	113	3.45
Aphredoderus sayanus	pirate perch	104	3.17
Lepomis gulosus	warmouth	96	2.93
Lepomis miniatus	redspotted sunfish	67	2.05
Pimephales vigilax	bullhead minnow	46	1.40
Ichthyomyzon gagei	southern brook lamprey	36	1.10
Lepomis marginatus	dollar sunfish	34	1.04
Notropis texanus	weed shiner	33	1.01
Etheostoma chlorosomum	bluntnose darter	32	0.98
Micropterus punctulatus	spotted bass	28	0.85
Opsopoeodus emiliae	pugnose minnow	24	0.73
Lepisosteus oculatus	spotted gar	24	0.73
Noturus gyrinus	tadpole madtom	24	0.73
Percina sciera	dusky darter	19	0.58
Ameiurus natalis	yellow bullhead	17	0.52
Cyprinella venusta	blacktail shiner	13	0.40
Dorosoma cepedianum	gizzard shad	13	0.40
Poecilia latipinna	sailfin molly	13	0.40
Notemigonus crysoleucas	golden shiner	11	0.34
Esox americanus	redfin pickerel	11	0.34
Erimyzon oblongus	creek chubsucker	9	0.27
Noturus nocturnus	freckled madtom	9	0.27
Etheostoma gracile	slough darter	8	0.24
Ameiurus melas	black bullhead	7	0.21
Fundulus notatus	blackstripe topminnow	6	0.18
Elassoma zonatum	banded pygmy sunfish	5	0.15
Micropterus salmoides	largemouth bass	5	0.15
Moxostoma poecilurum	blacktail redhorse	4	0.12
Ictiobus bubalus	smallmouth buffalo	4	0.12
Pomoxis annularis	white crappie	4	0.12
Ictalurus punctatus	channel catfish	3	0.09
Minytrema melanops	spotted sucker	3	0.09
Dorosoma petenense	threadfin shad	3	0.09
Percina maculata	blackside darter	1	0.03
Amia calva	bowfin	1	0.03
Notropis atherinoides	emerald shiner	1	0.03
Pylodictis olivaris	flathead catfish	1	0.03
Centrarchus macropterus	Flier	1	0.03
Lepomis microlophus	redear sunfish	1	0.03

Table 2.2: Detection probabilities [probability (0-1) and 95% confidence interval in parenthesis] for fish species sampled in the Calcasieu and Mermentau River Basin streams. NA= assumptions not met for that species.

Species	Detection Probability First Pass	Detection Probability Second Pass	Detection Probability Third Pass
Ameiurus melas	0.22 (0.01-0.78)	0.44 (0.03-0.95)	0.22 (0.01-0.78)
Ameiurus natalis	0.98 (0.01-1.0)	<0.01	<0.01
Amia calva	0.99 (0.99-0.99)	<0.01	<0.01
Aphredoderus sayanus	1.0 (0.87-1.0)	0.87 (0.64-0.98)	0.13 (0.02-0.36)
Centrarchus macropterus	0.99 (0.99-0.99)	<0.01	<0.01
Cyprinella venusta	<0.01	1.0 (0.14-1.0)	0.50 (0.04-0.86)
Dorosoma cepedianum	0.45 (0.10-0.86)	0.45 (0.10-0.86)	0.68 (0.16-0.96)
Dorosoma petenense	NA	NA	NA
Elassoma zonatum	0.29 (0.05-1.0)	<0.01	<0.01
Erimyzon oblongus	0.50 (0.12-0.88)	1.0 (1.0-1.0)	0.50 (0.25-0.88)
Esox americanus	0.72 (0.21-0.96)	0.48 (0.11-0.87)	0.72 (0.21-0.96)
Etheostoma chlorosomum	1.0 (0.99-1.0)	0.40 (0.15-0.70)	0.20 (0.04-0.50)
Etheostoma gracile	1.0 (0.99-1.0)	0.33 (0.02-0.84)	<0.01
Fundulus notatus	NA	NA	NA
Fundulus olivaceus	1.0 (0.99-1.0)	0.83 (0.52-0.96)	0.67 (0.38-0.87)
Gambusia affinis	1.0 (0.98-1.0)	0.89 (0.71-0.98)	0.89 (0.71-0.98)
Ichthyomyzon gagei	1.0 (0.79-1.0)	0.75 (0.41-0.95)	0.31 (0.15-0.50)
Ictalurus punctatus	NA	NA	NA
Ictiobus bubalus	<0.01	<0.01	0.99 (<0.01-1.0)
Lepisosteus oculatus	0.25 (0.04-0.65)	0.33 (0.06-0.76)	0.17 (0.02-0.53)
Lepomis cyanellus	1.0 (0.36-1.0)	0.20 (0.01-0.63)	0.20 (0.01-0.63)
Lepomis gulosus	0.53 (0.32-0.75)	0.53 (0.32-0.75)	0.37 (0.19-0.59)
Lepomis humilis	0.43 (0.14-0.77)	0.51 (0.18-0.85)	0.17 (0.03-0.48)
Lepomis macrochirus	1.0 (0.99-1.0)	0.86 (0.62-0.97)	0.57 (0.32-0.80)
Lepomis marginatus	1.0 (0.62-1.0)	1.0 (0.62-1.0)	1.0 (0.62-1.0)
Lepomis megalotis	0.82 (0.64-0.94)	0.82 (0.64-0.94)	0.62 (0.42-0.80)
Lepomis microlophus	NA	NA	NA
Lepomis miniatus	0.85 (0.61-0.97)	0.62 (0.38-0.83)	0.34 (0.15-0.58)
Lythrurus umbratilis	1.0 (0.93-1.0)	1.0 (0.93-1.0)	1.0 (0.93-1.0)
Micropterus punctulatus	1.0 (1.0-1.0)	0.25 (0.06-0.62)	0.50 (0.20-0.80)
Micropterus salmoides	0.50 (0.04-0.93)	1.0 (0.85-1.0)	0.50 (0.04-0.93)
Minytrema melanops	0.08 (0.02-0.26)	0.08 (0.02-0.26)	<0.01
Moxostoma poecilurum	<0.01	0.99 (<0.01-1.0)	<0.01
Notemigonus crysoleucas	<0.01	0.99 (0.03-1.0)	<0.01
Notropis atherinoides	0.99 (0.99-0.99)	<0.01	<0.01
Notropis texanus	1.0 (0.33-1.0)	1.0 (0.33-1.0)	<0.01
Noturus gyrinus	0.67 (0.27-0.92)	0.57 (0.23-0.86)	<0.01
Noturus nocturnus	<0.01	0.99 (0.38-1.0)	<0.01
Opsopoeodus emiliae	0.50 (0.22-0.81)	0.33 (0.12-0.62)	0.17 (0.04-0.41)
Percina maculata	0.99 (0.99-0.99)	<0.01	<0.01
Percina sciera	0.78 (0.35-0.99)	0.78 (0.35-0.99)	0.59 (0.19-0.92)
Pimephales vigilax	1.0 (1.0-1.0)	1.0 (1.0-1.0)	0.50 (0.12-0.88)
Poecilia latipinna	1.0 (0.99-1.0)	0.50 (0.06-0.94)	0.50 (0.06-0.94)
Pomoxis annularis	1.0 (0.38-1.0)	<0.01	1.0 (0.38-1.0)
Pylodictis olivaris	NA	NA	NA

Principal component analysis of fish species abundances produced four principal components (PCs, Table 2.3). Species correlations showed that PC1 was positively associated with non-game fishes characteristic of unaltered headwater streams, and negatively associated with western mosquitofish. Species that were typically found in larger streams and rivers in the region were positively correlated with PC2. Principal component 3 represented smaller recreationally important sunfishes and their associates, whereas PC4 represented a varied assemblage of recreationally important fishes, such as largemouth bass, and fishes of conservation importance, such as the banded pygmy sunfish. These two PCs showed little separation on the scree plot, resulting in differentiating the associated fish assemblages.

Table 2.3: Correlations between fishes with the four retained species principal components (PCs). Only correlations greater than |0.50| were interpreted and displayed.

	PC1	PC2	PC3	PC4
Gambusia affinis	-0.50389			
Notropis texanus	0.52429			
Micropterus punctulatus	0.53634			
Minytrema melanops	0.59830			
Ichthyomyzon gagei	0.62067			
Fundulus olivaceus	0.68591			
Lythrurus umbratilis	0.76086			
Percina sciera	0.80677			
Fundulus notatus	0.81080			
Moxostoma poecilurum	0.82329			
Etheostoma gracile	0.85429			
Aphredoderus sayanus	0.87488			
Etheostoma chlorosomum	0.87998			
Lepomis miniatus	0.92248			
Pomoxis annularis		0.78583		
Lepomis microlophus		0.96162		
Pylodictis olivaris		0.96162		
Dorosoma petenense		0.96162		
Ictiobus bubalus		0.96162		
Lepomis gulosus			0.63672	
Lepomis macrochirus			0.70664	
Poecilia latipinna			0.73577	
Notropis atherinoides			0.74456	
Ameiurus melas			0.76944	
Lepomis megalotis			0.82042	
Elassoma zonatum				0.73991
Lepomis marginatus				0.75144
Micropterus salmoides				0.75661
Erimyzon oblongus				0.81410
Esox americanus				0.84912

2.3.2 Habitat and Land Use

Habitat variables varied substantially across the study streams, e.g., average depth ranged from 20.8 cm (Alligator Bayou) to 61.5 cm (West Bayou Grand Marais), percent canopy cover from 16.2% (West Bayou Grand Marais) to 97.3% (Clear Creek), and average velocity from 0.0003 m/s (Petite Passe) to 0.3078 m/s (Alligator Bayou). All substrate categories were represented in the 13 streams, but silt and sand were the most prevalent categories at the study sites. Analysis of land use found substantial differences in the percentages of agriculture and forested lands among the watersheds (Table 2.3). Watersheds within the Calcasieu River basin had an average of 54.0% forested land cover and 37.5% agricultural land cover, whereas Mermentau River basin watersheds averaged 6.2% forested land cover and 78.5% agricultural land. Percentages of other land uses were relatively small with the exception of West Fork Caney Creek watershed, which included 43.9% of palustrine habitat.

Table 2.4: Sites, drainage, gradient, sub-watershed drainage area, and percentages of each land use category used in the structural equation models. ALL= Alligator Bayou, ARC= Bayou Arceneaux, BB= Big Brushy Creek, CC= Clear Creek, COU= Grand Coulee Ditch, EF6= East Fork Sixmile Creek, GM= West Bayou Grand Marais, LAC= East Bayou Lacassine, PAL= Bayou Pointe aux Loups, PP= Petite Passe, WF6= West Fork Sixmile Creek, WFC= West Fork Caney Creek, WIK= Bayou Wikoff. C= Calcasieu River drainage, M= Mermentau River drainage.

Site	Drainage (km^2)	Gradient (m/km)	Developed	Agriculture	Forested	Water	Palustrine
ALL C	19.96	2.07	3.36	92.18	1.45	0	3.01
ARC C	75.29	1.29	6.11	83.56	6.12	0.04	4.17
BB C	28.17	12.59	3.83	11	79.34	0.04	5.79
CC C	37.11	13.92	5.28	23.98	64.11	0.62	6.01
COU M	7.38	1.29	3.66	92.95	0.68	0	2.71
EF6 C	50.75	15.25	3.88	8.26	85.24	0.33	2.29
GM M	18.81	2.54	3.93	94.1	0.48	0	1.49
LAC M	54.38	1.59	5.19	94.37	0.28	0.07	0.09
PAL M	22.35	3.40	7.92	90.16	0.36	0	1.57
PP M	29.23	2.38	7.7	79.47	3.69	0.07	9.07
WF6 C	47.03	15.55	1.83	5.93	87.41	0.66	4.17
WFC M	15.09	3.52	10.74	7.62	37.64	0.07	43.94
WIK M	24.92	1.89	5.06	90.61	0.52	0.36	3.45

2.3.3 Structural Equation Models

Four structural equation models were used to examine fish-habitat interactions. The first SEM related species (described by PCA assemblages), to habitat, watershed, and land use variables. The three remaining models (Table 2.4) represented fish as functional groups defined by food habits, feeding habits, and spawning mode.

Table 2.5: Structural equation model fit statistics for each model used ordered by the Comparative Fit Index (CFI), root mean square error approximation (RMSEA), and Consistent AIC (CAIC). The Bentler-Bonnet Non-Normed Fit Index (NNFI) also is provided.

Fish Descriptor	RMSEA (smaller better)	NNFI (1 is best)	CFI (1 is best)	CAIC (smaller better)
Species	0.2505	0.7892	0.9271	572.09
Food habits	0.4649	0.3169	0.7639	752.30
Feeding habitat	0.4698	0.1081	0.6328	911.64
Spawning habitat	0.4391	0.2092	0.5921	1047.26

Analyses based on the PCA-defined species assemblages resulted in the best fit of the four models tested. Fit declined below interpretation guidelines for CFI and CAIC (e.g., Hu and Bentler 1995; Tomer and Pugesek 2003; Grace 2006) when functional traits were used to categorize species, suggesting that species traits were not as informative in assessing land use and habitat relationships with the stream fish assemblages.

I evaluated latent variable R^2 and inspected the standardized regression coefficients of the three interpretable SEMs (Figures 2.3 through 2.5; the SEM for spawning habitat traits is not depicted because the goodness of fit criteria were so low), which suggested several important and several less informative relationships. Generally, the latent variable land use ($R^2 = 0.25$) was a less important explanation than the latent variable proximal physical habitat ($R^2 = 0.60$) across the interpretable SEMs. This pattern was also evidenced by the much smaller magnitude of the standardized coefficients among land cover variables compared to habitat variables, except for the feeding locations SEM. Among physical habitat variables that I measured, substrate

characteristics were highly associated with the abundance of resident fishes. All four PCs were negatively related to all substrate types, particularly silt. Sites with large proportions of fine gravel and silt were positively related to the abundance of omnivores and detritivores, and negatively related to the abundance of piscivores and invertivores. Sites dominated by silt were positively related to the abundance of filterers, grazers, and benthic feeders, whereas these substrate conditions were negatively related to water column and surface feeders. Less informative relationships included small positive relationships between depth and woody debris with all of the PCs. Depth was also positively related with abundances of invertivores, detritivores, water column, and surface feeders. Woody debris also was positively related with abundances of omnivores, detritivores, filterers, grazers, and benthic feeders, but not invertivores, piscivores, water column, or surface feeders. Although land cover types were less informative regarding fish abundance patterns, increasing proportions of agriculture land cover exhibited a weak negative association with all of the PCs, omnivores, detritivores, filterers, grazers, and benthic feeders, and a positive association with water column feeders, surface feeders, invertivores and piscivores.

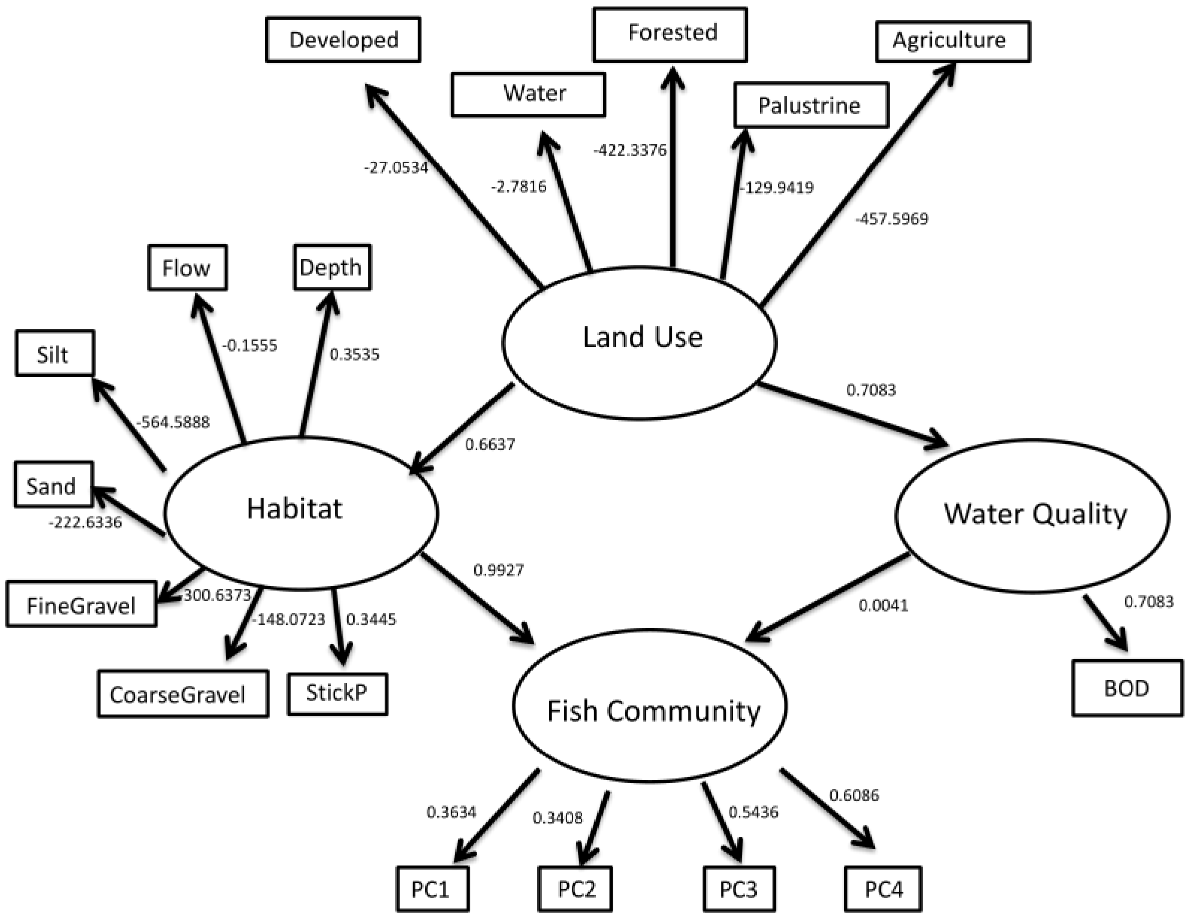


Figure 2.3: Standardized coefficients for the structural equation model based on fish species abundances (as described by PCA) Coefficients convey the relative magnitude of the contribution of the variables to the model.

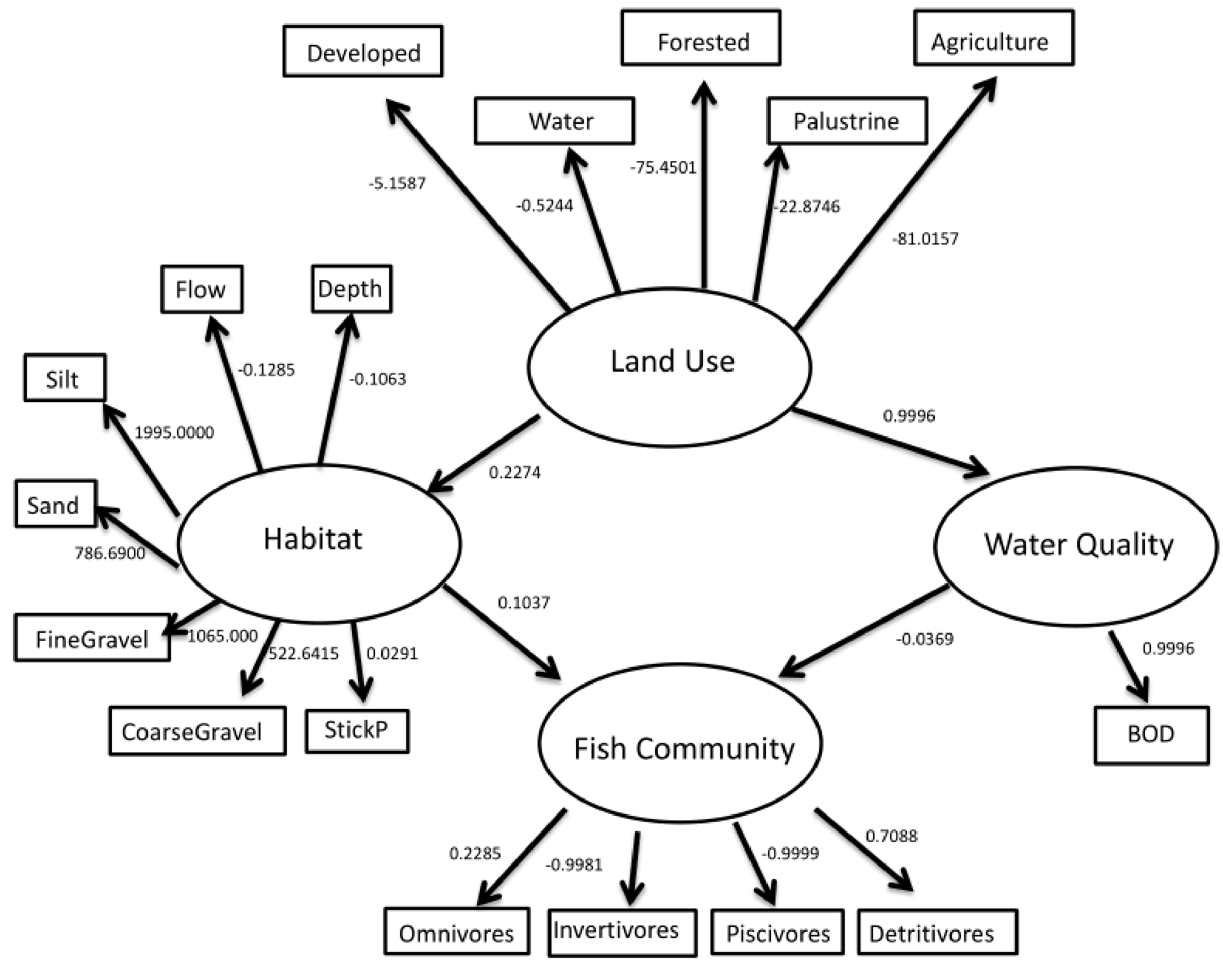


Figure 2.4: Standardized coefficients for the structural equation model based on species grouped by food habits. Coefficients are displayed to convey the relative magnitude of the contribution of the variables to the model.

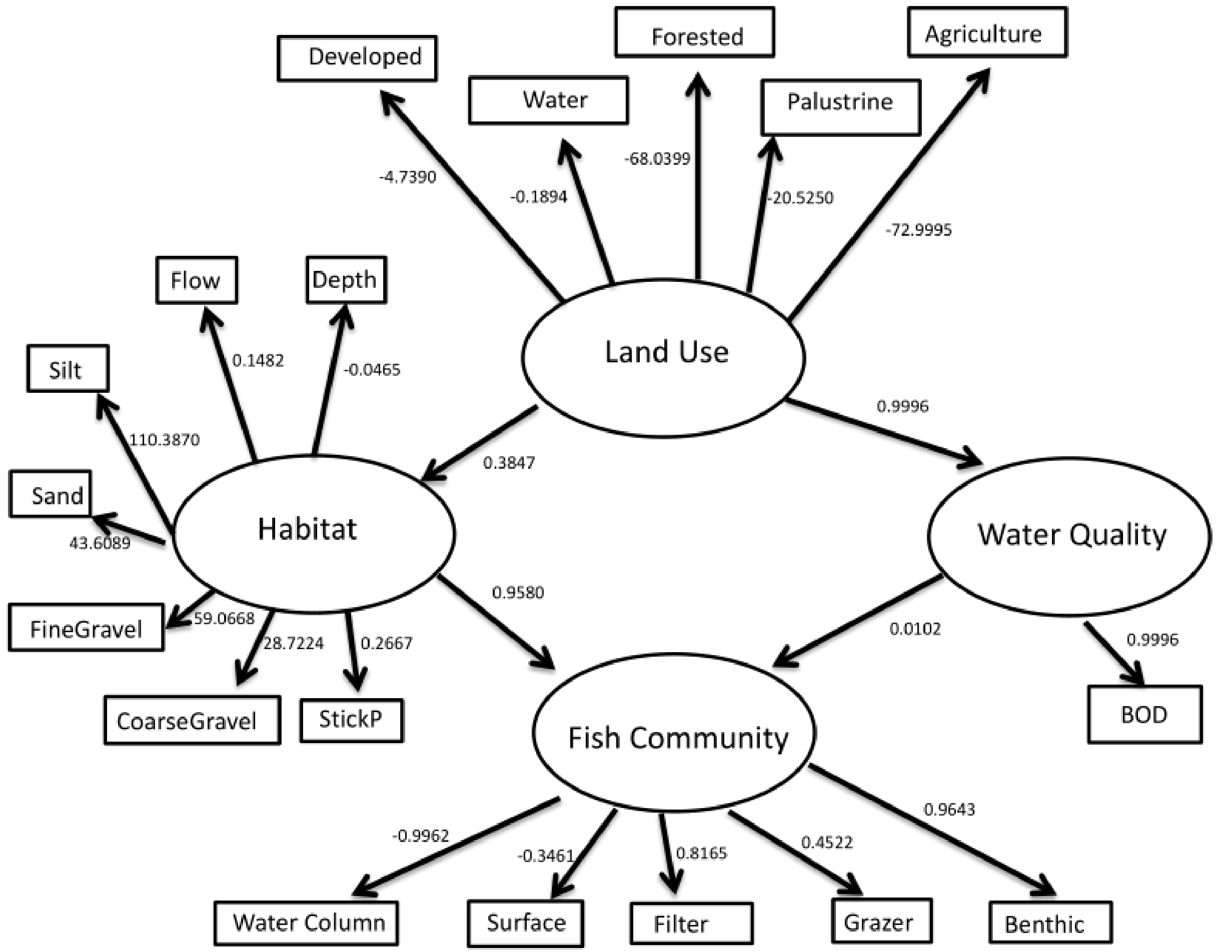


Figure 2.5: Standardized coefficients for the structural equation model based on species grouped by feeding habits. Coefficients are displayed to convey the relative magnitude of the contribution of the variables to the model.

2.4 DISCUSSION

Species assemblages as described by PCA provided the best fitting model for predicting relationships with habitat and land use characteristics of the study streams. Categorizing species based on functional groups decreased model fit considerably across all measures. Poor fit was the result of some functional groups (e.g., live bearers, filter feeders) that were either not present or were present disproportionately abundance within the two basins. Considerable taxonomic differences have been described between these basins because of the presence of a saltwater barrier to freshwater fish dispersal (McAllister et al. 1986; Felley 1992; Brown and Matthews

2006; Kaller et al. In press). It is likely, therefore, that the taxonomic differences, as well as, difference in watershed characteristics and in-stream habitat conditions within these two basins have selected for different functional groups within the fish assemblages.

Two important conclusions can be made regarding the relationships among species, habitat, and land use. First, although GIS summary data and observations at the study sites indicated substantial differences between basins and among streams, land use was not an important structuring factor for these fish assemblages. Taxonomic differences between the basins may be responsible for the apparent low explanatory power, as species assemblages within the study streams have already been filtered by past land uses and saltwater dispersal barriers. Calcasieu River Basin lands have historically been forested while lands within the Mermentau River Basin were predominantly prairie wetlands (Felley 1992; Vidrine et al. 2001). This dichotomy in land cover types, as well as, differences in soils across basins may have previously impacted assemblages prior to anthropogenic alteration. Even with the minimal explanatory power, however, there were still weak but detectable relationships between agricultural land use and fish assemblage structure. Interestingly, there were weak, positive associations between agriculture and piscivores, invertivores, water column feeders, and surface feeders. Study streams with high amounts of agricultural land cover demonstrated higher fish CPUEs than less impacted streams. These higher catch rates were predominately from increased numbers of sunfish and western mosquitofish. This unexpected association is likely due to the influence of unmeasured variables in the model. Because these agricultural streams have higher nutrients attributed to fertilizers and runoff as evidenced by their higher BODs (see Wiley et al. 1990, Scarsbrook and Halliday 1999), they are highly productive and can support a a variety of

food sources such as aquatic invertebrates and algae that provide a forage base for fishes (Sinsabaugh 1997; Bott et al. 1985; Corkum 1996).

Unlike this study, numerous studies comparing local physical and landscape variables have concluded that land use was more important than local scale variables (e.g., Vondracek et al. 2009; Esselman and Allan 2010). Agricultural land use has been found to be a strong predictor of fish abundance patterns in other regions of the U.S. (Trautman 1981; Harding et al. 1998; Walser and Bart 1999; Brown 2000; Infante et al. 2009). However, Wang et al. (2006) found that in undisturbed streams, fish assemblage structure was more influenced by local physical factors, whereas fishes in impacted streams appeared to be influenced more by watershed variables. Alternatively, many studies have reported opposite trends (Wang et al. 1997; Infante and Allan 2010). Wang et al. (1997) found that although increases in agricultural land coverage led to decreases in index of biotic integrity (IBI) scores, there was a critical threshold (> 50% coverage) that resulted in marked declines in IBI scores. In addition, streams with as much as 80% agricultural lands had relatively high IBI scores as long as the streams had relatively high gradients, rocky substrates, and minimal channelization. In my study streams, land cover thresholds may not have been exceeded, which may explain why land use did not appear to influence fish assemblages as strongly as in previously published studies. Alternatively, Diana et al. (2006) and Heitke et al. (2006) suggested that dominance of a land cover type within a watershed weakens relationships between aquatic biota with land use. Possibly, the dominance of forest cover in the Calcasieu Basin and agricultural cover in the Mermentau Basin did not offer enough variability in land cover types among sampled streams to detect relationships. The soils and topography of the Mermentau Basin is much more suited to agriculture than the nutrient poor, coarse substrates of the more rugged Calcasieu Basin, which is

dominated by forest managed for harvest (Welch 1942; Holland et al. 1952; Ishproding and Fitzpatrick 1992). In addition, gradient differences between basins may have played a factor in structuring assemblages. Surrounding land uses and in-stream habitat variables may have been affected by higher gradients in the Calcasieu River Basin when compared the Mermentau River Basin. Sampling and time constraints hindered my ability to obtain additional sites in multiple drainage basins representing a more diverse gradient of land uses. Future studies in the area should expand sampling locations to enable clearer distinctions among the role of land use and in-stream factors influencing streams and fishes in southwestern Louisiana. However, given these fixed land use patterns, my research suggests that modification of in-stream physical habitat, including reductions in fine sediment inputs in the Mermentau Basin, could provide the greatest benefits to fishes in these watersheds.

Second, although trait-based analyses have been reported to provide a more simplistic means of assessing and managing fish assemblages (Hoeinghaus et al. 2007; Frimpong and Angermeier 2010; Infante and Allan 2010), the streams in southwestern Louisiana may not be amenable to similar methods of assessment and management due to the unique nature of fish assemblages between the two basins, as well as, inherent issues with using function groupings in these streams. Functional groupings may have been too coarse for this particular study. Although groups based on feeding and spawning modes are present in the literature (Hoeinghaus et al. 2007), these streams may require additional, detailed sub-grouping. For example, groupings must account for species that exhibit ontogenetic shifts over a lifespan. Juveniles of a particular species may fall under a different feeding mode than larger adults. Because this study did not account for life history differences among life stages, functional group SEM fit may have

declined. In addition, many headwater species in my streams lacked baseline life history data, making more precise classification schemes difficult or impossible to use.

When examining each SEM in detail, we found several distinct relationships among species groups and the habitat variables. In particular, decreasing fine substrate and increasing the amount of woody debris and depth would have the most beneficial effect on all four assemblages. Increased sedimentation has been widely reported to reduce fish species richness in streams throughout the U.S. (Berkman and Rabeni 1987; Walser and Bart 1999), and reductions in fine sediment inputs through watershed erosion control can substantially increase the abundance and diversity of stream fishes (Wood and Armitage 1997). Similarly, increasing woody debris reduces erosion potential of streams, provides a variety of habitats including pools with high residual pool volume, and helps retain coarser substrates necessary for spawning while promoting the transport of fine sediments (Dolloff and Warren 2003). Greater mean depth and depth variability also contribute to fish assemblage richness (Infante and Allan 2010), and is typically inversely related to sediment inputs (Dolloff and Warren 2003). Reducing sediment inputs, particularly in the Mermentau basin, as well as increasing woody debris inputs would promote structural complexity in the study streams and improve habitat conditions for species of recreational and conservation interest.

Although trait-based SEMs exhibited poor fits with the data I collected, some conclusions were apparent. Detritivores such as southern brook lampreys tended to prefer shallow streams with fine substrates and little flow, whereas invertivores (e.g., percids and cyprinids) and piscivores (e.g., green sunfish, redfin pickerel) preferred deeper habitats with coarser substrates and higher water velocities, similar to fishes in Texas rivers (Hoeinghaus et al. 2007). Omnivores appeared more generalistic in their habitat associations, which has been reported in other studies

of stream fish assemblage structure (Hoeinghaus et al. 2007). The trophic group SEM suggested that benthic and filter feeders, such as slough darters and southern brook lamprey associated with shallow runs containing fine substrate and woody debris, similar to habitat preferences reported by Thomas et al. (2007). As expected, surface and water column feeders (e.g., blackspotted topminnows, golden shiners) preferred deeper pool-like habitats with coarse substrate and little woody debris, also reported by Thomas et al. (2007) for blackspotted topminnows and golden shiners. Although these associations were not particularly strong, they could be particularly useful in guiding restoration projects in these watersheds aimed at specific fish guilds.

Another important factor influencing the results of my study is that species found in low-order, headwater streams in southwestern Louisiana are highly resilient to natural and anthropogenic disturbance (Reice et al., 1990; Felley 1992; Winemiller and Rose 1992; Williams et al. 2003; Williams et al. 2007). Potentially, prior selection either as a response to past anthropogenic alteration, as described by Maloney et al. (2008) and Wenger et al. (2008) in Georgia, or geologic phenomena [e.g., fluctuating coastlines and deltaic development as proposed by Kaller and Kelso (2007) for coastal invertebrates] already removed species sensitive to disturbance. These coastal streams are known to be incredibly flashy and water velocity, turbidity, and depth can vary substantially and frequently, regardless of surrounding land use. It is likely that native fishes present in these systems are already equipped to survive impacts associated with altered land use.

Certainly, more research is needed in several areas. First, many streams in the region lack baseline information on the composition of the resident fish assemblage. Additionally, little is known about individual fish species ranges or life histories in southeastern Louisiana, which presents challenges in conservation efforts for rare native species (e.g., the scaly sand darter,

Ammocrypta vivax), as well as, the potential role land use may play in structuring these unique fish assemblages. This basic information must be known to determine how to better manage streams for desired species and to protect the native ichthyofauna of this region.

2.5 CONCLUSIONS

In summary, this study examined relationships among regional land use, in-stream physical habitat, and headwater stream fish assemblages in largely unstudied streams in southwestern Louisiana. I found that a species-based structural equation model was a better predictor of relationships among fish, land use, and in-stream habitat variables, when compared to species grouped by functional traits. Although this may be a more complex method, it provides greater detail in regards to particular species. However, using a modified trait-based approach may allow for more effective management techniques that target functional groups as a whole. It appears that the amount of agricultural land in these watersheds may not detrimentally affect these coastal stream fishes as has been reported in other aquatic systems and substrate type may be more important. Much research still remains in order to determine whether the research approach I took is the most effective way to assess fish-habitat relationships in these streams, and more importantly, whether the relationships I found apply in general to headwater streams along the Gulf of Mexico coast.

2.6 BIBLIOGRAPHY

American Public Health Association. 2005. Standard Methods for the Examination of Water and Wastewater. 21st edition. American Public Health Association. Washington, District of Columbia

Berkman, H.E. and C.F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes 18:285-294.

Bott, T.L., J.T. Brock, C.S. Dunn, R.J. Naiman, R.W. Ovink, and R.C. Petersen. 1985. Benthic community metabolism in four temperate stream systems – an inter-biome comparison and evaluation of the river continuum concept. Hydrobiologia 123: 3-45.

Brown, A.V. and W.J. Matthews. 2006. Stream ecosystems of the central United States. Pages 89-116 *in* C.E. Cushing, K.W. Cummins, and G.W. Minshall, editors. River and Stream Ecosystems of the World. University of California Press, Berkeley, California.

Brown, L.R. 2000. Fish communities and their associations with environmental variables, lower San Joaquin River drainage, California.. Environmental Biology of Fishes 57:251-269.

Carver, D.C. 1975. Life history study of the spotted bass (Micropterus punctulatus) (Rafinesque) in Six-Mile Creek, Louisiana. Fish. Bull. 15, Louisiana Department of Wildlife and Fisheries. Baton Rouge, Louisiana.

Cattell, R.B. 1966. The scree test for the number of factors. Journal of Multivariate Behavioral Research 12:289-325.

Connor, J.V. and R.D. Suttkus. 1986. Zoogeography of freshwater fishes of the western Gulf slope of North America. Pages 413-456 *in* C.T. Hackney, S.M. Adams, and W.H. Martin, editors. Biodiversity of the Southeastern United States. Aquatic Communities. John Wiley & Sons, Inc., New York, New York.

Corkum, L.D. 1996. Responses of chlororphyll-a, organic matter, and macroinvertebrates to nutrient additions in rivers flowing through agricultural and forested land. Archiv fur Hydrobiologie 136: 391-411.

Diana, M., J.D. Allan, and D. Infante. 2006. The influence of physical habitat and land use on stream fish assemblages in southeastern Michigan. Pages 359-374 in Hughes, R.M., L. Wang, and P. Seelbach, editors. Landscape Influences on Stream Habitats and Biological Assemblages. American Fisheries Society Symposium 48. American Fisheries Society, Bethesda, Maryland.

Dolloff, C.A. and M.L Warren, Jr. 2003. Fish relationships with large wood in small streams. Pages 179-194 *in* S.V. Gregory, K.L. Boyer, and A.M. Gurnell, editors. The ecology and management of wood in world rivers. American Fisheries Society, Symposium 37, Bethesda, Maryland.

Douglas, N.H. 1974. Freshwater Fishes of Louisiana. Claitor's Publishing Division, Baton Rouge, Louisiana.

Douglas, N.H. and R.J. Jordan. 2002. Louisiana's inland fishes: A quarter century of change. Southeastern Fishes Council Proceedings 43:1-10.

Ebert, D.J., S.P. Filipek, and M.E. Seehorn. 1991. Innovative techniques for warmwater stream management. Pages 197-203 *in* Cooper, J.L and R.H. Hamre (Editors). Warmwater Fisheries Symposium I, U.S.D.A. Forest Service General Technical Report RM-207.

Esselman, P.C. and J.D. Allan. 2010. Relative influence of catchment- and reach-scale abiotic factors on freshwater fish communities in rivers of northeastern Mesoamerica. Ecology of Freshwater Fish 19:439-454.

Fan, X., B. Thompson, and L. Wang. 1999. Effect of sample size, estimation methods, and model specification on structural equation modeling fit indices. Structural Equation Modeling 6:56-83.

Felley, J.D. 1992. Medium-low-gradient streams of the Gulf coastal plain. Pages 233-270 *in* C.T. Hackney, S.M. Adams, and W.H. Martin, editors. Biodiversity of the Southeastern United States. Aquatic Communities. John Wiley & Sons, Inc., New York, New York.

Franklin, S.B., D.J. Gibson, P.A. Robertson, J.T. Pohlmann, and J.S. Fralish. 1995. Parallel analysis: a method for determining significant principal components. Journal of Vegetation Science 6:99-106.

Frimpong, E. A., and P. L. Angermeier. 2010. Trait-based approaches in the analysis of stream fish communities. American Fisheries Society Symposium 73:109-136.

Gough, L. and J.B. Grace. 1999. Effects of environmental change on plant species density: comparing predictions with experiments. Ecology, 80:882-890.

Grace, J.B. 2006. Structural Equation Modeling and Natural Systems. Cambridge University Press, New York, New York.

Gu, W., and R.K. Swihart. 2004. Absent or undetected? Effects of nondetection of species occurrence on wildlife-habitat models. Biological Conservation 116:195-203.

Harding, J.S., E.F. Benfield, P.V. Bolstad, G.S. Helfman, and E.B.D. Jones, III. 1998. Stream biodiversity: The ghost of land use past. Proceedings of the National Academy of Science 95:14843-14847.

Hayduck, L.A. 1987. Structural Equation Modeling with LISREL: Essentials and Advances (Baltimore, MD: The Johns Hopkins University Press).

Hayer, C.A. and E.R. Irwin. 2008. Influence of gravel mining and other factors on detection probabilities of coastal plain fishes in the Mobile River basin, Alabama. Transactions of the American Fisheries Society 137:1606-1620.

Heitke, J.D., C.L. Pierce, G.T. Gelwicks, G.A. Simmons, and G.L. SIegworth. 2006. Habitat, land use, and fish assemblage relationships in Iowa streams: Preliminary assessment in an agricultural landscape. Pages 281-303 *in* Hughes, R.M., L. Wang, and P. Seelbach, editors. Landscape Influences on Stream Habitats and Biological Assemblages. American Fisheries Society Symposium 48. American Fisheries Society, Bethesda, Maryland.

Hoeinghaus, D. J., K.O. Winemiller, and J.S. Birnbaum. 2007. Local and regional determinants of stream fish assemblage structure: inferences based on taxonomic vs. functional groups. Journal of Biogeography, 34:324–338.

Holland, W.C., L.W. Hough, and G.W. Murray. 1952. Geology of Beauregard and Allen Parishes. Department of Conservation, Louisiana Geological Survey, Baton Rouge, Louisiana.

Horn, J.L. 1965. A rationale and test for the number of factors in factor analysis. Psychometrica 30:179-185.

Hoyle, R.T. and G.T. Smith. 1994. Formulating Clinical Research Hypotheses as Structural Equation Models: A Conceptual Overview. Journal of Consulting and Clinical Psychology 62:429-440.

Hoyle, R.H. (ed.) 1995. Structural Equation Modeling. SAGE Publications, Inc. Thousand Oaks, CA.

Hu, L.T. and P.M. Bentler. 1995. Evaluating model fit. Pages 76-99 *in* Hoyle, R., editor. Structural Equation Modeling: Issues, Concepts, and Applications. Sage Publishing, Newbury Park, California

Ice, G. and B. Sugden. 2003. Summer dissolved oxygen concentrations in forested streams of northern Louisiana. Southern Journal of Applied Forestry 27:92-99.

Infante, D.M. and J.D. Allan 2010. Response of Stream Fish Assemblages to Local-Scale Habitat as Influenced by Landscape: A Mechanistic Investigation of Stream Fish Assemblages Pages 371-397 *in* Gido, K.B. and D.A. Jackson, editors. Community ecology of stream fishes: concepts, approaches, and techniques. American Fisheries Society, Symposium 73, Bethesda, Maryland.

Isphrording, W.C. and J.F. Fitzpatrick, Jr. 1992. Geologic and evolutionary history of drainage systems in the southeastern United States. Pages 19-56 *in* Hackney,C.T., S.M. Adams, and W.H. Martin, editors. Biodiversity of the southeastern United States. Aquatic communities. John Wiley & Sons, Inc., New York, New York.

Jackson, D.C. 1991. Social and cultural values of turbid, warmwater streams and their fisheries in the southeastern United States. Pages 169-174 *in* Cooper, J.L and R.H. Hamre, editors. Warmwater Fisheries Symposium I, U.S.D.A. Forest Service General Technical Report RM-207.

Kaller, M.D. and W. E. Kelso. 2007. Association of macroinvertebrate assemblages with dissolved oxygen concentration and wood surface area in selected subtropical streams of the southeastern USA. Aquatic Ecology 41:95-110.

Kaller, M.D., C.E. Murphy, W.E. Kelso, and M.R. Stead. In press. Basins for fish and ecoregions for macroinvertebrates: Different spatial scales are needed to assess Louisiana wadeable streams. Transactions of the American Fisheries Society.

Larimore, R.W. 1981. Progress and challenges of the fishery biologist in warmwater stream investigations. Pages 120-126 *in* Krumholz, L.A., editor. The Warmwater Streams Symposium. Southern Division of the American Fisheries Society, Allen Press, Lawrence, KA.

Lowe, W.H., and G.E. Likens. 2005. Moving headwater streams to the head of the class. BioScience 55:196-197.

MacKenzie, D.I., J.D. Nichols, G. Lachman, S. Droege, A. Royle, and C. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83: 224-2255.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2006. Occupancy estimation and modeling. Elsevier Academic Press, New York.

Maloney, K.O., J.W. Feminella, R.M. Mitchell, S.A. Miller, P.J. Mulholland, and J.N. Houser. 2008. Landuse legacies and small streams: Identifying relationships between historical land use and contemporary conditions. Journal of North American Benthological Society 27: 280-294.

Marsh, H.W., J.R. Balla, R.P. McDonald. 1988. Goodness-of-fit indices in confirmatory factor analysis: The effect of sample size. Psychological Bulletin 103: 391-410.

McAllister, D.R., S.P. Platania, F.W. Shueler, M.E. Baldwin, and D.S. Lee. 1986. Ichthyofaunal patterns on a geographic grid. Pages 17-51 *in* C.H. Holcutt and E.O. Wiley, editors. The Zoogeography of North American Freshwater Fishes. John Wiley and Sons, Inc., New York, New York.

Meyer, K.A. and B. High. 2011. Accuracy of removal electrofishing estimates of trout abundance in Rocky Mountain streams. North American Journal of Fisheries Management 31: 923-933.

Price, A.L. and J.T. Peterson. 2010. Estimation and modeling of electrofishing capture efficiency for fishes in wadeable warmwater streams. North American Journal of Fisheries Management 30: 481-491

Pugesek, B.H. 2003. Concepts of structural equation modeling in biological research. Pages 42-59 *in* Pugesek, B.H., A. Tomer, and A. von Eye, editors. Structural Equation Modeling: Applications in Ecological and Evolutionary Biology. Cambridge University Press, New York, New York.

Rabeni, C.F. and R.B. Jacobsen. 1999. Warmwater streams. Pages 505-528 *in* Kohler, C.C. and W.A. Hubert, editors. Inland Fisheries Management in North America, 2nd Edition. American Fisheries Society, Bethesda, MD.

Rabeni, C.F., J. Lyons, N. Mercado-Silva, and J.T. Peterson. 2009. Warmwater fishes in wadeable streams. Pages 43-58 *in* Bonar, S.A., W.A. Hubert, and D.W. Willis, editors. Standard Methods for Sampling North American Freshwater Fishes. American Fisheries Society, Bethesda, MD.

Robinson, H.W. Zoogeographic implications of the Mississippi River basin. Pages 267-285 *in* C.H. Holcutt and E.O. Wiley, editors. The Zoogeography of North American Freshwater Fishes. John Wiley and Sons, Inc., New York, New York.

Ross, S.T. 2002. Inland Fishes of Mississippi. University Press of Mississippi. Oxford, Mississippi.

Scarsbrook, M.R., J.M. Quinn, J. Halliday, and R. Morse. 2001. Factors controlling litter input dynamics in streams draining pasture, pine, and native forest catchments. New Zealand Journal of Marine and Freshwater Research 35: 751-762.

Sinsabaugh, R.I. 1997. Large-scale trends for stream benthic respiration. Journal of the North American Benthological Society 16: 119-122.

Stevens, J.P. 2002. Applied multivariate statistics for the social sciences, 4rth edition. Lawrence Erlbaum Publishers, New Jersey.

Thomas, C., T.H. Bonner, and B.G. Whiteside. 2007. Freshwater Fishes of Texas. Texas A&M University Press, College Station, Texas.

Tomer, A. and B.H. Pugesek. 2003. Guidelines for the implementation and publication of structural equation models. Pages 125-140 *in* Pugesek, B.H., A. Tomer, and A. von Eye, editors. Structural Equation Modeling: Applications in Ecological and Evolutionary Biology. Cambridge University Press, New York, New York.

Trautman, M.B. 1981. The fishes of Ohio. Ohio State University Press, Columbus.

Vidrine, M.F., W.R. Fontenot, C.M. Allen, B. Borsari, and L. Allain. 2001. Prairie Cajuns and the Cajun Prairie: A history. Proceedings of the 17th Annual North American Prairie Conference 220-224.

Vondracek, B., K.L. Blann, C.B. Cox, J.F. Nerbonne, L.A. Sovell, and J.K.H. Zimmerman. 2005. Land use, spatial scale, and stream systems: Lessons from an agricultural region. Environmental Management 36: 775-791.

Walser, C.A. and H.L. Bart. 1999. Influence of agriculture on in-stream habitat and fish community structure in Piedmont watersheds of the Chattahoochee River System. Ecology of Freshwater Fish 8:237-46.

Wang, L., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environmental Management 28:255-266.

Wang, L., J. Lyons, P. Kanehl, and R. Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22:6-12.

Wang, L., J. Lyons, P. Rasmussen, P. Seelbach, T. Simon, M. Wiley, P. Kanehl, E. Baker, S. Niemela, and P. M. Stewart. 2003. Watershed, reach, and riparian influences on stream

fish assemblages in the Northern Lakes and Forest Ecoregion, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 60:491-505.

Wang, L.P., W. Seelbach, and J. Lyons. 2006. Effects of levels of human disturbance on the influence of catchment, riparian, and reach-scale factors on fish assemblages. Pages 199–220 in R. M. Hughes, L. Wang, and P. W. Seelbach, editors. Influences of landscapes on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland.

Wegner, S.J., J.T. Peterson, M.C. Freeman, B.J. Freeman, and D.D. Homans. 2008. Stream fish occurance in response to impervious cover, historic land use, and hydrogeomorphic factors. Canadian Journal of Fisheries and Aquatic Sciences 65:1250-1264.

Weitjers, M.J., J.H. Janse, R. Alkmade, and J.T.A. Verhoeven. 2009. Quantifying the effect of catchment land use and water nutrient concentrations on freshwater river and stream biodiversity. Aquatic Conservation 19:104-112.

Welch, R.N. 1942. Geology of Vernon Parish. Department of Conservation, Louisiana Geological Survey, Baton Rouge, Louisiana.

Wentworth, C. K., 1922, A scale of grade and class terms for cladistic sediments. Journal of Geology 30:377-392.

White, G.C., and K.P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 (Supplement):120-138.

Wiley, M.J., L.L. Osborne, and R.W. Larimore. 1990. Longitudinal structure of an agricultural prairie river system and the relationship to current stream ecosystem theory. Canadian Journal of Fisheries and Aquatic Sciences 53: 2199-211.

Williams, L.R., M.L. Warren Jr., S.B. Adams, J.L. Arvai, and C.M. Taylor. 2004. Basin visual estimation technique (BVET) and representative reach approaches to wadeable stream surveys: methodological limitations and future directions. Fisheries 29:12-22.

Wood, P.L. & Armitage, P.D. 1997. Biological effects of fine sediment in the lotic environment. Environmental Management 21:203–217.

CHAPTER 3: MACROHABITAT ASSOCIATIONS OF HEADWATER STREAM FISHES IN SOUTHWESTERN LOUISIANA

3.1 INTRODUCTION

It is estimated that at least 70 percent of stream channel length in the United States is found in headwater streams (Leopold et al. 1964 in Lowe and Likens 2005). Although small in size, these streams provide a multitude of benefits across the landscape including maintenance of natural flow regimes, nutrient retention, sediment regulation, and processing of organic matter (Lowe and Likens 2005). Meyer et al. (2007) argued that because their small catchments are easily influenced by surrounding conditions, headwater streams are one of the most variable of all lotic habitats. This spatial and temporal habitat variability is reflected in the resident diversity of headwater-specialist species, riverine species that exploit headwater streams for particular life history stages, and terrestrial species with close ties to streams (Lowe and Likens 2005, Meyer et al. 2007).

The physical structure of a stream can be subdivided into macrohabitats (sensu Arend 1999), including riffles, pools, eddies, and glides, which exhibit characteristic differences in physicochemistry, particularly depth, flow, and substrate composition (Arend 1999). These macrohabitat differences are often reflected in macrohabitat-specific invertebrates and fishes (Wallace and Anderson 1996; Ross 2001), and can provide unique environmental conditions required by particular life-history stages such as larvae and juveniles (Lowe and Likens 2005). In many cases, species may not be able to colonize headwater streams if needed macrohabitats are not available (Lowe and Likens 2005).

Within macrohabitats, hard substrates such as boulders, cobble, and rocky outcrops are important in providing colonization areas for invertebrates and algae, fish refugia during high

flows, and fish spawning substrate in streams and rivers throughout the United States (Walser and Bart 1999; Allan and Castillo 2007). However, many low-gradient headwater streams in the southeastern U.S. are dominated by finer sand-silt substrates with woody debris providing the only form of hard substrate available to the resident aquatic biota (Monzyk et al. 1997; Kaller and Kelso 2007, 2010). Woody debris enhances structural complexity of aquatic habitats, increases retention rates of course and fine particulate organic matter (Smock et al. 1989), and provides colonization substrate for algae and macroinvertebrates (Angermeier and Karr 1984; Schneider and Winemiller 2008), refugia for fish and macroinvertebrates from high water velocities and predation (Smock et al. 1989; Dolloff and Warren 2003), and fish spawning and rearing habitat (Dolloff and Warren 2003).

Although fish macrohabitat components have been well-studied in north-temperate stream systems (e.g., Gorman and Karr 1978), little research has examined the role of these habitat variables in structuring fish assemblages in lowland headwater streams of the southeastern United States (Felley 1992). The goal of this study was to explore fish-macrohabitat associations in relatively undisturbed headwater streams in the Kisatchie National Forest, southwestern Louisiana. Specifically, I wanted to determine the relative abundance of fishes and fish functional groups occupying the different macrohabitats that characterize these streams, and the relative influence of various physicochemical characteristics on fish habitat use patterns.

3.2 METHODS

3.2.1 Site Description

This study took place in three adjacent 1st order headwater streams located within the 10,500 km^2 Calcasieu River watershed in southwestern Louisiana, (U.S. Environmental Protection Agency Level III Southern Coastal Plain ecoregion; Daigle et al. 2006). Average

monthly temperatures in southwestern Louisiana range from 10.2°C in January to 27.9°C in July with an annual average temperature of 19.9°C. Total annual rainfall for the region is 139 cm. The three study streams included East Fork Sixmile Creek (EF6), West Fork Sixmile Creek (WF6), and Big Brushy Creek (BB), which are located within the Kisatchie National Forest (Figure 3.1). These three streams are relatively undisturbed and contain similar habitat characteristics and fish species (Kaller et al. In press).

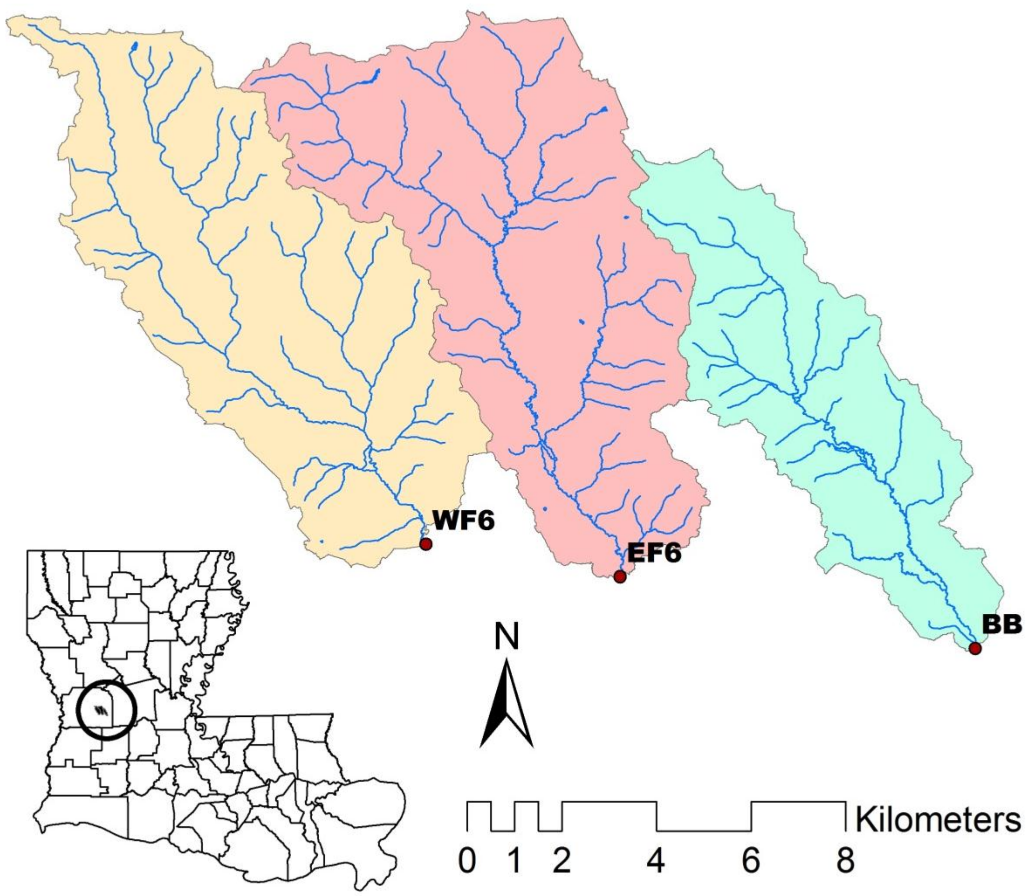


Figure 3.1: West Fork Sixmile Creek (WF6), East Fork Sixmile Creek (EF6), and Big Brushy Creek (BB) and individual macrohabitat sampling locations within each watershed in the Calcasieu River Drainage Basin, Louisiana.

Within each of the study streams, fishes were sampled in pools and glides, which were the two dominant macrohabitat types (Arend 1999) found in these systems (see Williams et al.

2005). Importantly, these macrohabitats were characterized by varying amounts of woody debris (none, primarily fine, or large woody debris), which has been reported to exert strong influences on the biotic composition of sand-substrate coastal plain streams (Williams et al. 2005). In addition to pools and glides, the study streams also had a limited number of straight scours, lateral scours, backwater eddies, channel confluences, and alcove pocket waters, which represented the range of in-stream macrohabitats found in low-order streams within the Southern Coastal Plain ecoregion. A macrohabitat was considered a pool if obvious deepening of the stream channel, decreasing water velocity, and other pool-like characteristics were present. A macrohabitat was considered a glide if stream channel depth decreased, water velocity increased, and was otherwise obviously distinguishable from neighboring pool macrohabitats. A total of 60 macrohabitats were selected among the three study streams and sampled once each during early summer of 2012. Efforts were made to spread sample points out across the watersheds as much as possible, although access to several upstream sites was limited by military training exercises (U.S. Army Joint Readiness Training Center and Ft. Polk), U.S. Forest Service controlled burns, and dewatering of ephemeral tributaries.

3.2.2 Field Sampling and Measurements

Fish sampling: Block nets were placed around each macrohabitat prior to electrofishing to prevent fish from leaving the sample area. I used a Smith Root LR-24 backpack DC electrofishing unit to sample fish at each of the 60 macrohabitats based on the point abundance or fractional method (Perrow et al. 1996; Scholten 2003; Lapointe et al. 2006), i.e., sampling a specific macrohabitat until all fishes were collected. Fish were identified to species and released at original place of capture, excluding individuals kept as voucher specimens, and those that could not be identified on site. Unidentified individuals were placed in an ice slurry and returned

to the lab for further identification. Shocking seconds were recorded in order to estimate catch-per-unit-effort (CPUE) at each site. Fish were collected under valid state collection permits and Institutional Animal Care and Use Committee (IACUC) protocols.

Habitat- Following fish collection, I recorded the length (m), width (m), and depth (cm; 9 measurements) of each site. Average water column velocity was also measured at three points within the site, and dominant substrate was visually categorized as coarse gravel (16-64 mm), fine gravel (2-16 mm), sand (0.06-2 mm), silt/clay/muck (<0.06 mm), and hardpan (firm, consolidated fine substrate). Substrate particle size classification was verified by a concurrent study that collected, dried and sieved substrate samples from these streams (unpublished data). Fine woody debris was estimated by stick counts within a 0.5-m radius of five sample points. Two size categories of large woody debris (>5 cm diameter, >10 cm diameter) were recorded within each macrohabitat, and percent cover of woody debris (%) was a visual estimate of the total area covered by sticks, logs, and leaves.

3.2.3 Statistical Analysis

In-stream habitat variables and species data were analyzed with canonical correlation analysis (CCorA, Gittens, 1985; Leurgans et al. 1993; Stevens, 2002; Anderson and Willis 2003; PROC CANCORR, SAS version 9.3, SAS Institute, Inc., Cary, North Carolina, USA). The CCorA correlated fish species abundance with macrohabitats as well as the variables describing macrohabitat characteristics, such as woody debris and substrate composition. I also constructed three additional CCorAs examining these relationships based on species functional traits, including feeding modes (piscivore, invertivore, omnivore, or detritivore), feeding locations (benthic feeder, water column filterer, plants and plant surface feeder, water surface feeder, water column predator), and spawning modes (cavity spawner, nest spawner, nest associate,

broadcast spawner, live bearer, plant spawner, or non- nest building substrate spawner) to determine if habitat associations were more evident based on these species groupings. Traits for each species were determined from literature specific to fishes of the region (Ross 2001; Thomas et al. 2007). For these analyses, abundance estimates were not adjusted for detection probabilities, which were overwhelmingly high (> 0.90 for 23 of 45 species) for the species we encountered in these streams (unpublished data). For these analyses, correlations exceeding 0.50 were considered interpretable based on Stevens (2002).

3.3 RESULTS

3.3.1 Fish and Habitat Results

Sampling yielded 399 individuals comprising 27 species of fish from the three study streams. Pirate perch were most abundant (15.79 % of total), followed by longear sunfish (15.04%) and redfin shiner (14.79%) (Table 3.1). Macrohabitat sites varied in size, with West Fork Sixmile Creek Glide10 being the smallest (3.1 m long x 0.9 m wide) and East Fork Sixmile Creek Glide2 being largest (12.2 m long x 6.8 m wide). Average macrohabitat site depth ranged from 4.33 cm (Big Brushy Creek, Glide6) to 85.11 cm (West Fork Sixmile Creek, Pool1). Average flow ranged from 0.006 m/s (Big Brushy Creek, Pool6) to 0.674 m/s (East Fork Sixmile Creek, Glide8). Dominant substrate ranged from sand (East Fork Sixmile Creek, West Fork Sixmile Creek) to fine gravel (Big Brushy Creek). Woody debris quantities varied substantially, with the number of logs per site ranging from 0 (multiple sites) to 58 (East Fork Sixmile Creek, Glide7), and percent woody debris coverage ranging from 0 (multiple sites) to 100 % of surface area (East Fork Sixmile Creek, Glide5).

Table 3.1: Complete list of all species captured, total collected, and percent of total abundance for all macrohabitat sample sites during spring 2012.

Scientific Name	**Common Name**	**Total Collected**	**% Total Abundance**
Aphredoderus sayanus	pirate perch	63	15.79
Lepomis megalotis	longear sunfish	60	15.04
Lythrurus umbratilis	redfin shiner	59	14.79
Fundulus olivaceus	blackspotted topminnow	30	7.52
Ichthyomyzon gagei	southern brook lamprey	28	7.02
Cyprinella venusta	blacktail shiner	18	4.51
Lepomis miniatus	redspotted sunfish	18	4.51
Noturus nocturnus	freckled madtom	15	3.76
Etheostoma chlorosomum	bluntnose darter	12	3.01
Moxostoma poecilurum	blacktail redhorse	11	2.76
Lepomis marginatus	dollar sunfish	11	2.76
Gambusia affinis	western mosquitofish	11	2.76
Notropis texanus	weed shiner	10	2.51
Erimyzon oblongus	creek chubsucker	7	1.75
Esox americanus	redfin pickerel	7	1.75
Noturus gyrinus	tadpole madtom	7	1.75
Lepomis macrochirus	bluegill	6	1.50
Percina sciera	dusky darter	6	1.50
Elassoma zonatum	banded pygmy sunfish	3	0.75
Notropis atherinoides	emerald shiner	3	0.75
Opsopoeodus emiliae	pugnose minnow	3	0.75
Micropterus punctulatus	spotted bass	3	0.75
Lepomis gulosus	warmouth	3	0.75
Etheostoma gracile	slough darter	2	0.50
Labidesthes sicculus	brook silverside	1	0.25
Lepomis cyanellus	green sunfish	1	0.25
Ammocrypta vivax	scaly sand darter	1	0.25

Table 3.2: Averages (standard errors) of habitat variables for each stream and each macrohabitat type sampled in the Calcasieu River Basin, Louisiana in late spring, 2012.

Stream	Site Type	Length (m)	Width (m)	Depth (cm)	Velocity (m/s)	Sticks	Logs	Substrate
Big Brushy	Pool	8.43 (0.76)	4.27 (0.34)	38.09 (5.80)	0.03 (0.00)	0.80 (0.34)	1.50 (0.30)	Fine gravel
Big Brushy	Glide	6.34 (0.85)	2.40 (0.46)	13.35 (2.85)	0.19 (0.04)	0.23 (0.08)	0.19 (0.10)	Coarse gravel
East Fork Sixmile	Pool	6.77 (0.63)	5.10 (0.27)	45.73 (2.75)	0.09 (0.01)	2.16 (0.42)	3.33 (0.64)	Sand
East Fork Sixmile	Glide	6.70 (0.76)	3.71 (0.32)	26.29 (2.04)	0.20 (0.05)	2.60 (0.49)	3.00 (0.52)	Sand
West Fork Sixmile	Pool	6.38 (0.49)	4.75 (0.28)	46.48 (5.09)	0.10 (0.01)	6.22 (0.68)	3.91 (0.77)	Sand
West Fork Sixmile	Glide	7.33 (0.80)	4.71 (0.38)	27.81 (1.91)	0.17 (0.02)	5.43 (0.69)	4.58 (0.63)	Sand

3.3.2 Statistical Results

The CCorA based on species abundances (Wilk's Lambda = 0.001, $F_{216, 208.47}$ =1.39, p=0.009, 37% of variation; Figure 3.2), feeding location (Wilk's Lambda = 0.22, $F_{40, 207.66}$ =2.15, p=0.003, 49% of variation; Figure 3.3), and spawning modes (Wilk's Lambda = 0.13, $F_{56, 247.64}$ = 2.02, p=0.001, 36% of variation; Figure 3.4) were all statistically significant, whereas the canonical variates (hereafter axes) of the food habit CCorA (p=0.0774) were not interpretable. Axis 1 of CCorA based on species indicated macrohabitat type (pool vs. glide), substrate, and woody debris were important habitat variables influencing fish assemblage structure. Pirate perch and redfin pickerel were positively associated with pools and fine gravel, whereas dusky darters, freckled madtoms, and southern brook lamprey were positively associated with glides, sandy substrate, and increasing woody debris.

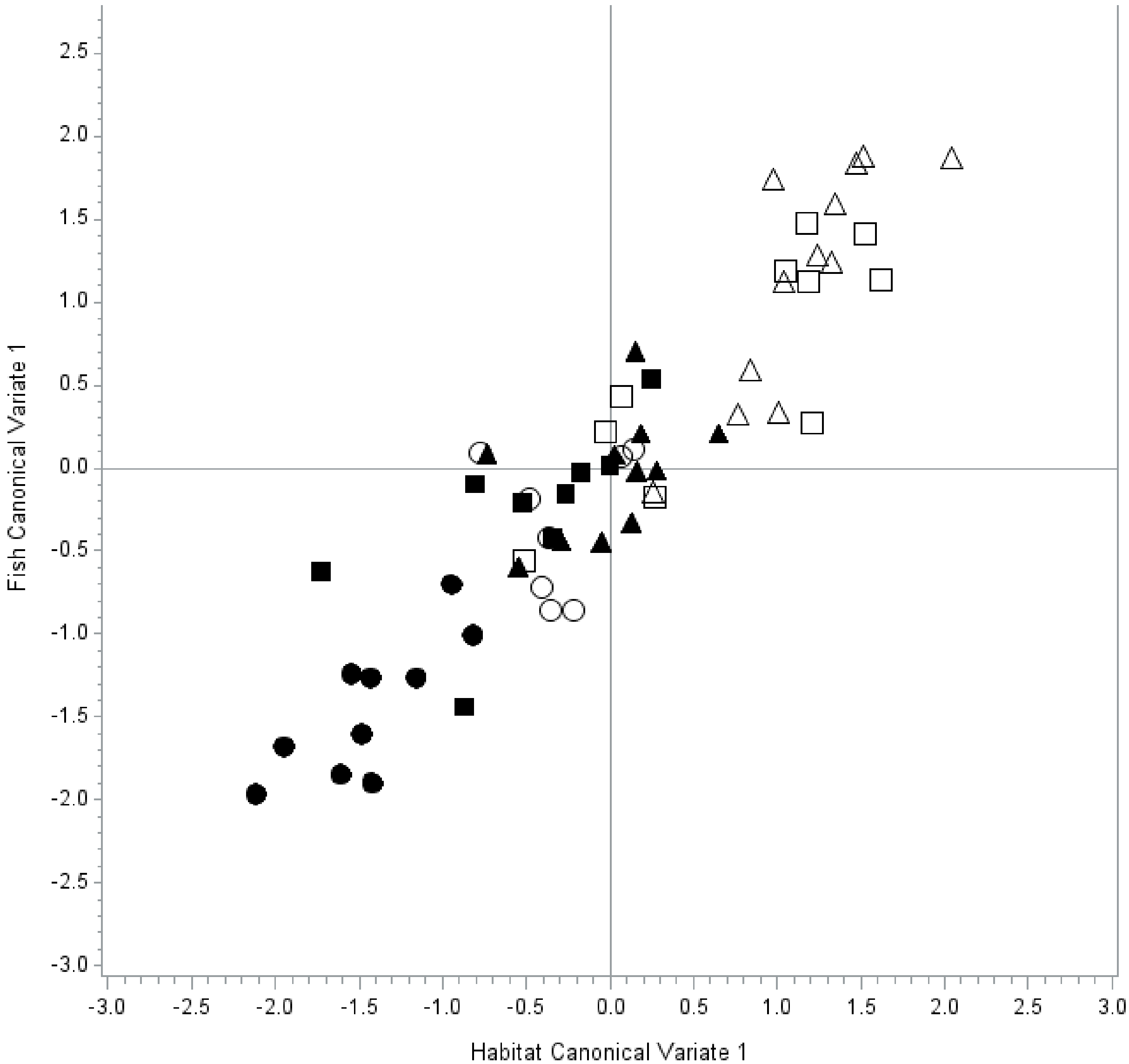


Figure 3.2: Macrohabitat plot along the first fish species and habitat canonical variates. Filled shapes are pools, and unfilled shapes are runs. Circles are macrohabitats in Big Brushy Creek, squares are macrohabitats in East Fork of Sixmile Creek, and triangles are macrohabitats in West Fork of Sixmile Creek.

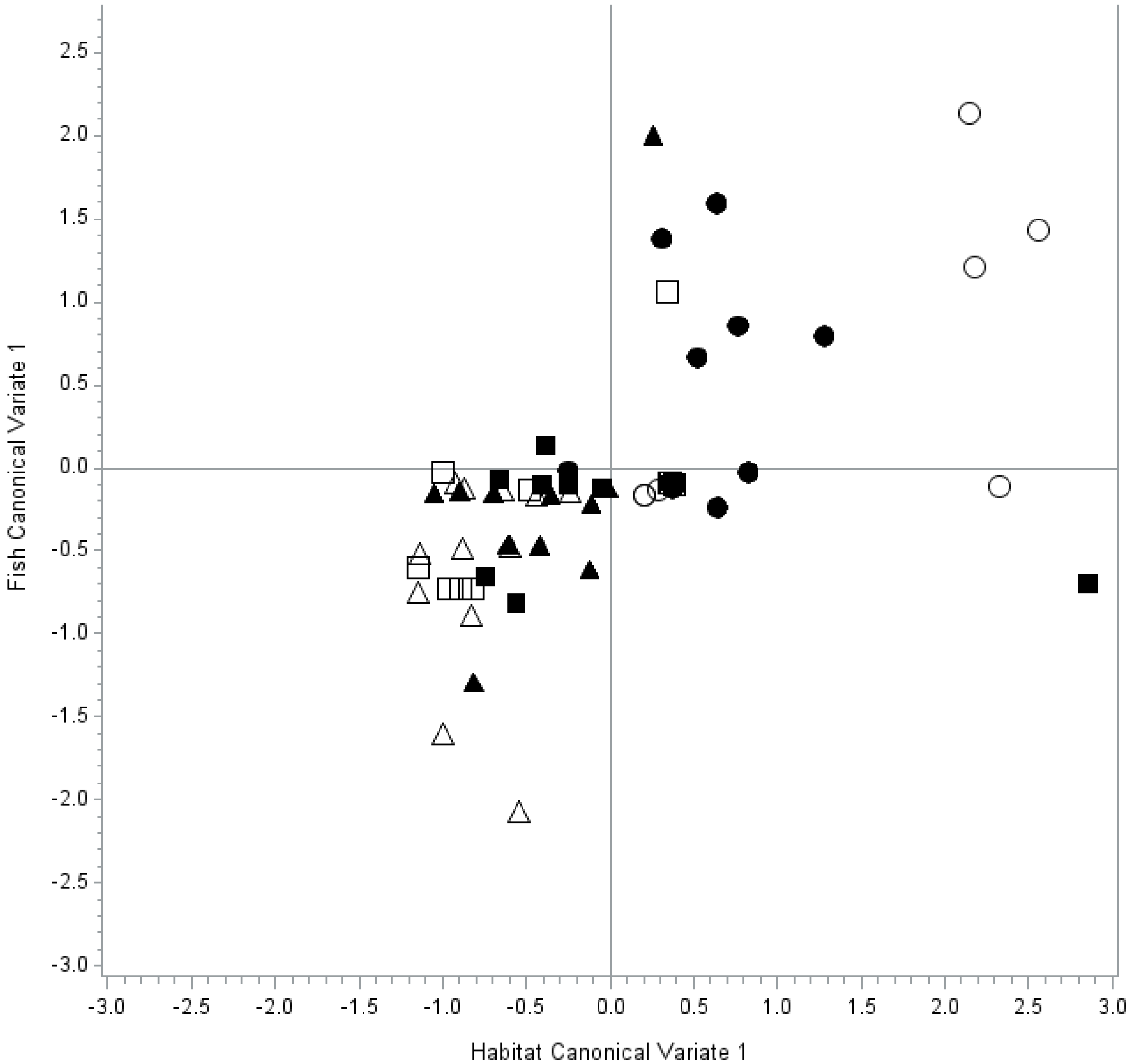


Figure 3.3: Macrohabitat plot along the first fish feeding modes and habitat canonical variates. Filled shapes are pools, and unfilled shapes are runs. Circles are macrohabitats in Big Brushy Creek, squares are macrohabitats in East Fork of Sixmile Creek, and triangles are macrohabitas in West Fork of Sixmile Creek.

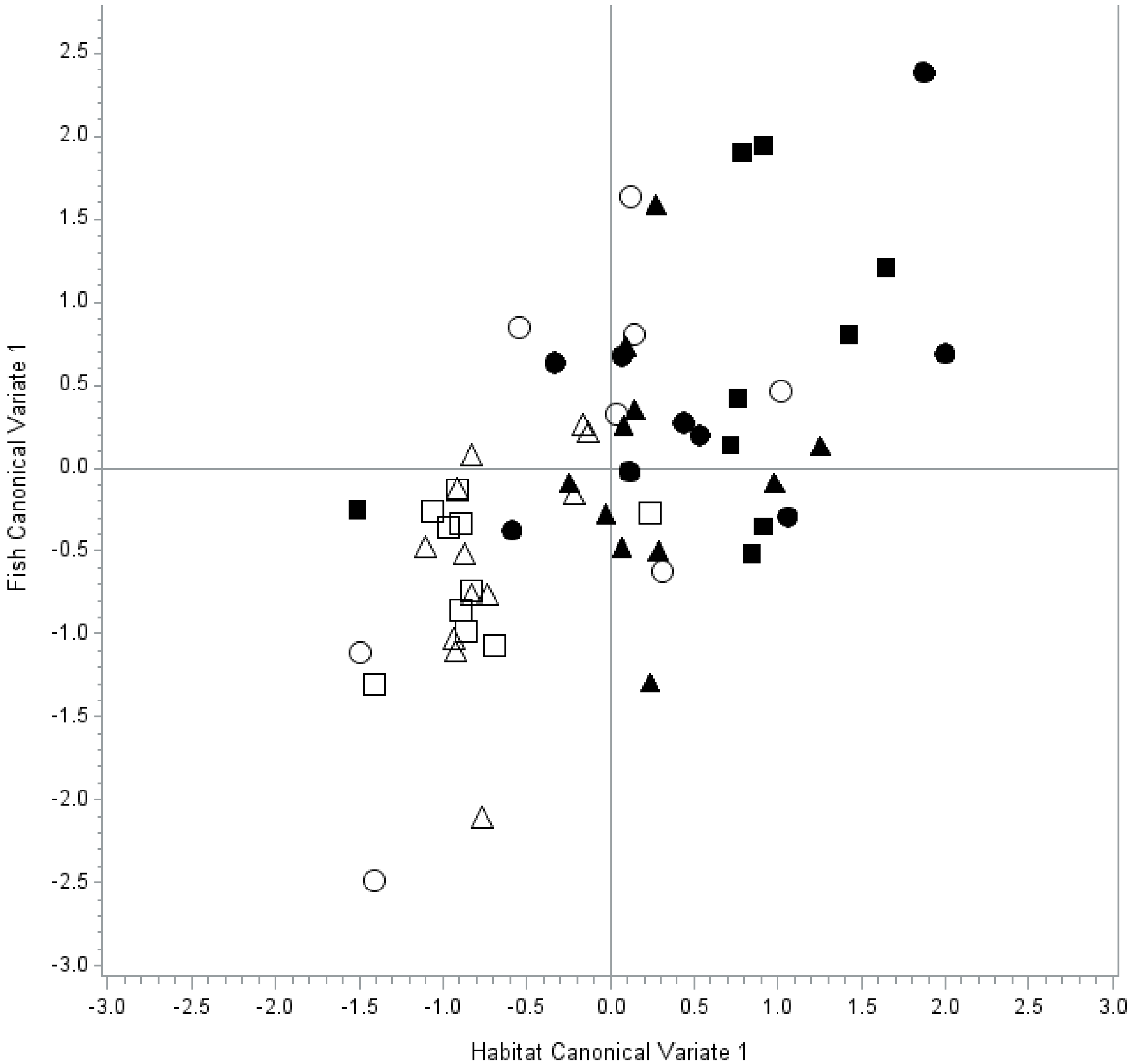


Figure 3.4: Macrohabitat plot along the first fish spawning locations and habitat canonical variates. Filled shapes are pools, and unfilled shapes are runs. Circles are macrohabitats in Big Brushy Creek, squares are macrohabitats in East Fork of Sixmile Creek, and triangles are macrohabitas in West Fork of Sixmile Creek.

The CCorA based on feeding locations produced two axes that contrasted coarse substrate and low woody debris abundance with sandy substrates and high woody debris densities (axis 1), and coarse versus fine substrate types (axis 2). Benthic feeders and water column predators were positively correlated with fine gravel, whereas water column filter feeders were positively correlated with increasing stick and large woody debris abundance and

sandy substrates. Axis 2 correlated water column predators and water surface feeders positively with coarse gravel. The CCorA based on spawning traits produced two axes related to macrohabitat type, substrate, and woody debris. Axis 1 positively correlated nest spawners, cavity spawners, and live bearers with glides and increasing fine woody debris, whereas plant spawners and nest associates were positively correlated with pools. Axis 2 positively correlated non-nest building substrate spawners with glides containing large woody debris and sand, whereas pools with fine gravel were positively correlated with nest spawners, plant spawners, and broadcast spawners.

3.4 DISCUSSION

Results of my research demonstrated several approaches in terms of assigning fish to taxonomic or functional groups to analyze fish-macrohabitat relationships in small headwater streams along the Gulf coastal plain. Generally, fishes in these streams had varying degrees of correlation with macrohabitat type (pool vs. glide) depending on whether analyses were based on taxonomic or functional group data. This is likely due to microhabitat variables, such as woody debris presence and substrate type, influencing fish-macrohabitat associations (e.g., Dolloff and Warren 2003). Although pools might be favored over glides for a particular species, cover provided by wood for shelter or foraging habitat may be the most important factor determining habitat choice, regardless of macrohabitat. In addition, because these streams have very low gradients (Felley 1992), distinctions among pool-riffle-glide macrohabitat sequences may not be as pronounced as in higher-gradient streams found in other regions (Brown and Matthews 2006). This gradual change among macrohabitat types likely results in considerable movement of many

species among macrohabitats regardless of preference, leading to difficulties in determining trends in macrohabitat selection.

Substrate type also had strong associations with species and functional groups. Dusky darters, freckled madtoms, and southern brook lamprey, which spend much of their time on or in the substrate (Ross 2001), oriented to sandy substrates in this study, whereas more mobile species tended to correlate with gravelly sites. In addition, non-nest building substrate spawners (e.g., dusky darters) correlated with the percentage of sand in the substrate, whereas nest spawners (predominantly Centrarchidae), plant spawners, and broadcast spawners associated with fine gravel. Although plant and broadcast spawners correlated with gravel, this may not necessarily be a function of spawning substrate preferences. Because neither of these groups directly use substrate to spawn, this correlation may be influenced by other habitat variables, such as the co-occurrence of fine gravel and pools. Additionally, lower velocities may provide better habitat for aquatic plants that are needed for plant spawners. Understanding these fish-macrohabitat relationships may thus be dependent on an understanding of underlying hydrologic and geomorphologic processes that characterize macrohabitats and their microhabitat components.

I expected more definitive correlations among fishes and the macrohabitats in these streams, because fish-macrohabitat correlations are well documented in the literature (Rowe et al. 2009). The streams were selected because they represent some of the least disturbed conditions in the region, and have habitat characteristics believed to be indicative of idealized fish habitats (Felley 1992; Louisiana Department of Environmental Quality 2011; Kaller et al. In press). Presumably, because such reference or least-impaired locations have been extensively used to document and develop predictive fish-macrohabitat relationships (Gorman and Karr

1978; Whittier et al. 2007), I would have expected to readily detect fish-macrohabitat relationships. Surprisingly, few fish species demonstrated clear correlations with either macrohabitats or their microhabitat components. Williams et al. (2005) reached a similar conclusion that physical attributes did not explain a significant portion of the variation in fish species abundance in southeastern Louisiana streams. These authors attributed the lack of well-defined fish-habitat relationships to high variability in physical habitat within and among streams, and the ubiquity of many fishes found in the Calcasieu River drainage basin. Differences in dominant substrate among my study streams suggest similar confounding differences. Big Brushy Creek was dominated by fine gravel in pools and coarse gravel in glides when compared to East and West Fork Sixmile Creeks with dominant substrate being sand. This dichotomy of substrate types among the three streams likely played a role in fish-macrohabitat associations.

Conversely, functional groups demonstrated clearer fish-macrohabitat associations, similar to Hoeinghaus et al. (2007) who found strong relationship between trophic and life history groupings with riffle macrohabitats, as well as, microhabitat characteristics, such as substrate. Functional groups may be the better assessment classification scheme when management, conservation, or restoration strategies target macrohabitats, whereas fish species may be more appropriate when assessments are based on microhabitats or landscapes (Infante and Allan 2010).

It is important to remember that functional group-habitat correlations do not necessarily imply causation. Fish-macrohabitat correlations are important in helping to elucidate the role of various habitat components in structuring fish assemblages (Williams et al. 2005). However, temporal factors must also be considered in the assessment of these relationships, and it is clear

that seasonality impacts macrohabitat usage by fishes (Thomas et al. 2007). Because my research was conducted during late spring, which is the peak spawning season for several species in my study streams (Ross 2001; Thomas et al. 2007), fish-habitat associations may not have been representative of those during the rest of the year. However, Williams et al. (2005) reported that seasonality only explained 6% of the variation in fish abundance data in headwater streams in the Calcasieu River. Another factor to consider when using functional traits is the likelihood that various species exhibit ontogenetic shifts in life history traits. Juveniles of a particular species may fall under a different feeding mode than larger adults. Because this study did not account for functional trait differences among life stages, interpretability may have declined. Additional research is needed to examine these macrohabitat associations across all seasons for multiple years to determine which variables truly have the greatest influence on fish abundance and assemblage composition.

3.5 CONCLUSIONS

In summary, this study examined relationships among fish assemblages and macrohabitats in headwater streams of southwestern Louisiana. I found that species- and functional trait-based CCorAs were able to determine correlations with various macrohabitats and variables within macrohabitats. Three CCorAs were statistically significant, and results indicate that species traits may be better measures of assemblage structure when macrohabitat-scale management, conservation, or restoration is the goal.

3.6 BIBLIOGRAPHY

Allan, J.D. and M.M. Castillo. 2007. Stream ecology: Structure and function of running waters, 2nd Edition. Springer, New York. 436 pp.

Anderson, M.J. and T.J. Willis. 2003. Canonical analysis of principal coordinates: a useful method of constrained ordination for ecology. Ecology 84:511-525.

Angermeier, P.L. and J.R. Karr. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. Transactions of the American Fisheries Society 113:716-726.

Arend, K.K. 1999. Macrohabitat Identification. Pages 75-94 in Bain, M.B. and N.J. Stevenson, editors. Aquatic Habitat Assessment: Common Methods. American Fisheries Society, Bethesda, Maryland.

Brown, A.V. and W.J. Matthews. 2006. Stream ecosystems of the central United States. Pages 89-116 *in* C.E. Cushing, K.W. Cummins, and G.W. Minshall, editors. River and Stream Ecosystems of the World. University of California Press, Berkeley, California.

Dolloff, C.A. and M.L. Warren, Jr. 2003. Fish relationships with large wood in small streams. Pages 179-194 *in* Gregory, S.V., K.L. Boyer, and A.M. Gurnell, editors. The ecology and management of wood in world rivers. American Fisheries Society, Symposium 37, Bethesda, Maryland.

Felley, J.D. 1992. Medium-low-gradient streams of the Gulf coastal plain. Pages 233-270 *in* C.T. Hackney, S.M. Adams, and W.H. Martin, editors. Biodiversity of the Southeastern United States. Aquatic Communities. John Wiley & Sons, Inc., New York, New York.

Gittens, R. 1985. Canonical Analysis: A Review with Applications in Ecology. Springer Verlag, Berlin, Germany.

Gorman O.T. and J.R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59, 507–515.

Hoeinghaus, D. J., K.O. Winemiller, and J.S. Birnbaum. 2007. Local and regional determinants of stream fish assemblage structure: inferences based on taxonomic vs. functional groups. Journal of Biogeography, 34:324–338.

Hrodey, P.J. and T.M. Sutton. 2008. Fish Community Response to Half-log Additions in Warmwater Streams. North America Journal of Fisheries Management 28:70-80.

Infante, D.M. and J.D. Allan 2010. Response of stream fish assemblages to local-scale habitat as influenced by landscape: a mechanistic investigation of stream fish assemblages Pages 371-397 *in* Gido, K.B. and D.A. Jackson, editors. Community ecology of stream fishes: concepts, approaches, and techniques. American Fisheries Society, Symposium 73, Bethesda, Maryland.

Kaller, M.D., C.E. Murphy, W.E. Kelso, and M.R. Stead. In press. Basins for fish and ecoregions for macroinvertebrates: Different spatial scales are needed to assess Louisiana wadeable streams. Transactions of the American Fisheries Society.

Kaller, M. D. and W.E. Kelso. 2010. The importance of small woody debris in stream restoration: invertebrate community diversity in lowland, subtropical streams in the Gulf of Mexico coastal plain. Pages 1-40 *in* G.D. Hayes and T.S. Flores., editors. Stream Restoration: Halting Disturbances, Assisted Recovery and Managed Recovery. Nova Science Publishers, Inc., Hauppauge, New York.

Kaller, M.D. and W. E. Kelso. 2007. Association of macroinvertebrate assemblages with dissolved oxygen concentration and wood surface area in selected subtropical streams of the southeastern USA. Aquatic Ecology 41:95-110.

Lapointe, N.W.R., L.D. Corkum, and N.E. Mandrak. 2006. Point sampling by boat electrofishing: A test of the effort required to assess fish communities. North American Journal of Fisheries Management 26:793-799.

Leurgans, S.E., R.A. Moyeed, and B.W. Silverman. 1993. Canonical correlation analysis when the data are curves. J Roy Stat Soc B 55:725-740.

Louisiana Department of Environmental Quality (LDEQ). 2011. Louisiana water quality inventory: integrated report fulfilling requirements of the federal clean water act, sections 305(b) and 303(d). Baton Rouge, LA

Lowe, W.H., and G.E. Likens. 2005. Moving headwater streams to the head of the class. BioScience 55: 196-197.

Meyer, J.L., D.L. Strayer, J.B. Wallace, S.L. Eggert, G.S. Helfman, and N.E. Leonard. 2007. The contribution of headwater streams to biodiversity in river networks. Journal of the American Water Resources Association 43: 86-103.

Meyer, J.L. and J.B. Wallace. 2001. Lost linkages and lotic ecology: rediscovering small streams. Pages 295-317 *in* M.C. Press, N.J. Huntley, and S. Levin, Editors. Ecology: Achievement and Challenge, Blackwell Science, Malden, Massachusetts.

Monzyk, F.R., W.E. Kelso, and D.A. Rutherford. 1997. Characteristics of woody cover used by brown madtoms and pirate perch in coastal plain streams. Transactions of the American Fisheries Society 126: 665-675.

Perrow, M.R., A.J.D. Jowitt, and Z.Gonzalez. 1996. Sampling fish communities in shallow lowland lakes: Point-sample electric fishing vs. electric fishing within stop-nets. Fisheries Management and Ecology 3:303-313.

Ross, S.T. 2001. Inland Fishes of Mississippi. University Press of Mississippi. Oxford, Mississippi.

Rowe, D.C., C.L. Pierce, and T.F. Wilton. 2009. Fish assemblage relationships with physical habitat in wadeable Iowa streams. North American Journal of Fisheries Management 29:1314-1332.

Scholten, M. 2003. Efficiency of point abundance sampling by electro-fishing modified for short fishes. Journal of Applied Ichthyology 19:265-277.

Schneider, K.N. and K.O. Winemiller. 2008. Structural complexity of woody debris patches influences fish and macroinvertebrate species richness in a temperate floodplain river system. Hydrobiologia 610:235-244.

Smock, L.A., G.M. Metzler, and J.E. Gladden. 1989. Role of debris dams in the structure and functioning of low-gradient headwater streams. Ecology 70:764-775.

Stevens, J.P. 2002. Applied Multivariate Statistics for the Social Sciences, 4th edition. Lawrence Erlbaum Publishers, New Jersey.

Thomas, C., T.H. Bonner, and B.G. Whiteside. 2007. Freshwater Fishes of Texas. Texas A&M University Press, College Station, Texas.

Wallace, J. B. and N. H. Anderson. 1996. Habitat, life history, and behavioral adaptations of aquatic insects. Pages 41-73 *in* R. W. Merritt and K. W. Cummins, editors. An introduction to the aquatic insects of North America. Kendall Hunt Publishing, Dubuque, Iowa.

Walser, C.A. and H.L. Bart. 1999. Influence of agriculture on in-stream habitat and fish community structure in Piedmont watersheds of the Chattahoochee River System. Ecology of Freshwater Fish 8:237-46.

Whittier, T.R., R.M. Hughes, J.L. Stoddard, G.A. Lomnikcy, D.V. Peck, and A.T. Herlihy. 2007. A structured approach for developing indices of biotic integrity: Three examples from streams and rivers in the western USA. Transactions of the American Fisheries Society 136:718-735.

Williams, L.R., T.H. Bonner, J.D. Hudson III, M.G. Williams, T.R. Leavy, and C.S. Williams. 2005. Interactive effects of environmental variability and military training on stream biota of three headwater drainages in Western Louisiana. Transactions of the American Fisheries Society, 134:192–206.

CHAPTER 4: SUMMARY

Results of my research revealed several important conclusions regarding the relative importance of land use and in-stream physical habitat in structuring headwater stream fish assemblages. A species-based structural equation model better predicted relationships among fish, land use, and habitat variables, when compared to species grouped by functional traits. However, a modified trait-based approach may be more effective for designing management strategies that target functional groups, as opposed to individual species. Importantly, it appears that high areal coverages of agricultural land within a watershed may not be as detrimental to coastal stream fishes as was previously thought. However, agriculturally-based erosion is often reflected in the size composition of the substrate, and results of my study indicate that substrate type may be the most important manageable habitat parameter in these stream systems.

When examining macrohabitat associations of headwater fishes in relatively undisturbed landscapes, I found that taxonomic and functional group analyses were able to determine associations among fishes and macrohabitat variables. Although multiple models were statistically significant, model utility may differ depending on the association of interest (i.e., spawning traits and season, or taxonomic composition and macrohabitat specificity). Species traits may be better descriptors of assemblage composition when macrohabitat-scale management, conservation, or restoration is the goal.

Although I expected land use to heavily influence in-stream habitat and fish assemblage composition in headwater streams of southwestern Louisiana, my research indicated that in-stream physical habitat was be more influential than land use in determining the species composition of these fish assemblages. I also expected species- and trait-based models to

successfully predict fish-macrohabitat associations. The findings of this study confirmed my initial predictions that multiple techniques for assessing fish-macrohabitat associations exist, although the most appropriate method may depend on specific management, restoration, or conservation goals.

APPENDIX A: FUNCTIONAL GROUP CATEGORIZATION FOR ALL SPECIES COLLECTED DURING 2011-2012 SAMPLING EVENTS IN SOUTHWESTERN LOUISIANA.

Species	Scientific Name	Feeding mode	Feeding location	Spawning mode
banded pygmy sunfish	*Elassoma zonatum*	invertivore	water column	plant spawner
black bullhead	*Ameiurus melas*	omnivore	benthic	nest spawner
blackside darter	*Percina maculata*	invertivore	benthic	substrate spawner
blackspotted topminnow	*Fundulus olivaceus*	invertivore	surface	substrate spawner
blackstripe topminnow	*Fundulus notatus*	invertivore	surface	plant spawner
blacktail redhorse	*Moxostoma poecilurum*	invertivore	benthic	nest spawner
blacktail shiner	*Cyprinella venusta*	invertivore	water column	cavity spawner
bluegill	*Lepomis macrochirus*	invertivore	water column	nest spawner
bluntnose darter	*Etheostoma chlorosomum*	invertivore	benthic	plant spawner
bowfin	*Amia calva*	piscivore	water column	nest spawner
brook silverside	*Labidesthes sicculus*	invertivore	water column	plant spawner
bullhead minnow	*Pimephales vigilax*	invertivore	benthic	cavity spawner
channel catfish	*Ictalurus punctatus*	omnivore	benthic	cavity spawner
creek chubsucker	*Erimyzon oblongus*	omnivore	benthic	nest spawner
dollar sunfish	*Lepomis marginatus*	invertivore	water column	nest spawner
dusky darter	*Percina sciera*	invertivore	benthic	substrate spawner
emerald shiner	*Notropis atherinoides*	omnivore	water column	broadcast spawner
flathead catfish	*Pylodictis olivaris*	piscivore	benthic	cavity spawner
flier	*Centrarchus macropterus*	invertivore	water column	nest spawner
freckled madtom	*Noturus nocturnus*	invertivore	benthic	cavity spawner
gizzard shad	*Dorosoma cepedianum*	detritivore	benthic	broadcast spawner
golden shiner	*Notemigonus crysoleucas*	invertivore	water column	plant spawner
green sunfish	*Lepomis cyanellus*	piscivore	water column	nest spawner
largemouth bass	*Micropterus salmoides*	piscivore	water column	nest spawner
longear sunfish	*Lepomis megalotis*	invertivore	water column	nest spawner
orangespotted sunfish	*Lepomis humilis*	invertivore	water column	nest spawner
pirate perch	*Aphredoderus sayanus*	invertivore	benthic	plant spawner
pugnose minnow	*Opsopoeodus emiliae*	invertivore	water column	cavity spawner
redear sunfish	*Lepomis microlophus*	invertivore	benthic	nest spawner
redfin pickerel	*Esox americanus*	piscivore	water column	plant spawner
redfin shiner	*Lythrurus umbratilis*	invertivore	surface	nest associate
redspotted sunfish	*Lepomis miniatus*	invertivore	benthic	nest spawner
sailfin molly	*Poecilia latipinna*	omnivore	grazer	live bearer
scaly sand darter	*Ammocrypta vivax*	invertivore	benthic	substrate spawner
slough darter	*Etheostoma gracile*	invertivore	benthic	plant spawner
smallmouth buffalo	*Ictiobus bubalus*	invertivore	benthic	broadcast spawner
southern brook lamprey	*Ichthyomyzon gagei*	detritivore	filterer	nest spawner
spotted bass	*Micropterus punctulatus*	piscivore	water column	nest spawner
spotted gar	*Lepisosteus oculatus*	piscivore	water column	plant spawner
spotted sucker	*Minytrema melanops*	invertivore	benthic	broadcast spawner
tadpole madtom	*Noturus gyrinus*	invertivore	benthic	cavity spawner
threadfin shad	*Dorosoma petenense*	omnivore	water column	broadcast spawner
warmouth	*Lepomis gulosus*	piscivore	water column	nest spawner
weed shiner	*Notropis texanus*	invertivore	grazer	broadcast spawner
western mosquitofish	*Gambusia affinis*	invertivore	surface	live bearer
white crappie	*Pomoxis annularis*	piscivore	water column	nest spawner
yellow bullhead	*Ameiurus natalis*	omnivore	benthic	cavity spawner

APPENDIX B. WATERSHED DELINEATION AND LAND USE CALCULATION: A HOW-TO GUIDE USING ARCMAP

The following is a summary of data and steps involved to delineate a watershed using ArcMap. Step-by-step instructions and screenshots will follow the summary to show you exactly what is discussed here.

GPS coordinates were taken for each stream site in the field using a Garmin GPSmap 60CS handheld GPS unit. The converted coordinates were imported into ArcGIS and reprojected to the UTM Zone 15N coordinate system. High-resolution imagery was downloaded through ArcGIS (http://www.arcgis.com). This 1-m² resolution imagery was taken from the United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP) 2010 imagery. Light Detection and Ranging (LIDAR) elevation data was downloaded via Atlas (http://atlas.lsu.edu/lidar/).

Land cover data was obtained using the Louisiana 2006 Land Cover Data accessed from National Oceanic and Atmospheric Administration (NOAA) Ocean Service, Coastal Services Center website (http://www.csc.noaa.gov/crs/lca). This raster dataset used color-coded pixels to display 2006 land use across Louisiana which included urban, rural, and forested land uses with a variety of sub-categories which were later reclassified based on my particular research goals. Stream information was obtained from the National Hydrography Dataset (NHD) 1:24,000 provided by the United States Geologic Survey (http://datagateway.nrcs.usda.gov/GDGOrder.aspx). The NHD vector dataset provides spatial data that contains information about surface water features linked into the NHD surface water drainage network enabling analysis of water-related data in an upstream or downstream order. Any data layers not already in NAD 1983 Zone 15N were defined and reprojected as needed using the “define projection” and “project” tools.

Drainages were created using a simplified method for creating a watershed layer from a DEM (http://courses.washington.edu/geog460/Lab/resource_page.htm). This process required the use of a variety of hydrology tools. First, a polygon was manually drawn around each upstream watershed purposefully containing portions of the surrounding watersheds. This rough polygon was converted to a feature. The new feature was then used to extract LIDAR by mask so that individual LIDAR sections could be used in conjunction with the hydrology tools. Next, the

“Fill” tool was used to fill in sinks and repair minor imperfections in the LIDAR data so the other hydrology tools could run correctly. Flow direction was calculated using filled masks and the “Flow direction” tool. This tool determines how rainfall would flow across the landscape for each raster cell. Flow accumulation was developed using the flow direction determined in the previous step as an input. This tool produces a map showing the hypothetical rainfall that fell on the surface, upslope of the raster cell.

The next step in the watershed delineation process involved making a pour point feature using the drawing tool and converting the point to a feature for each stream. Because the hydrology tools may not produce a stream channel directly where the GPS point is located, you have to create a new “GPS point” that is directly on top of the flow accumulation stream channel. These pour point features were then converted to pour points using the “snap pour point” hydrology tool with the manually made pour points and stream flow accumulations as inputs. This tool basically converts one raster cell within the stream channel to a pour point so the upstream watershed flows directly into that point enabling the calculation of the upstream watershed area. The watershed tool was then used to create upstream watersheds for each pour point and flow direction. These watershed rasters were then converted to polygons using the “raster to polygon” tool found in ArcToolbox. All watersheds were then smoothed using the “Smooth” tool to take off the edges associated with raster cells.

Although the 2006 landcover data included a variety of land cover types, for the purposes of this project, I needed to reclassify these types into six major land use categories. The first step was to take the entire LA 2006 landuse dataset and reclassify land uses using the “reclassify” tool found in the “Spatial Analyst” toolbox. The following table illustrates how each land use was reclassified:

After the land uses were reclassified, they were masked for each watershed. This was done by using the “extract by mask” tool found in the Spatial Analyst tools. Appropriate color schemes were selected for land uses. For each watershed, the associated attribute table for the land uses needed to be joined to the existing attribute table. This was done using the “join” tool found in the properties box for each watershed.

The final step was to calculate the percentages of each land use type for each watershed. This was done in the attribute table for each watershed using the field calculator. Because the land use data is a raster layer, calculating the total area of each land use actually provides the total pixel count for each land use. However, because each pixel represents a 30x30 m^2 area, they can be converted to area using a conversion formula. The formula is as follows:

$$Area\ (km^2) = \frac{\#\ pixels * (30m * 30m)}{1{,}000{,}000}$$

For example:

$$Area\ (km^2) = \frac{2181\ pixels * (30m * 30m)}{1{,}000{,}000} = 1.96km^2$$

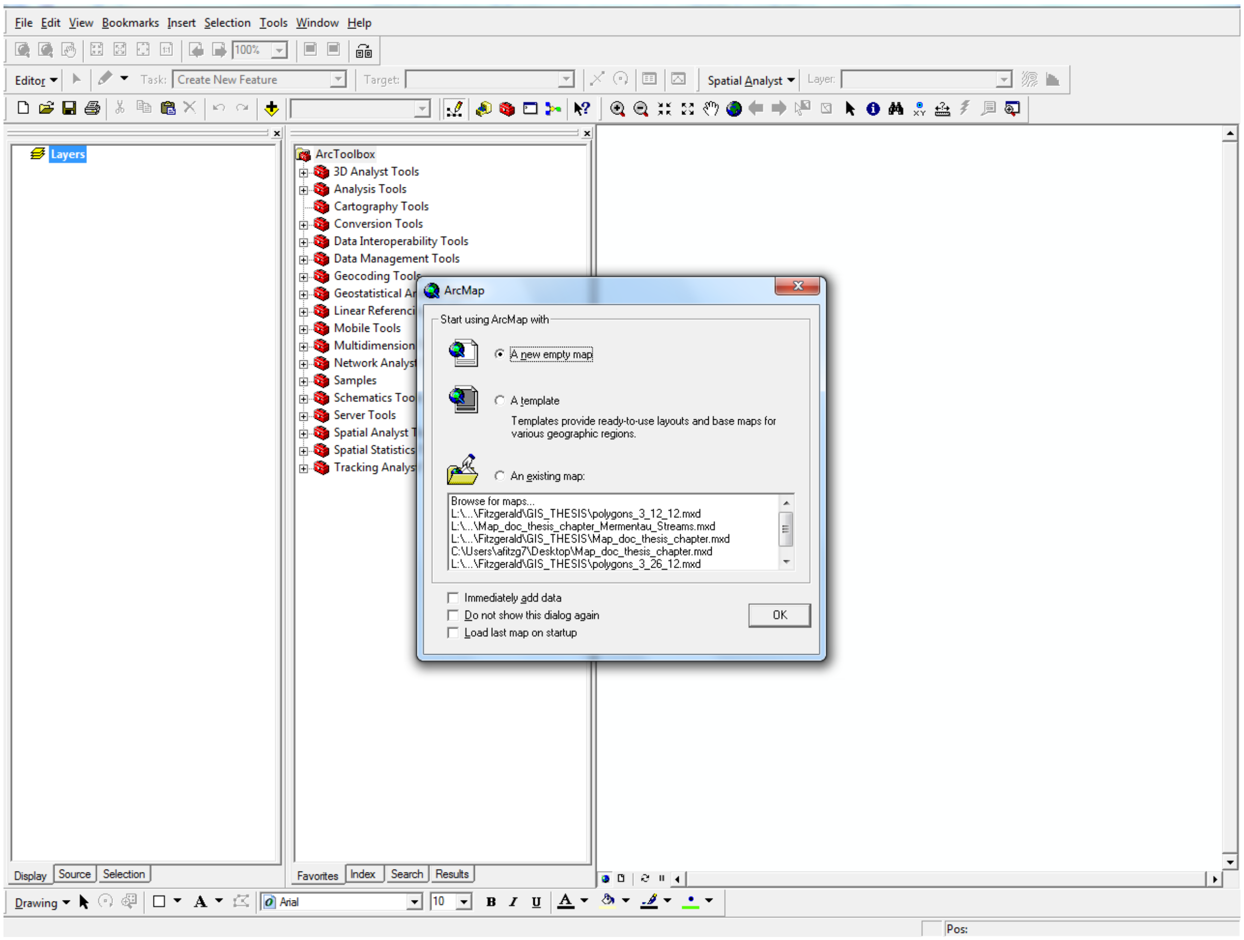
These values were then converted to percentages for ease of interpretation. Figure 1 illustrates the development from extracted mask to reclassified land uses for a particular watershed.

APPENDIX C.STEP-BY-STEP WATERSHED DELINEATION HOW-TO GUIDE

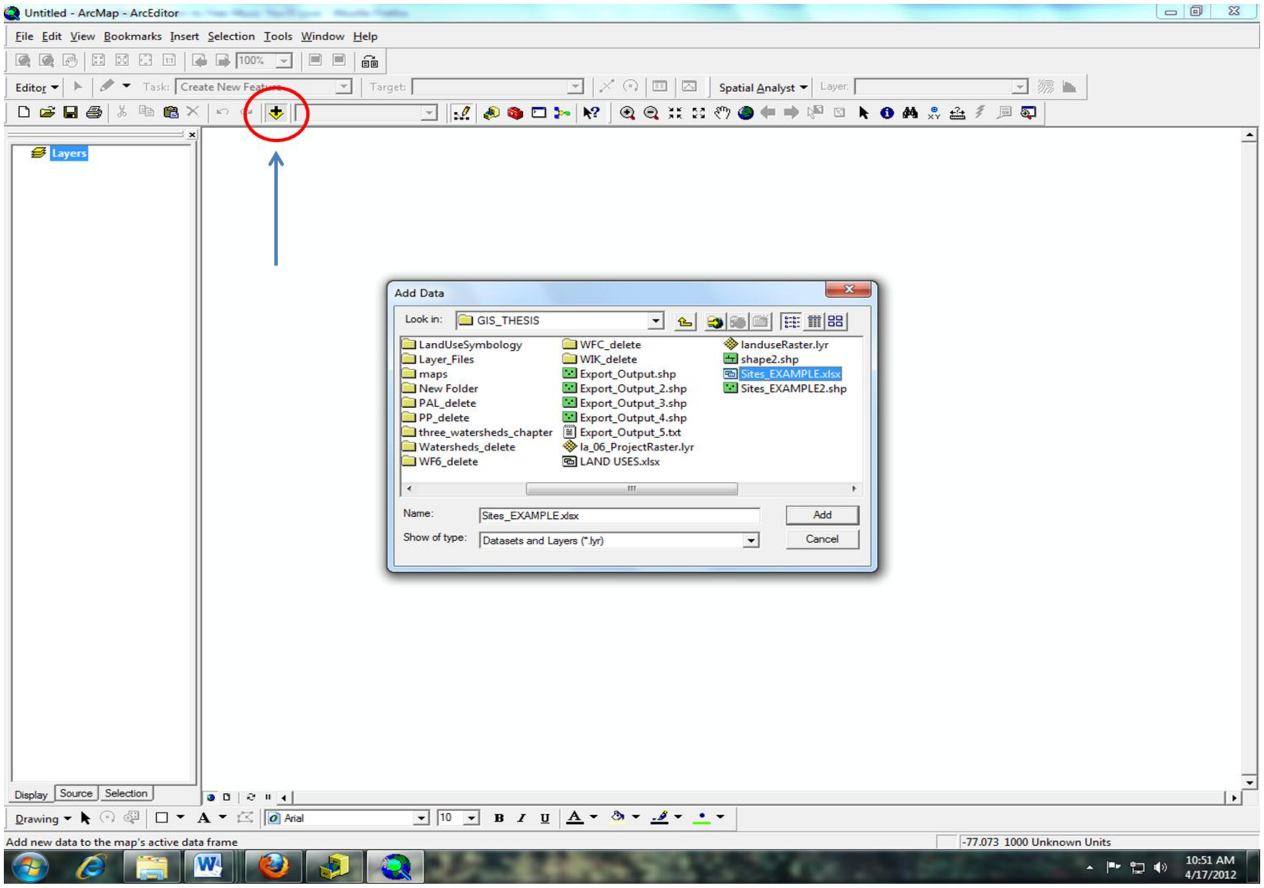
Prior to beginning the GIS portion of this guide, you must first import all site GPS into an excel file and prepare it to be imported into ArcMap. The text below is a simple guide to creating watersheds

Adding Data

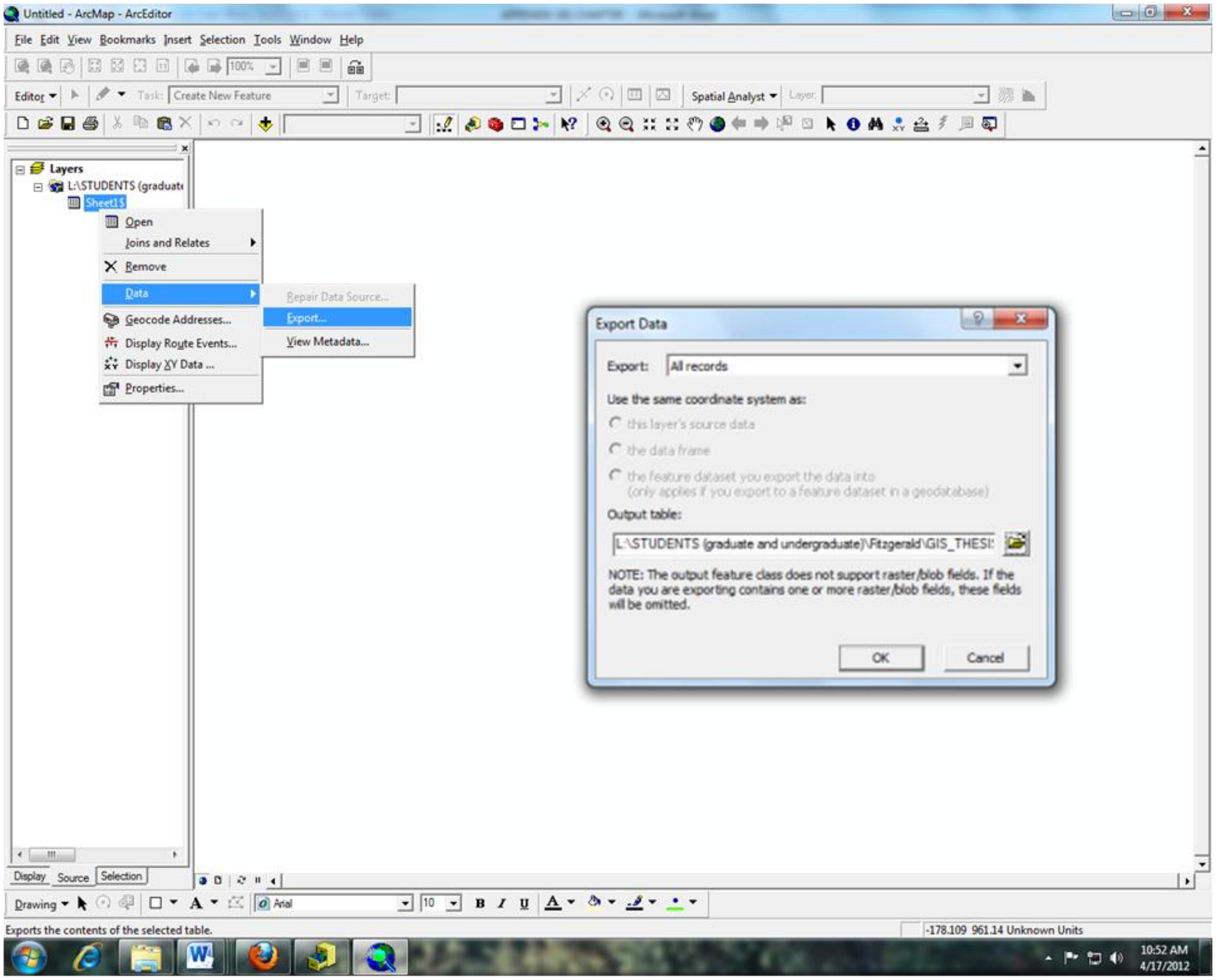
Step 1: Open ArcMap and start a new empty map.



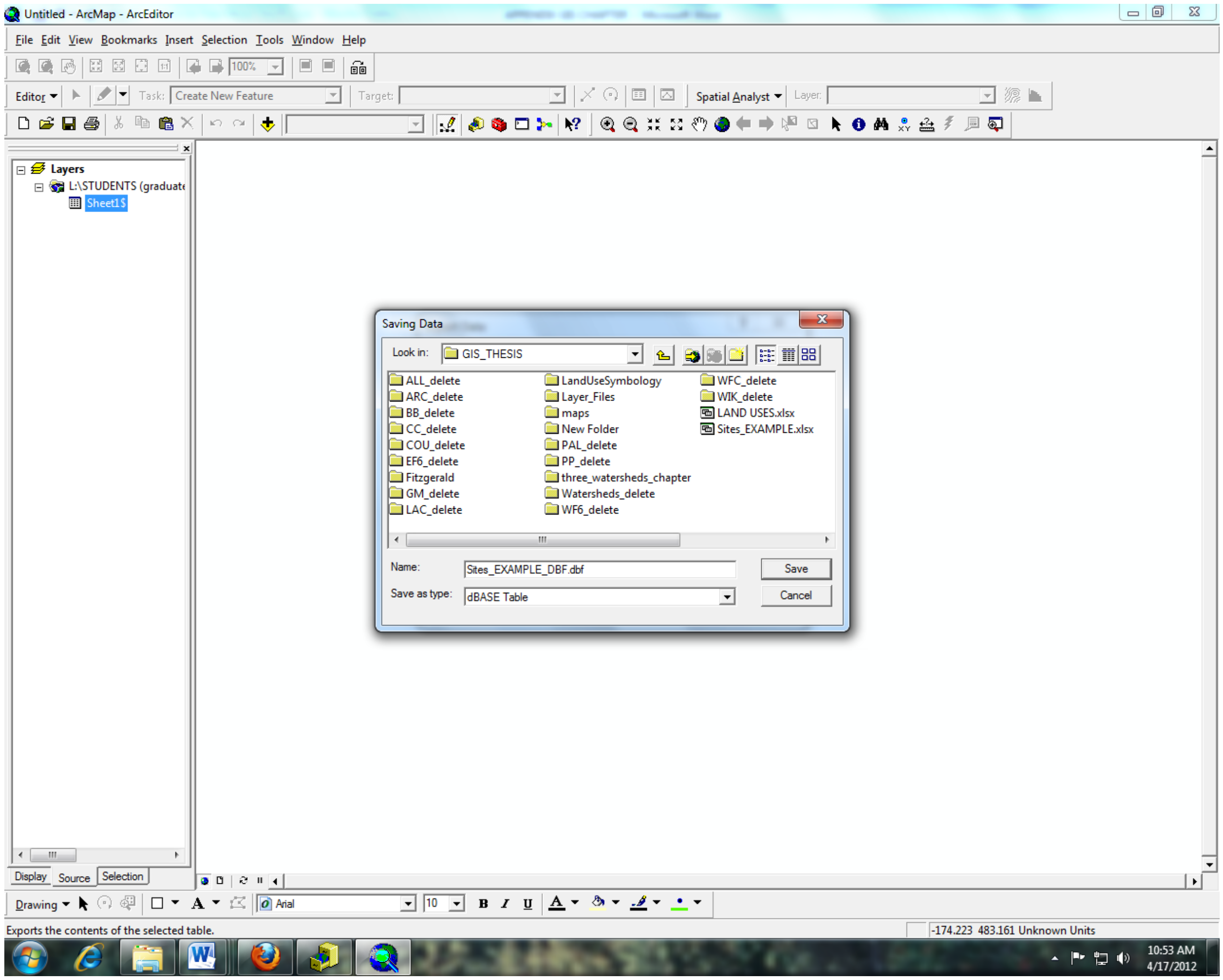
Step 2: Click the "Add Data" button, then navigate to where the sample site excel file is saved. Select this file and click "Ok"



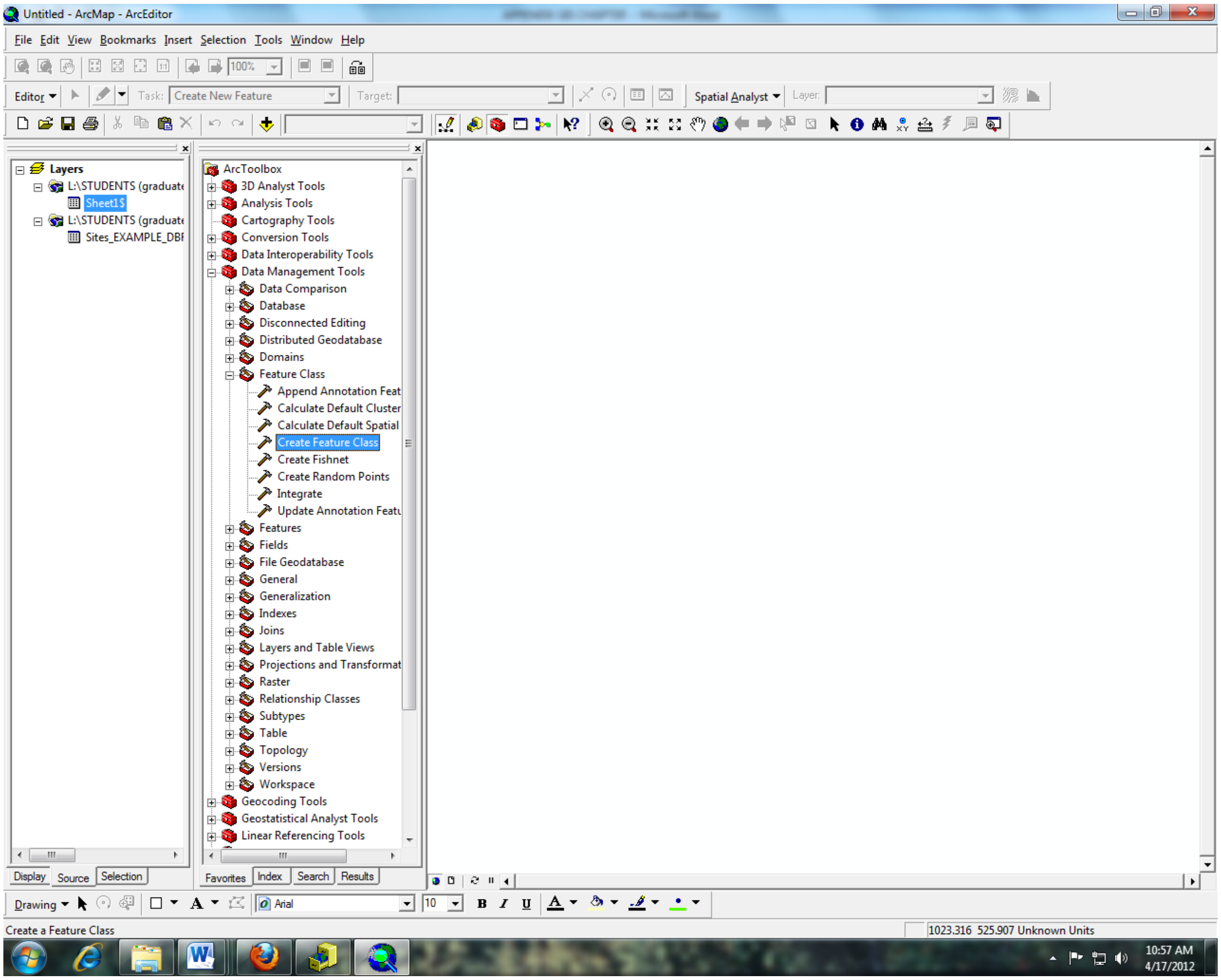
Step 3: Right click the excel sheet in ArcMap and click "Data" then "Export Data". Be sure to export "all records".



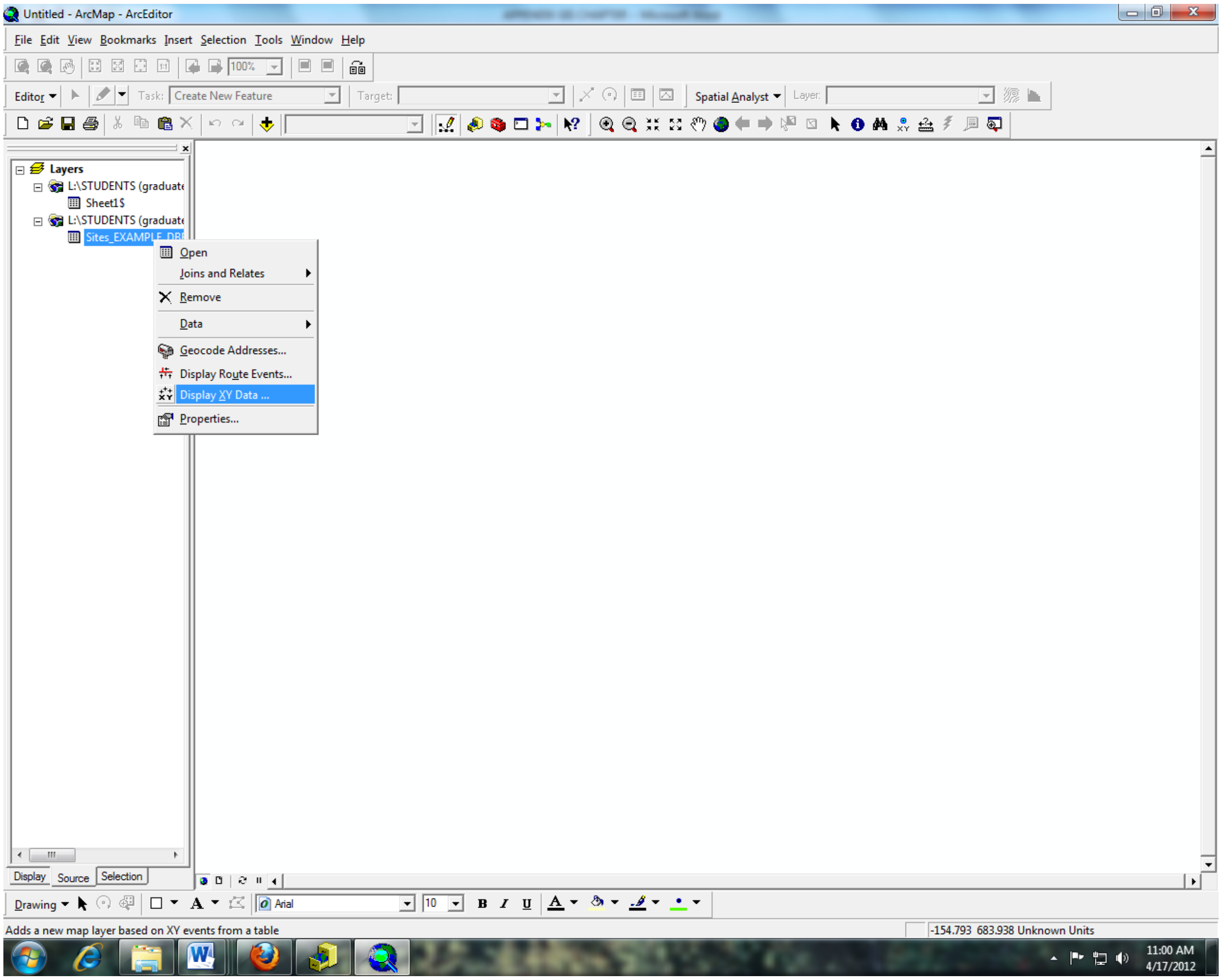
Step 4: Navigate to where you wish the dbf file to be saved, name it appropriately, then click "Save". When prompted, add the new DBF file to the map document.



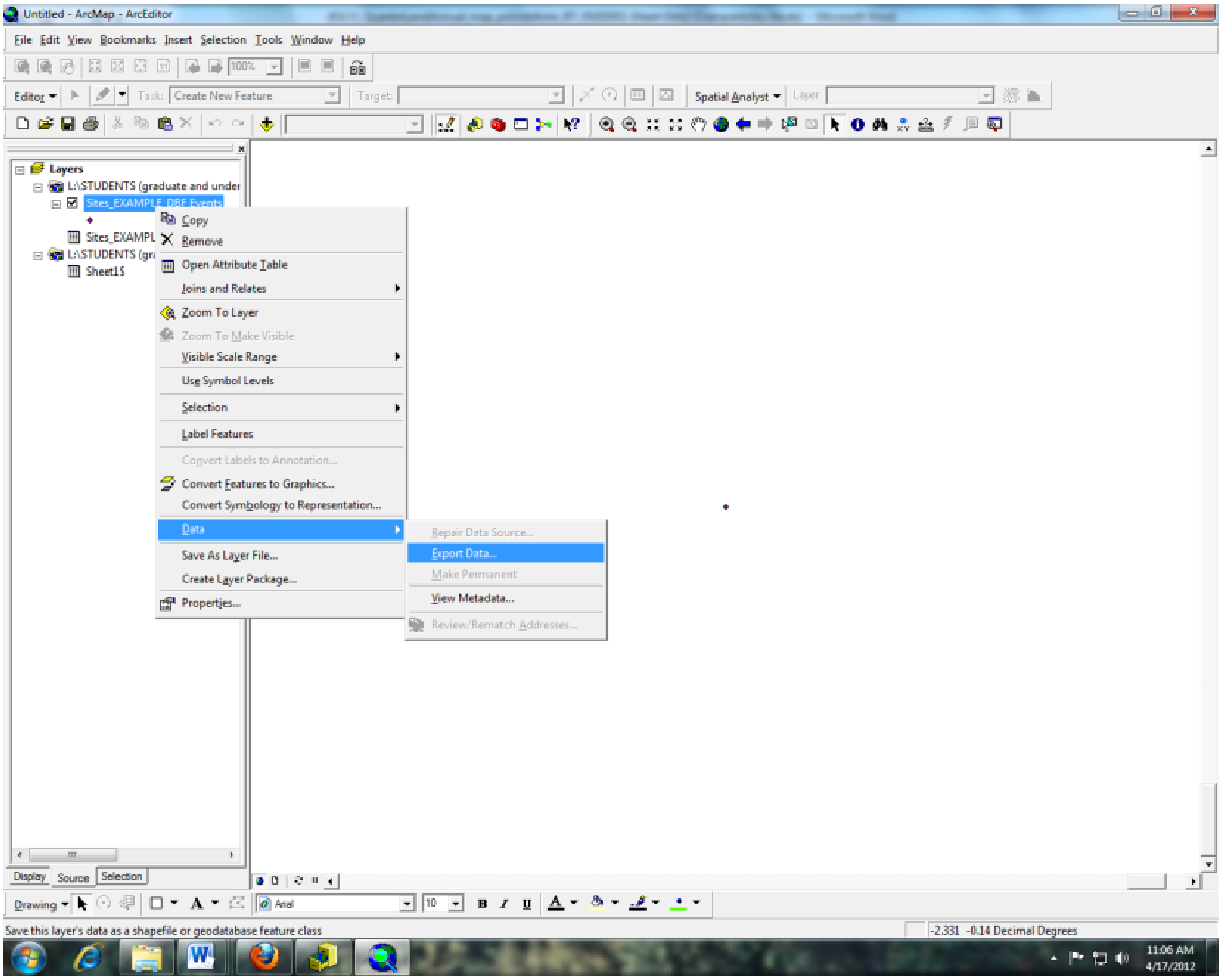
Step 5: Open "ArcToolbox" and navigate to "Data Management Tools", then "Feature Class", then "Create Feature Class".



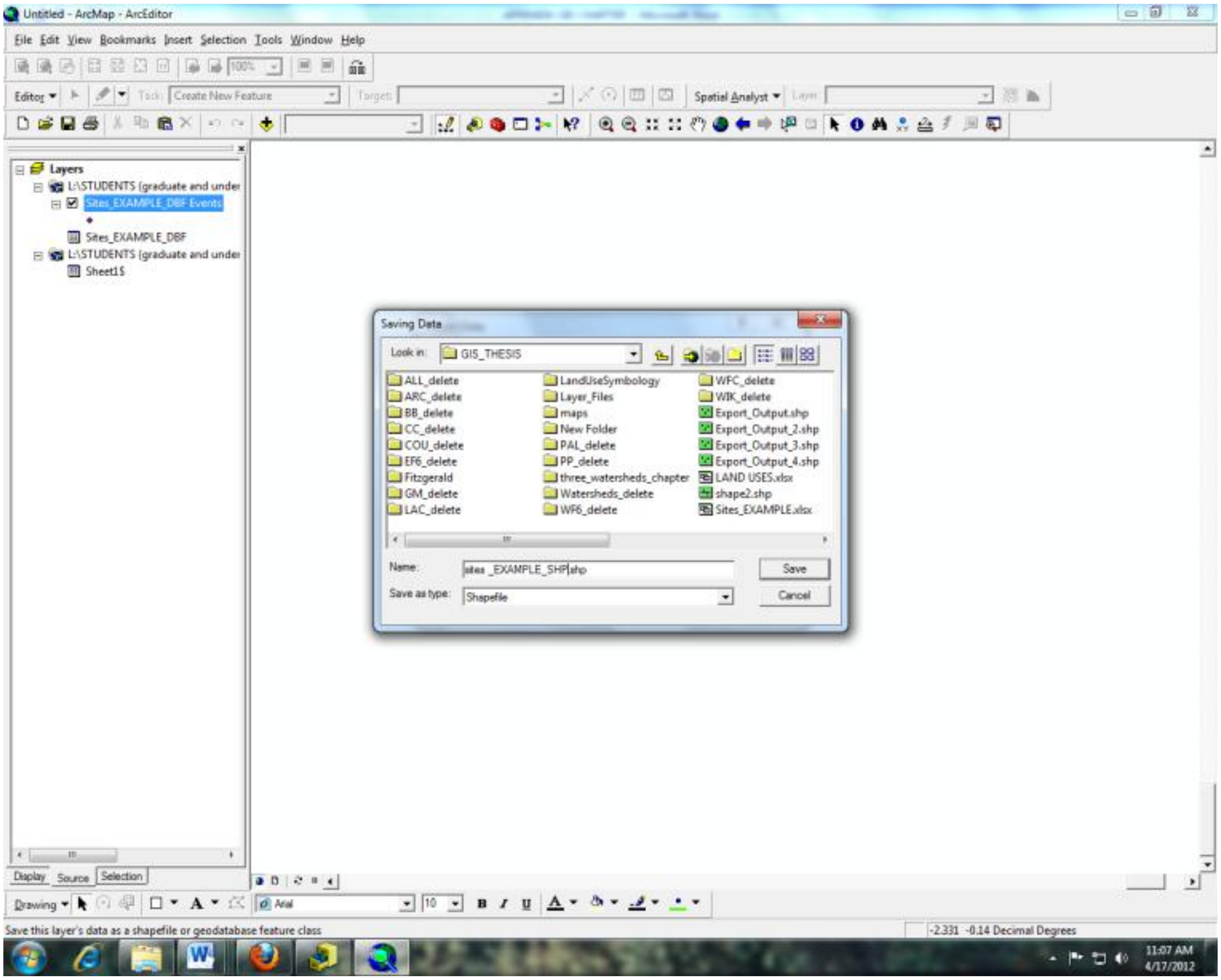
Step 6: Right click on the new DBF file, click “Display XY Data”, then click “OK”. This creates a temporary “events layer” that displays the samples points on the map.



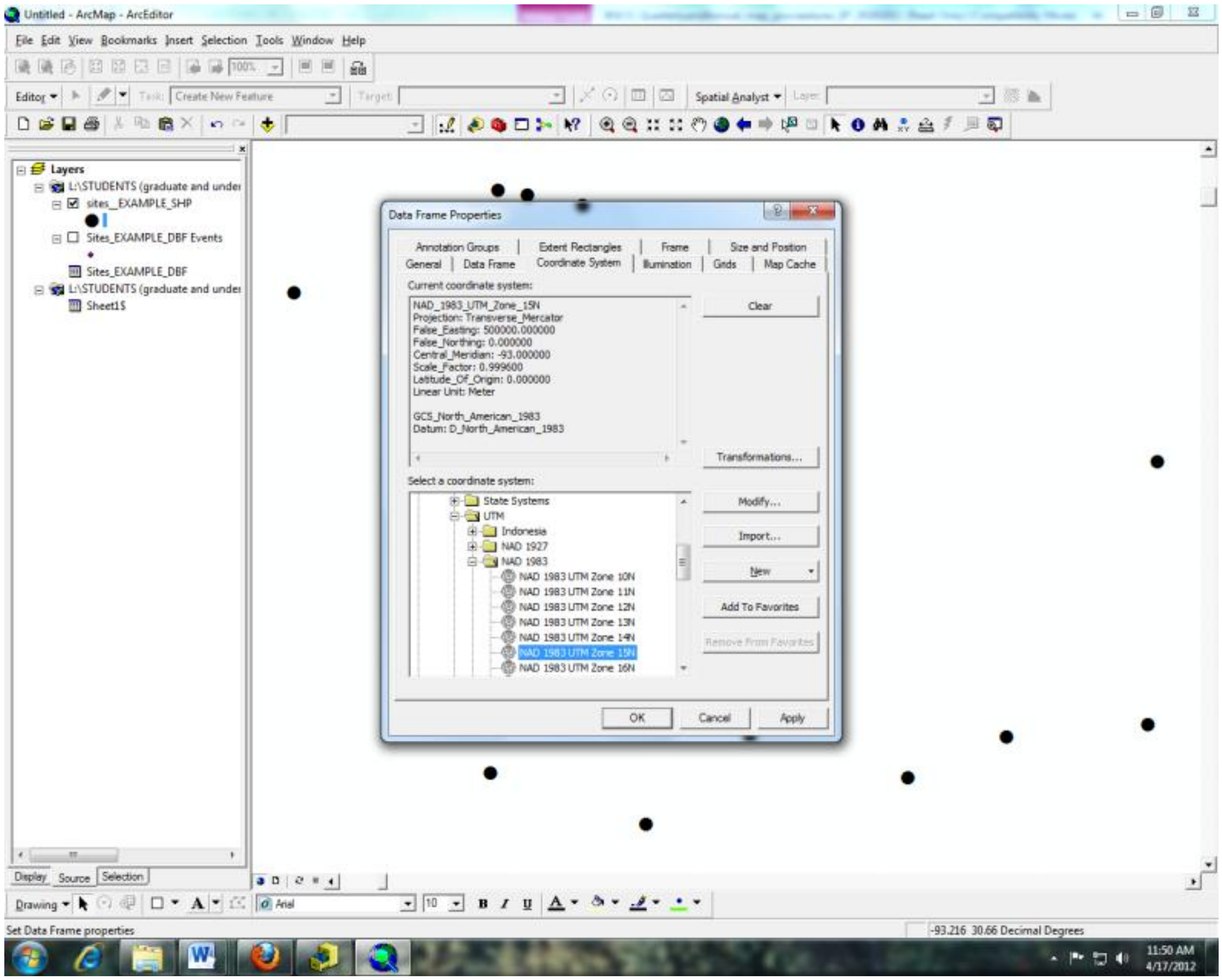
Step 7: Create a permanent layer file by right clicking the new "events layer", click "Data", then "Export Data…"



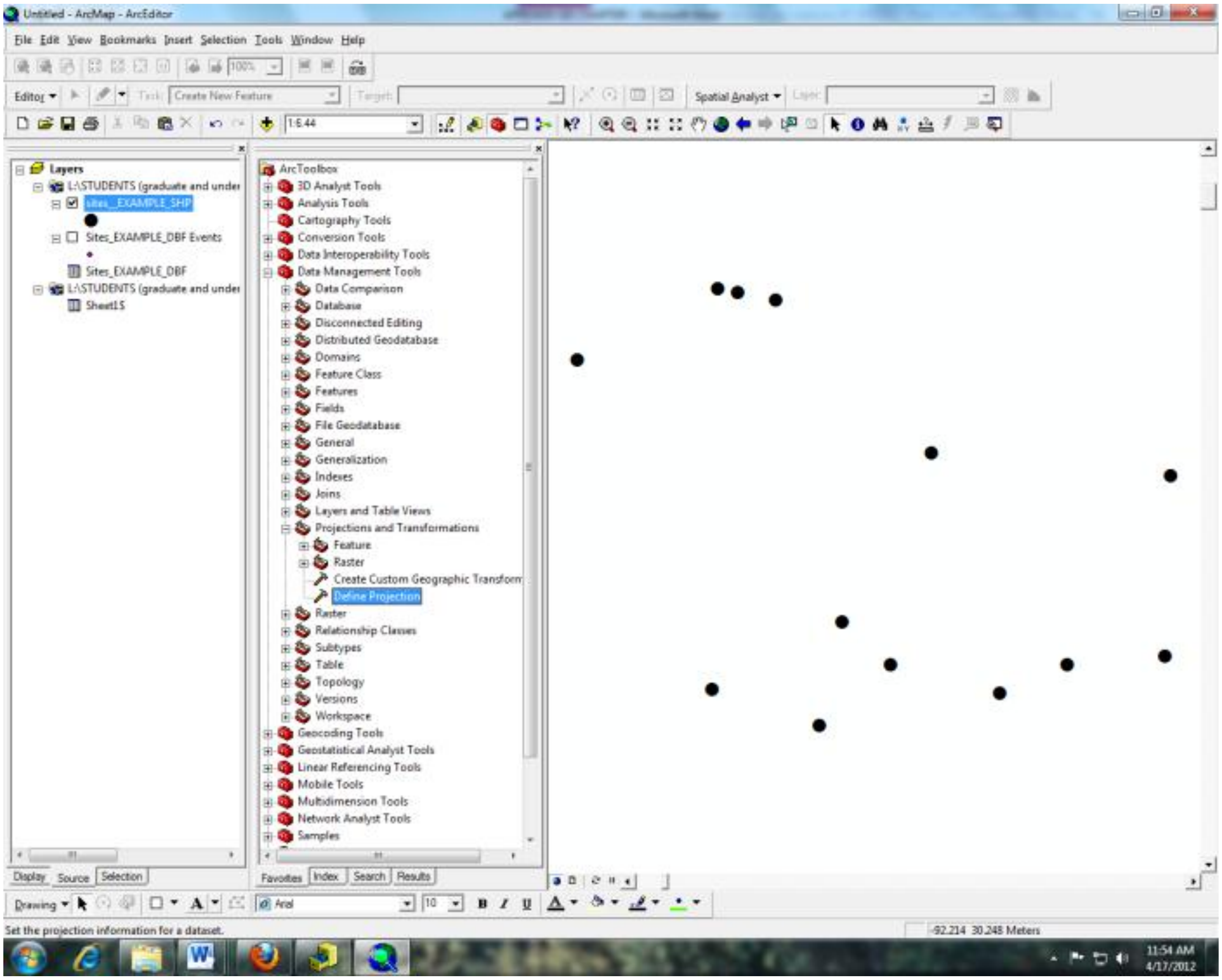
Step 8: Name the file and save it in the desired folder. Click “Save”, then “OK”. When prompted to add the layer to the map document, click “Yes”.



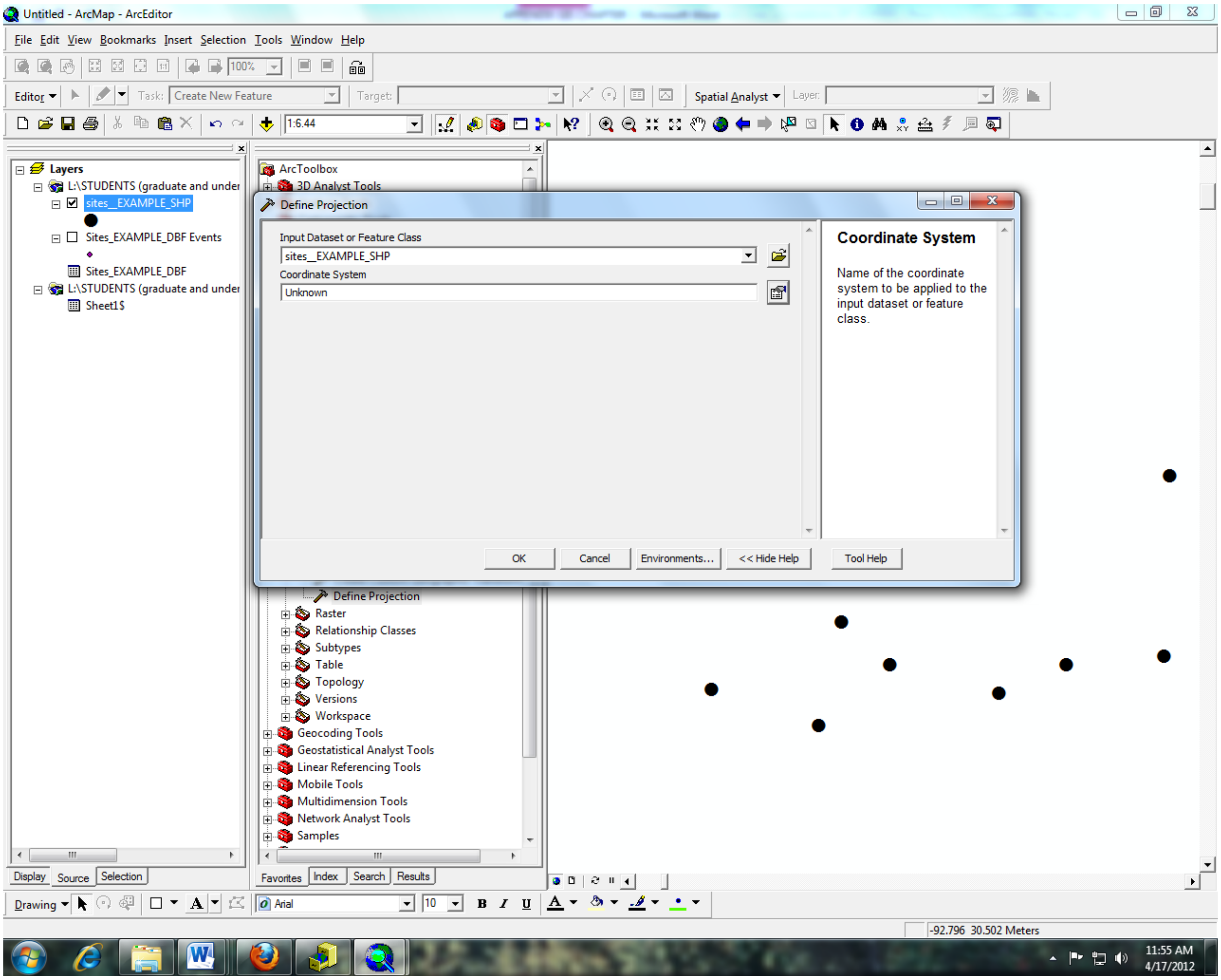
Step 9: If not already set, make sure to set the data frame projection to something appropriate for your research area. Right-click in the data frame window, click "data frame properties", click the "coordinate system" tab, select Predefined>Projected Coordinate Systems>UTM>NAD 1983>NAD 1983 UTM Zone 15N. Click "OK".



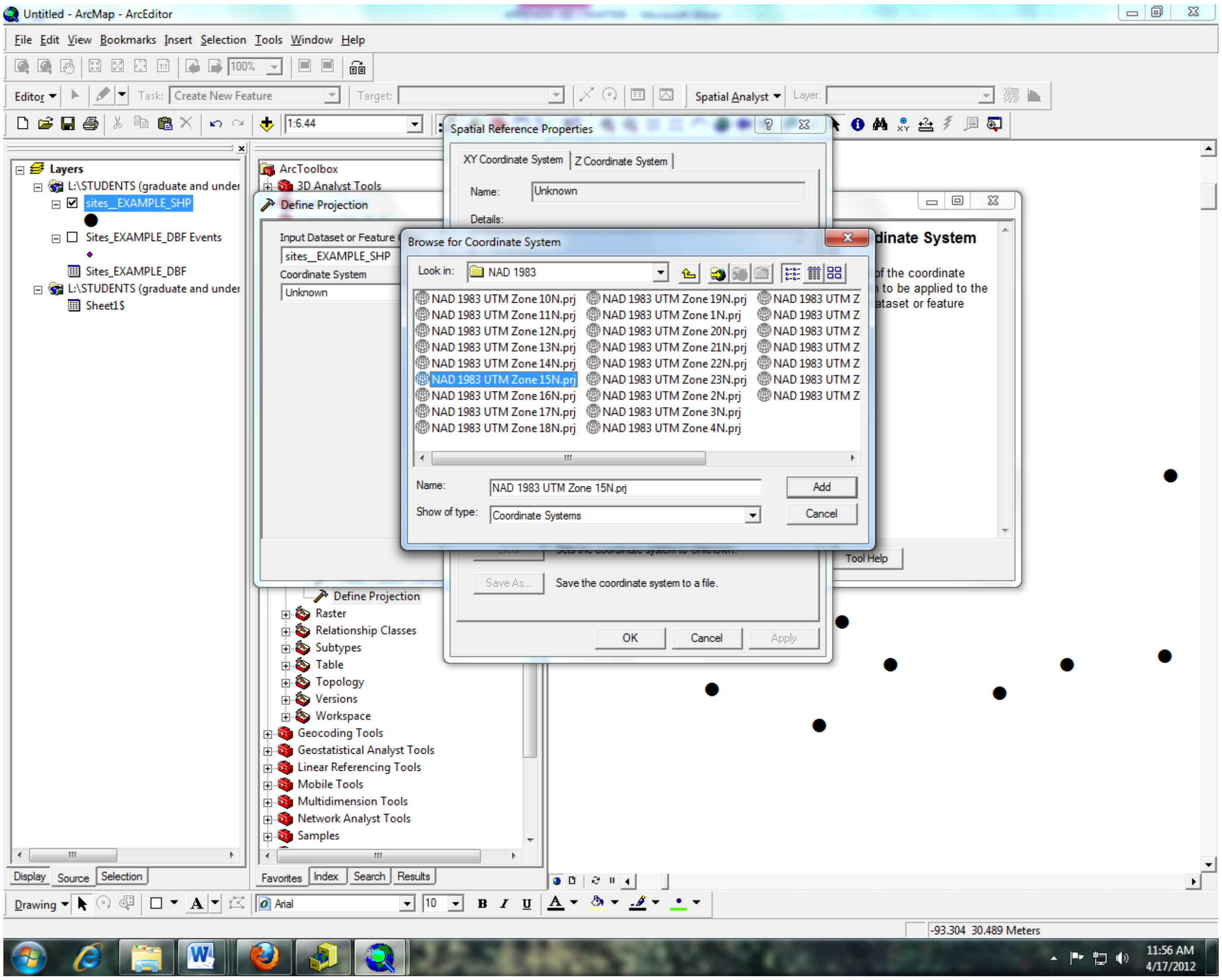
Step 10: At this point, you may need to define and project your data points into the desired projection selected above. Open "ArcToolbox" and navigate to "Data Management Tools">"Projections and Transformations">"Define Projection".



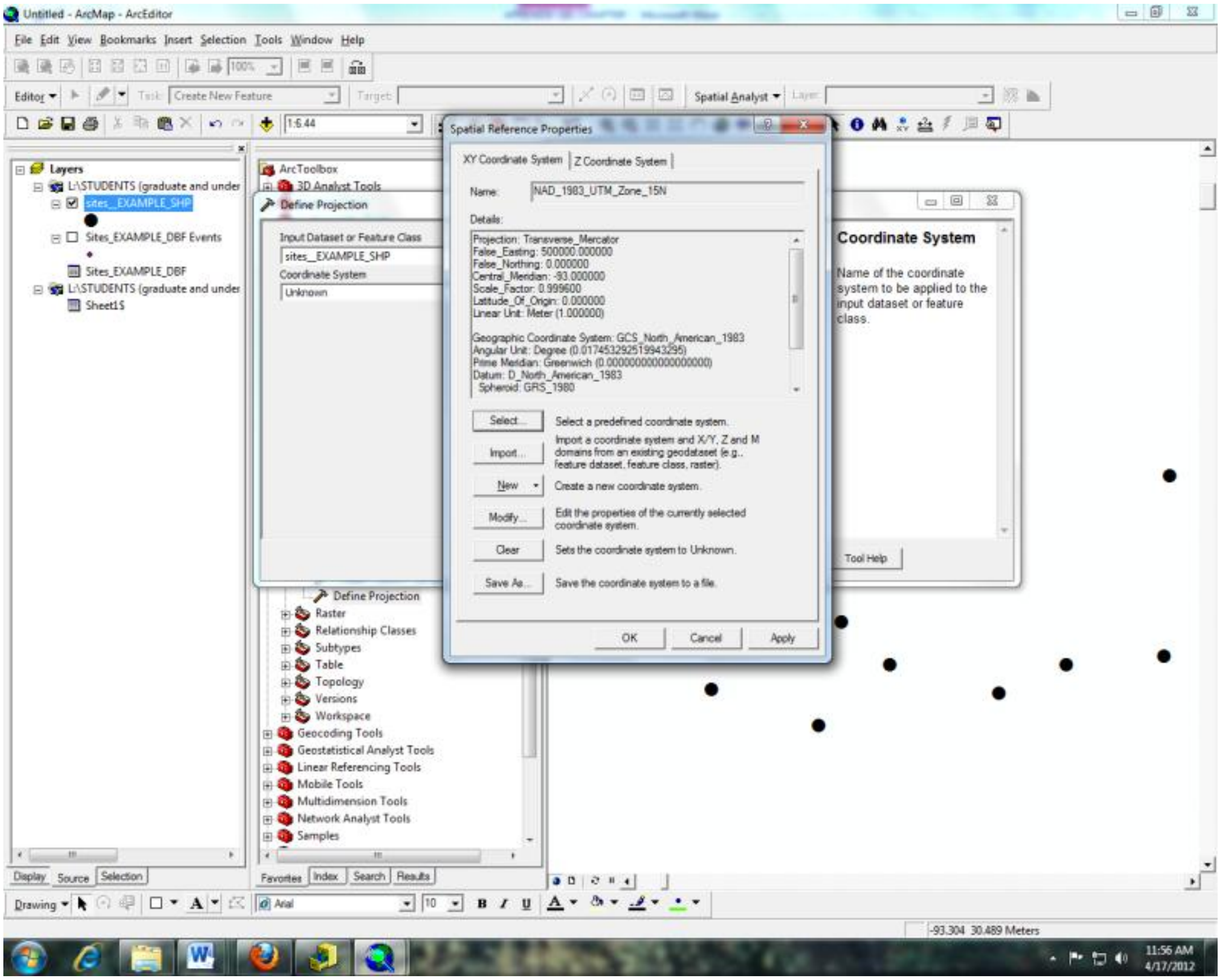
Select your sites shapefile for the input feature class.



Select NAD 1983 Zone 15 N for the coordinate system and click “Add”.



Click “OK”. (At this point you can delete the old excel, dbf, and events layers from the map document.)



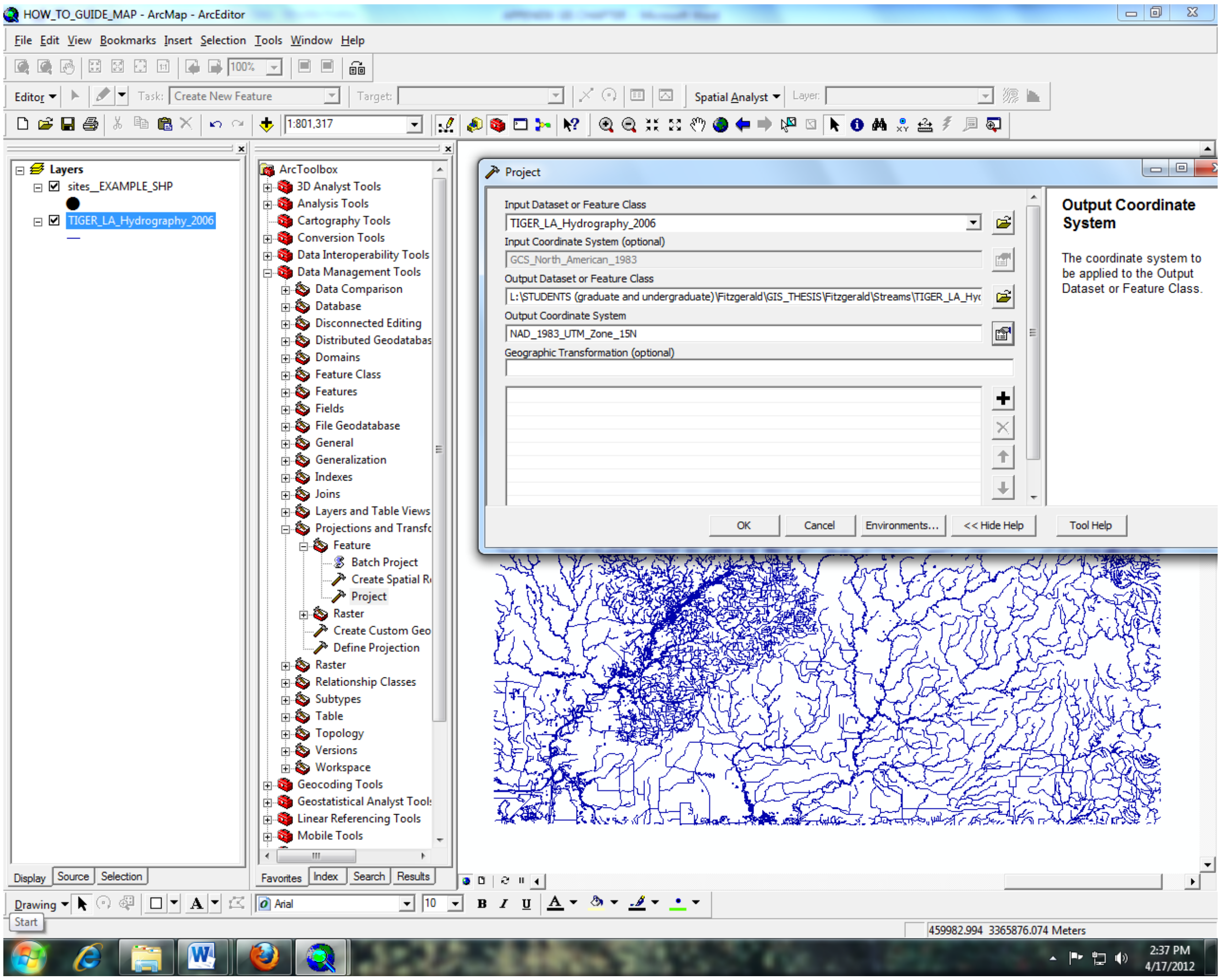
Step 11: The next step is to download and import any other data layers needed for your analysis. In this case, you need LIDAR, National Hydrography Dataset (streams and other water features), and the most current land cover data for the study area. Below are links to the aforementioned data available for free downloading. Save them in the appropriate location to be added to the map.

National Hydrography: http://datagateway.nrcs.usda.gov/GDGOrder.aspx

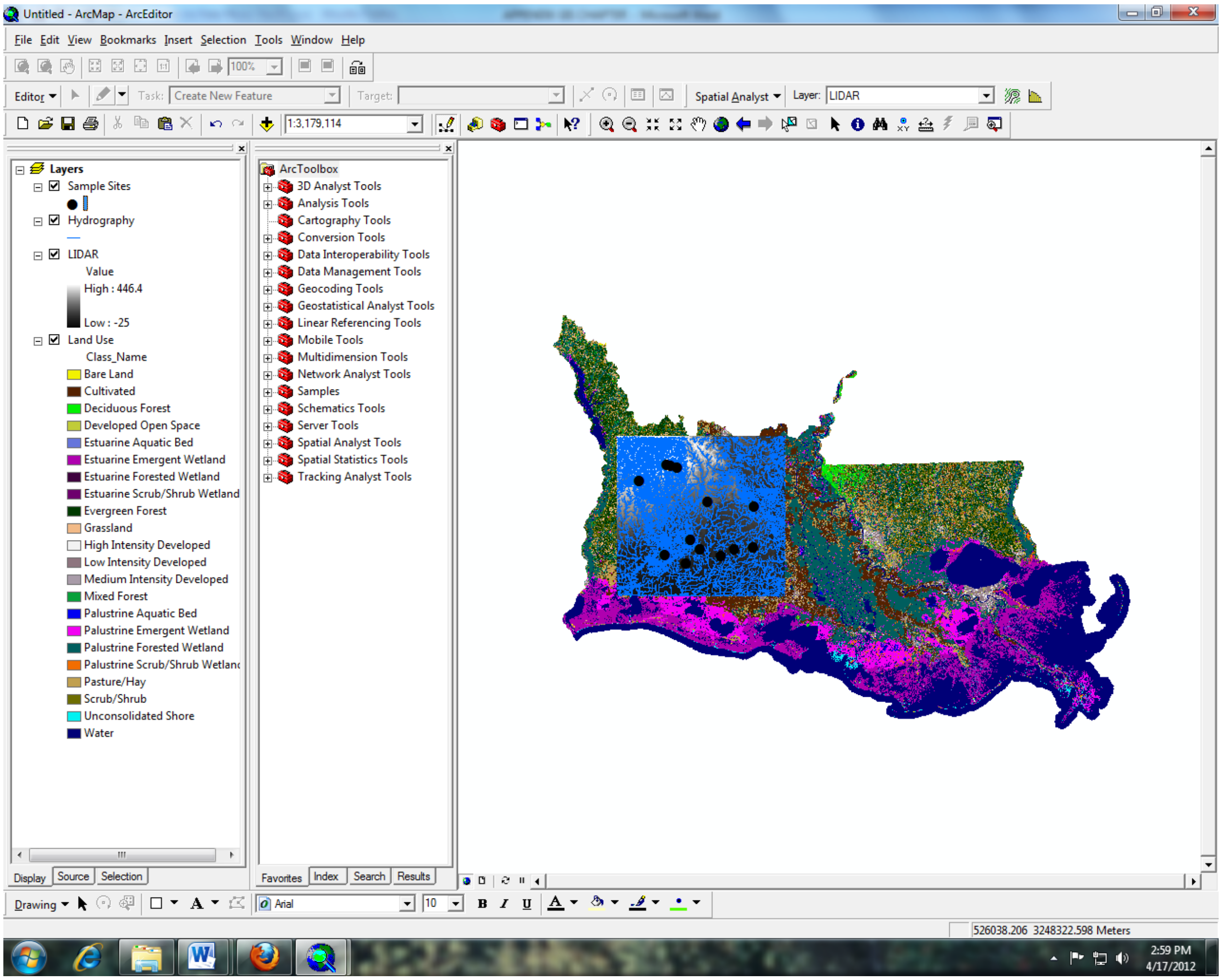
LIDAR: http://atlas.lsu.edu/rasterdown.htm

Land Use: Post-Katrina 2006 Land Cover Data http://www.csc.noaa.gov/crs/lca/katrina/

Add additional layers to the map document using the "Add Data" button. You may want to clip the data down because the layers can be very large and slow the program down significantly. Also, check to make sure all layers are in the same projection. If not, reproject them to NAD 1983 UTM Zone 15N as previously described.



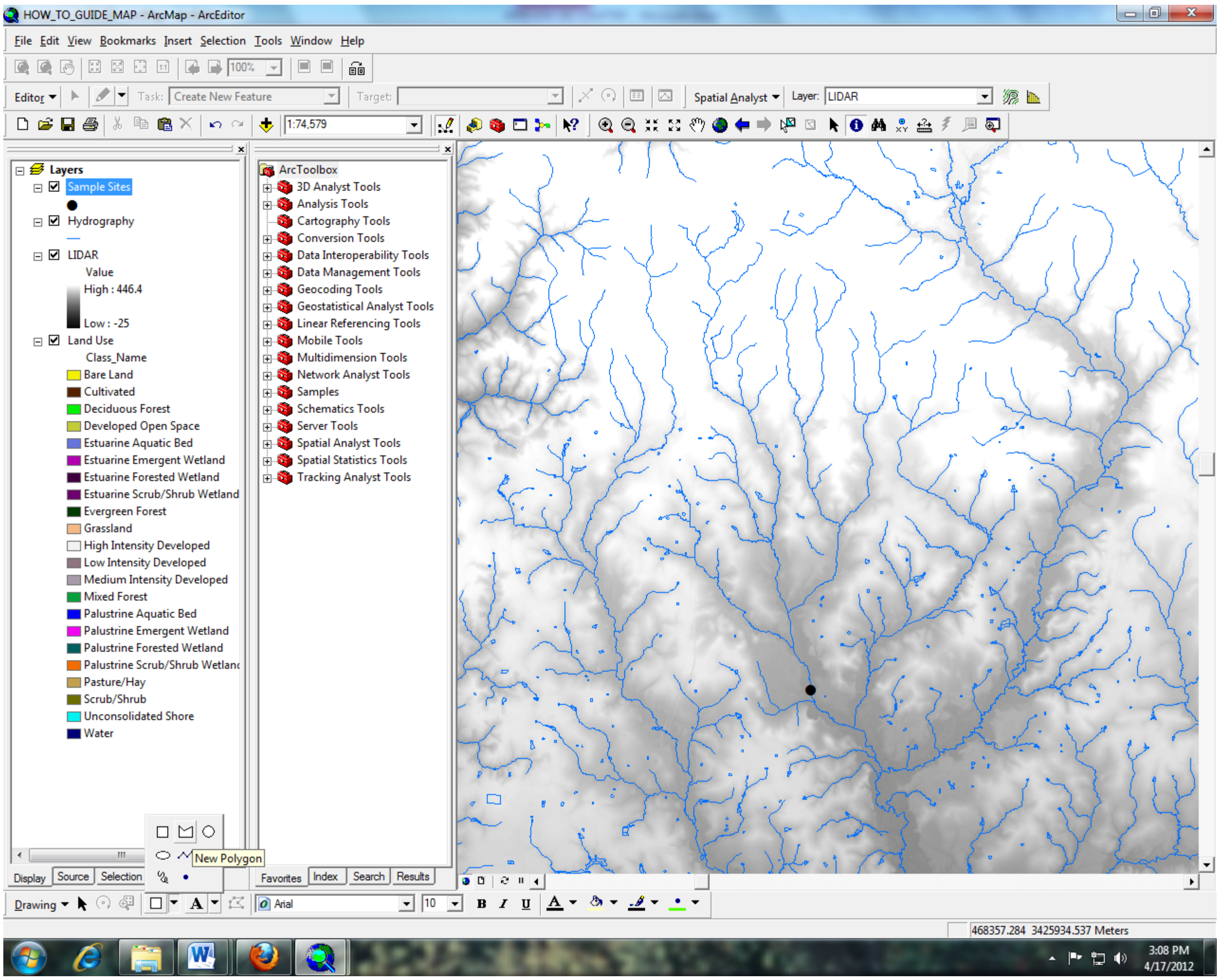
After all of the data layers are added, you should get something like this:



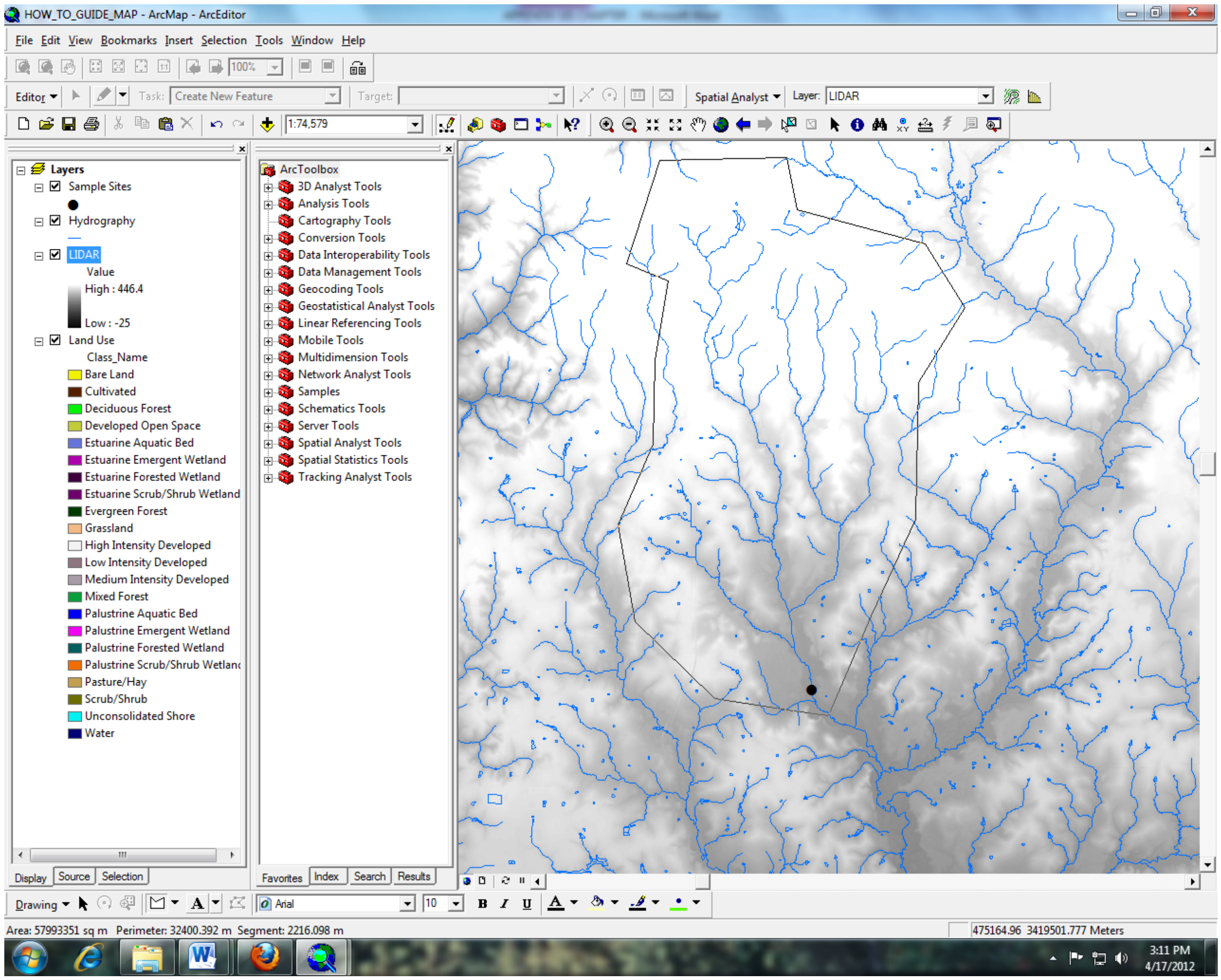
Manually Creating a Rough Watershed

This section may appear to be unnecessary work, but the rough watershed you will create here will be used to create a more statistically precise watershed in later steps.

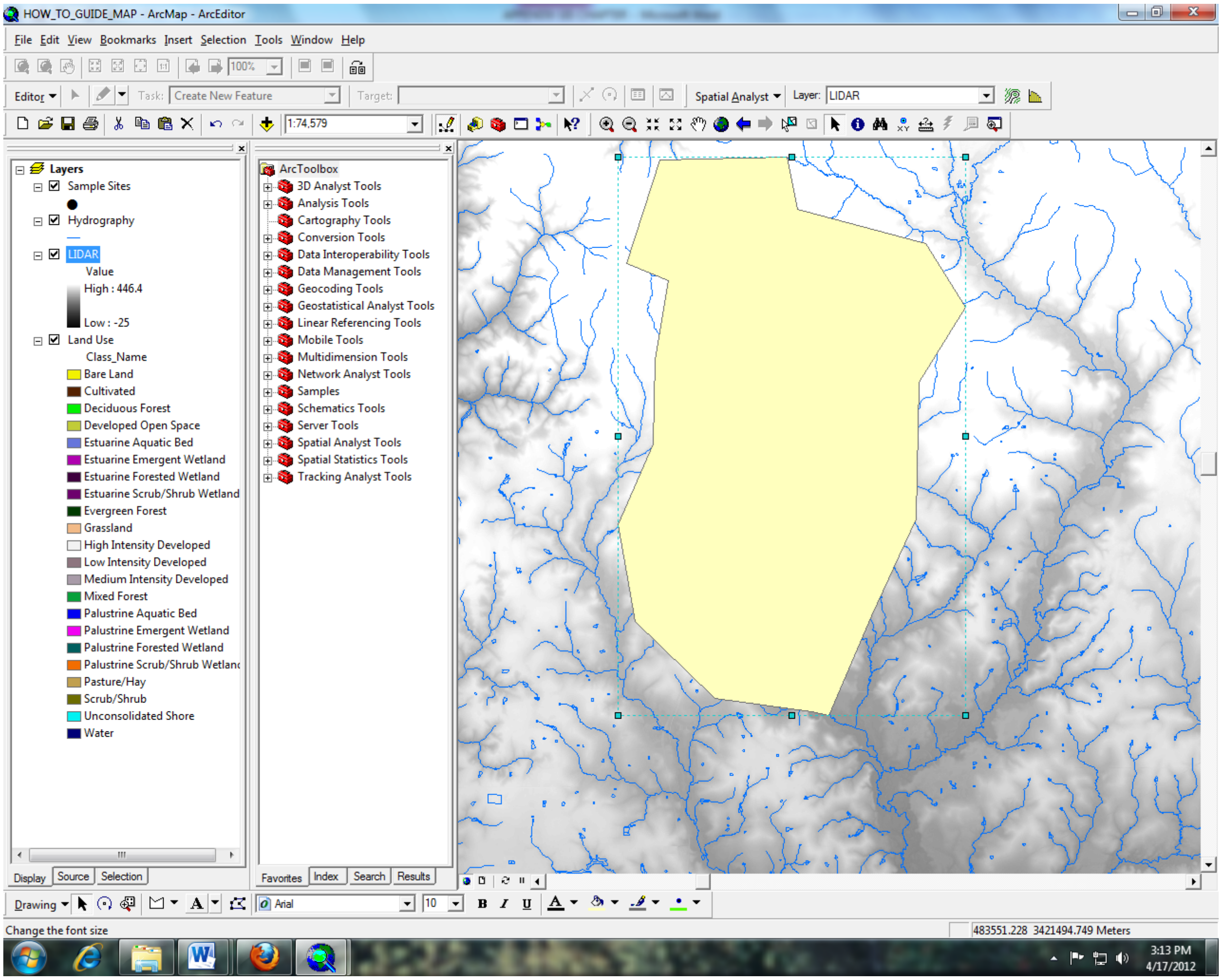
Step 1: Zoom in to your area of interest using the magnifying glass tool on the tool bar.



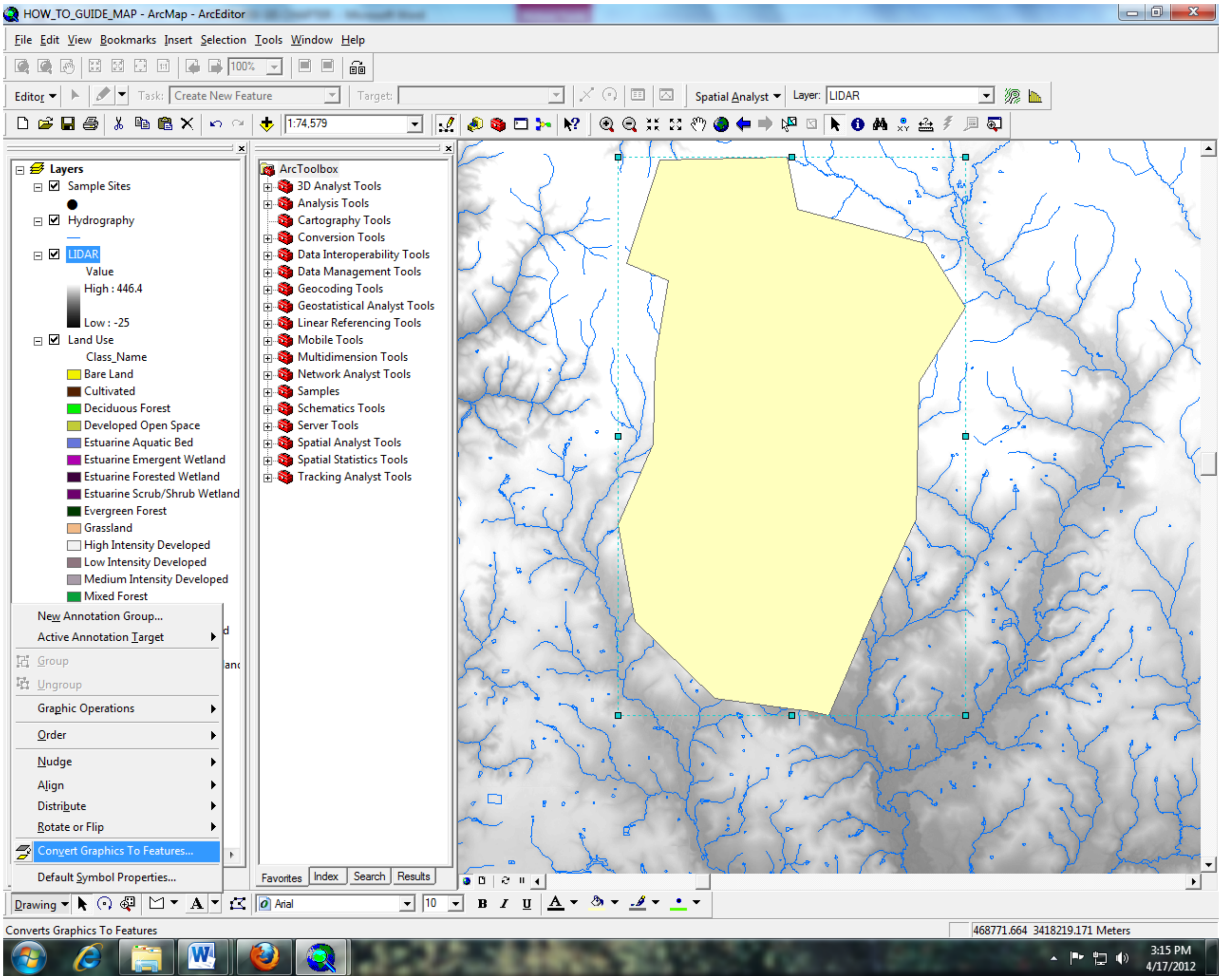
Step 2: Draw a new polygon around your upstream watershed using the drawing tools. This is a rough polygon and will later be fitted to the exact watershed. The goal is to quickly draw a polygon that just includes the edges of the surrounding drainages. Again, these will be discarded in later steps.



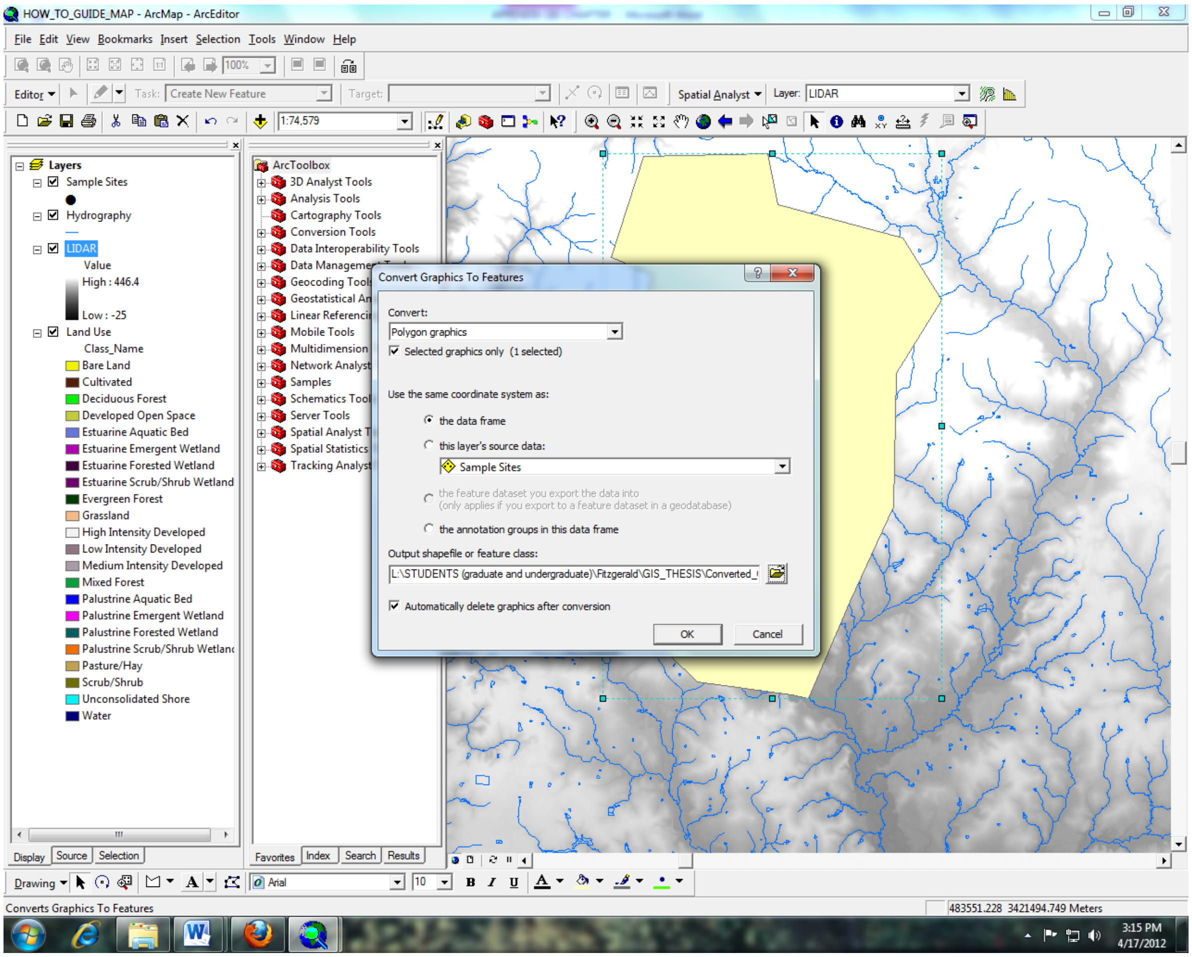
Once you've completed the polygon double-click to close the polygon. Now you need to export this shape as a permanent feature.



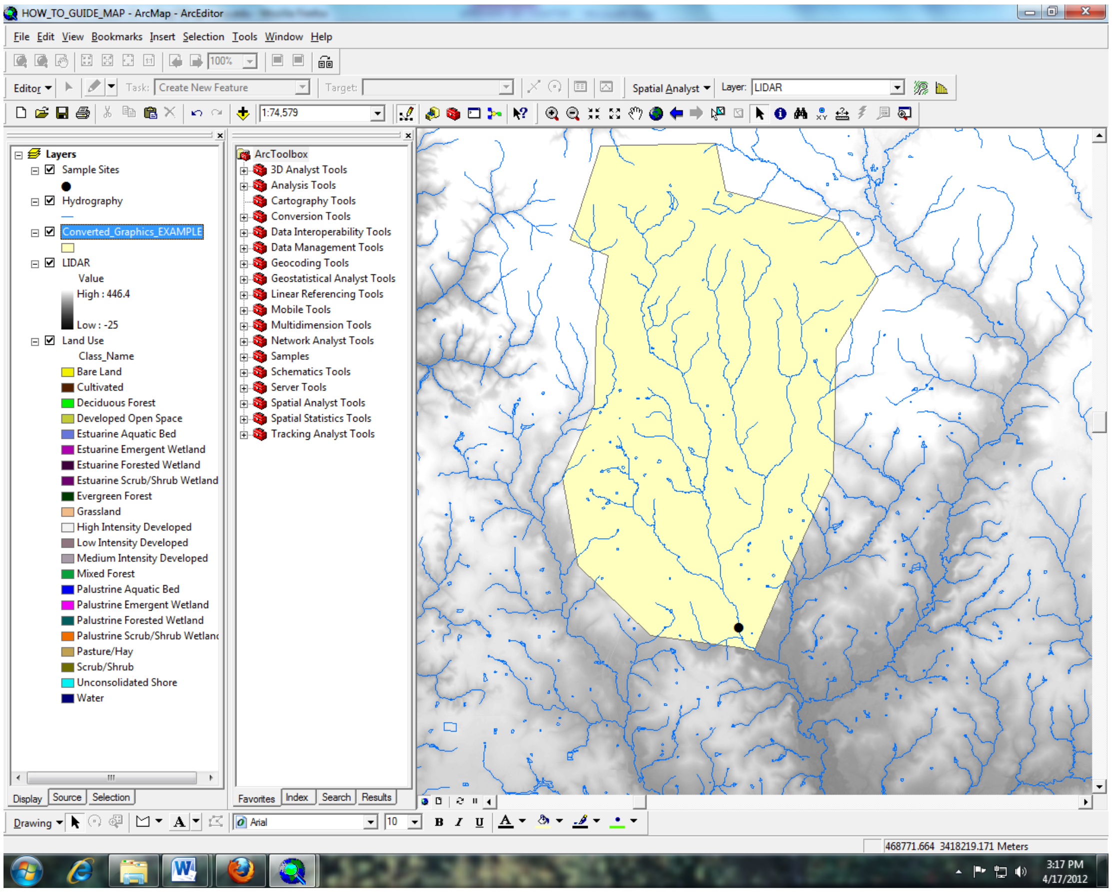
Step 3: Click “drawing”>”Convert graphics to features”.



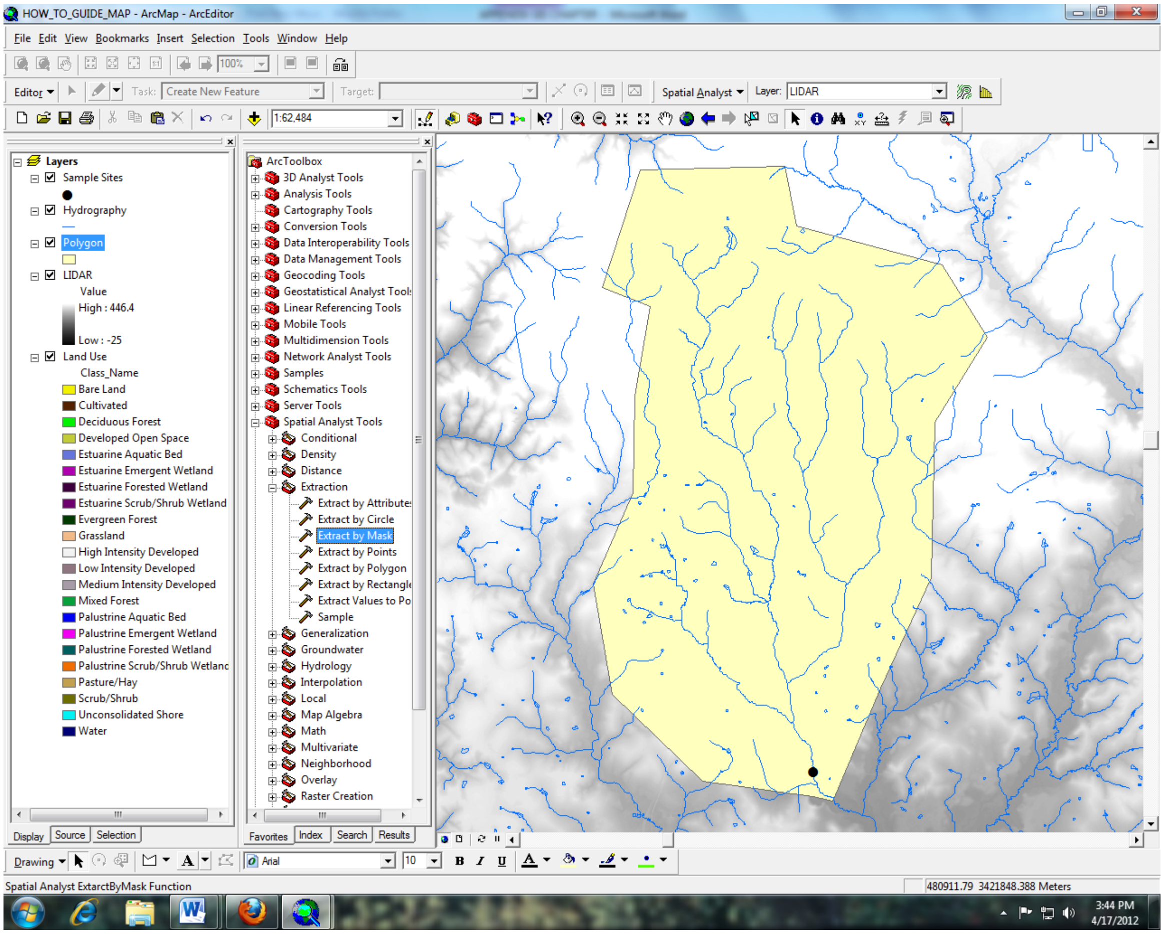
Step 4: Save it in the appropriate folder and check the box to "delete graphics after conversion".



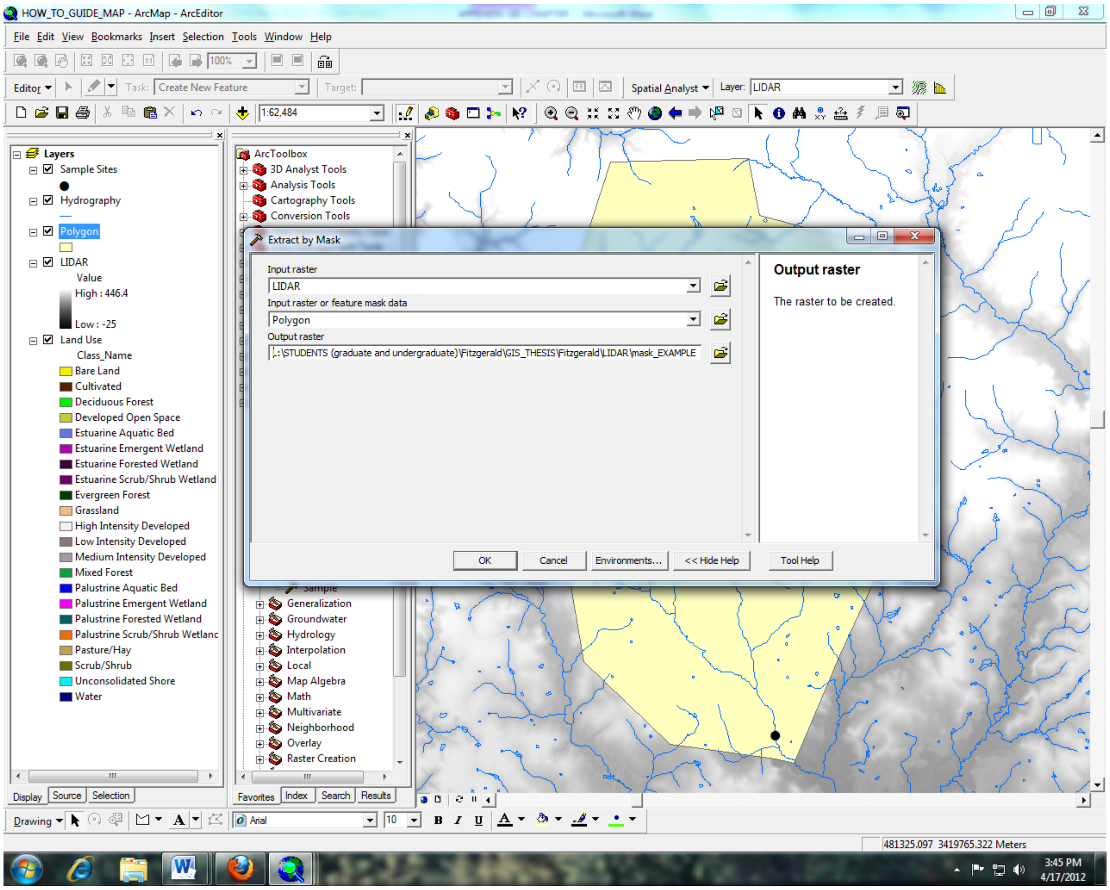
Click “OK” and add it to the map when prompted.



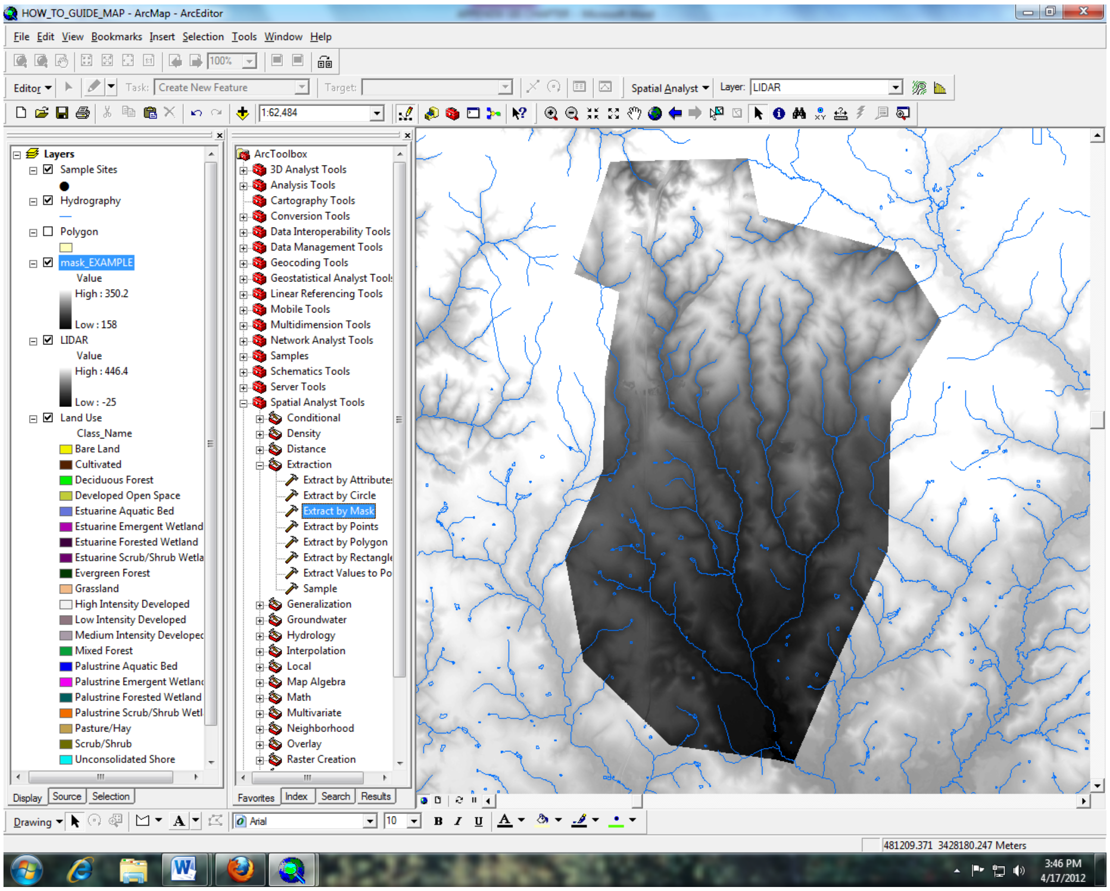
Step 5: The next step is to extract the LIDAR by the polygon you just created. In ArcToolbox, navigate to "Extraction">"Extract by Mask".



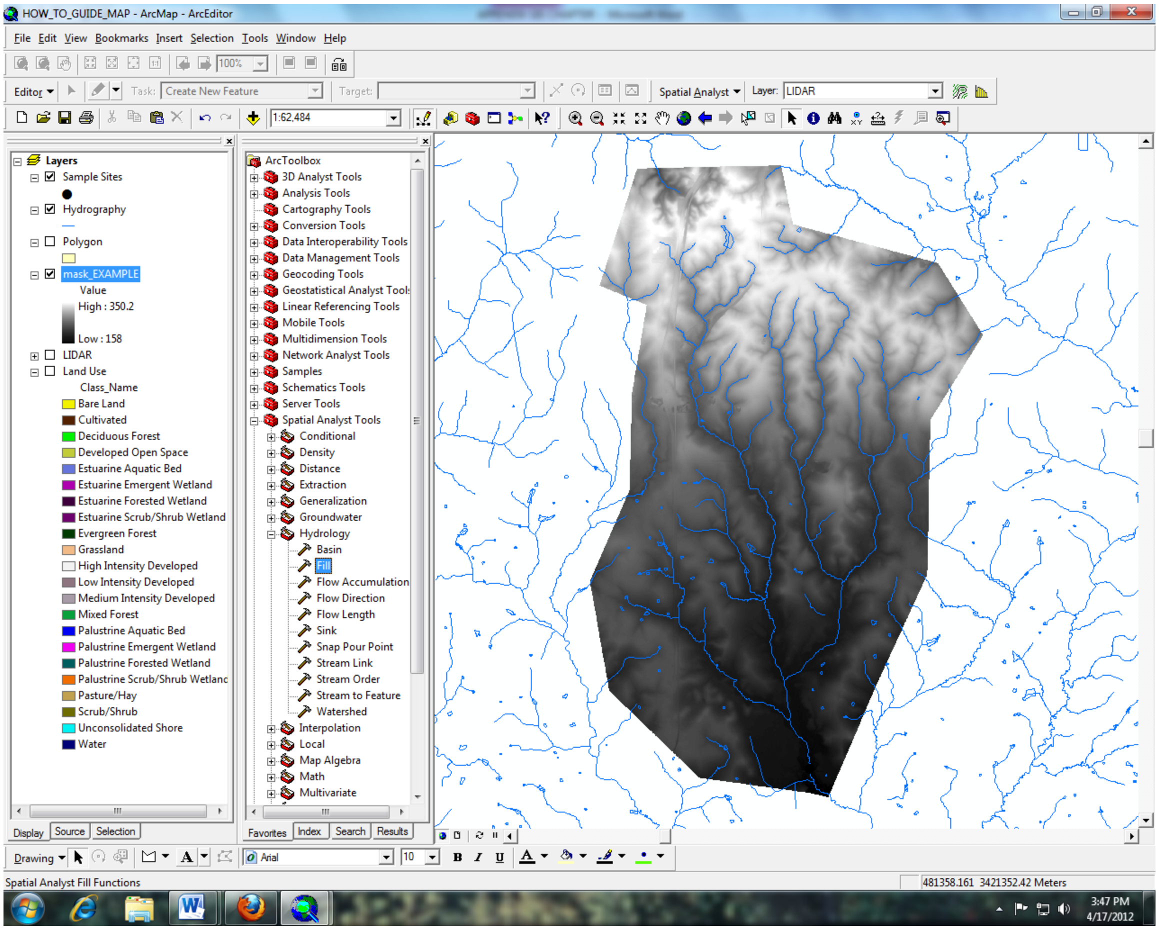
Step 6: Select the LIDAR as the input raster and the polygon as the input feature. Save the file in an appropriate location and click “OK”.



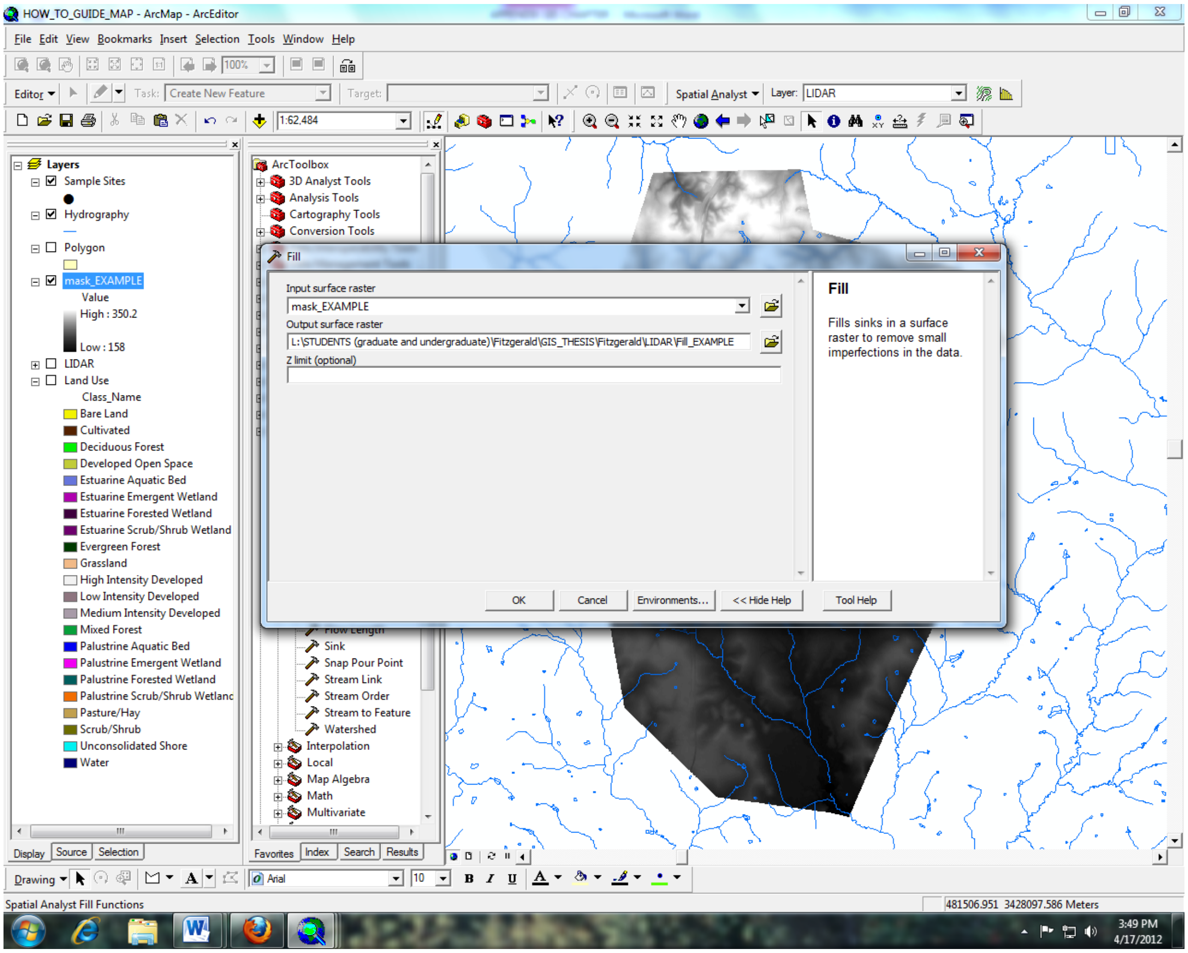
The product is the LIDAR data fitted to your polygon of interest.



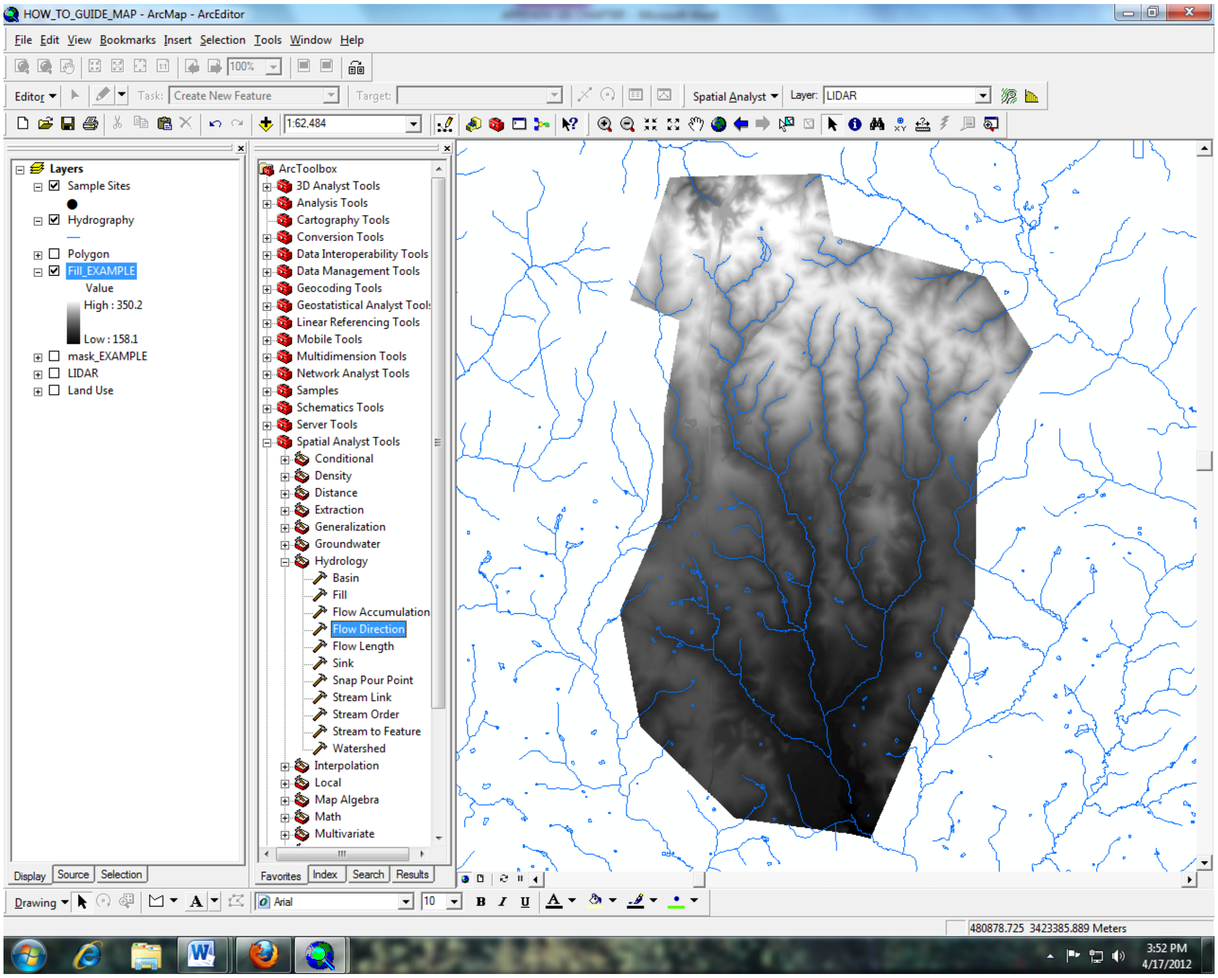
Step 7: The next step involves filling the LIDAR mask. In ArcToolbox navigate to "Spatial Analyst Tools">"Hydrology">"Fill".



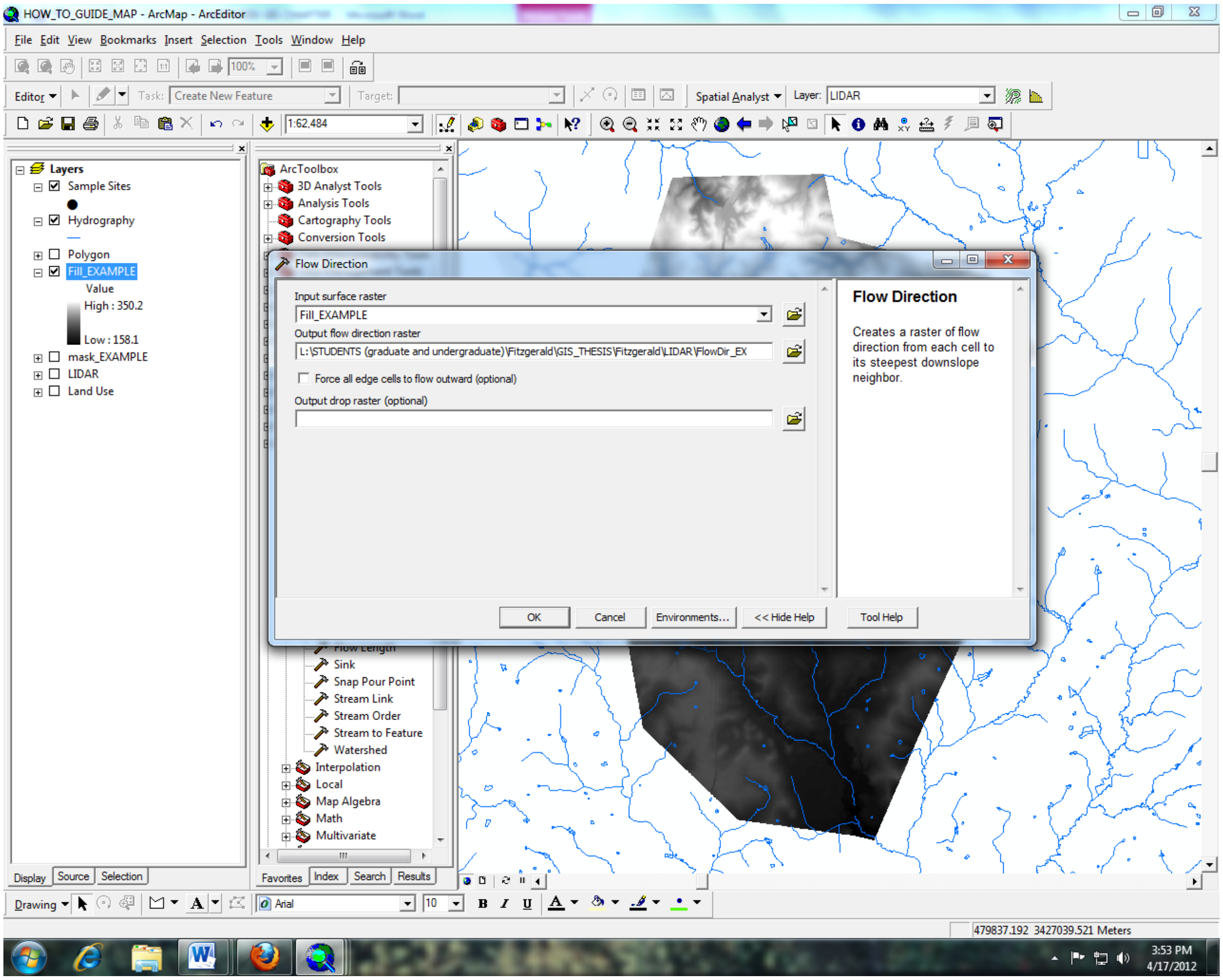
Step 8: The masked polygon you just made in the previous step will be the input surface raster. Save the new file in the appropriate location and click “OK”.



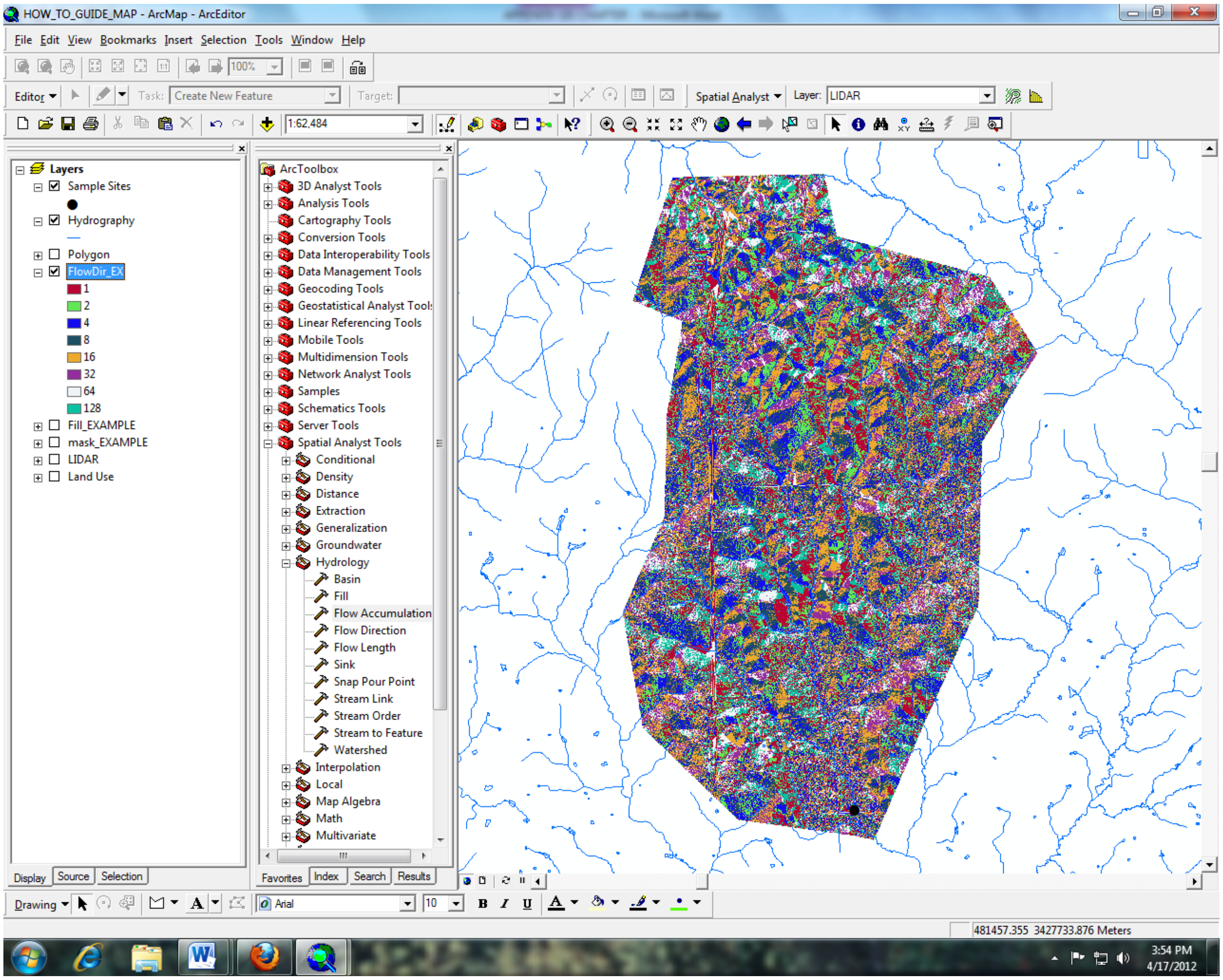
Step 9: The next step is to run the flow direction tool. Navigate to "Spatial Analyst Tools">"Hydrology">"Flow Direction".



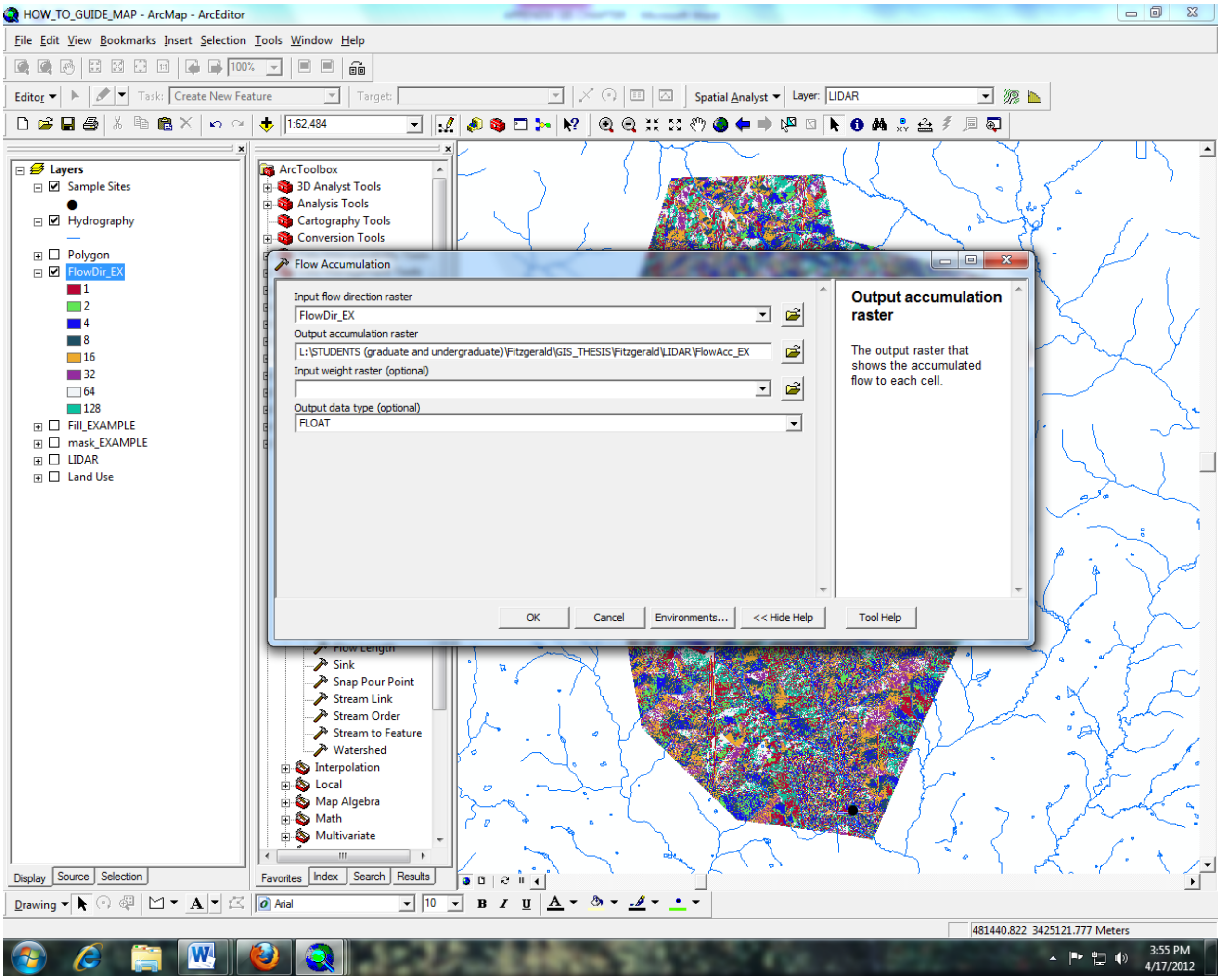
Step 10: The input raster will be the Fill layer you just completed. Save the output in the appropriate location and click "OK".



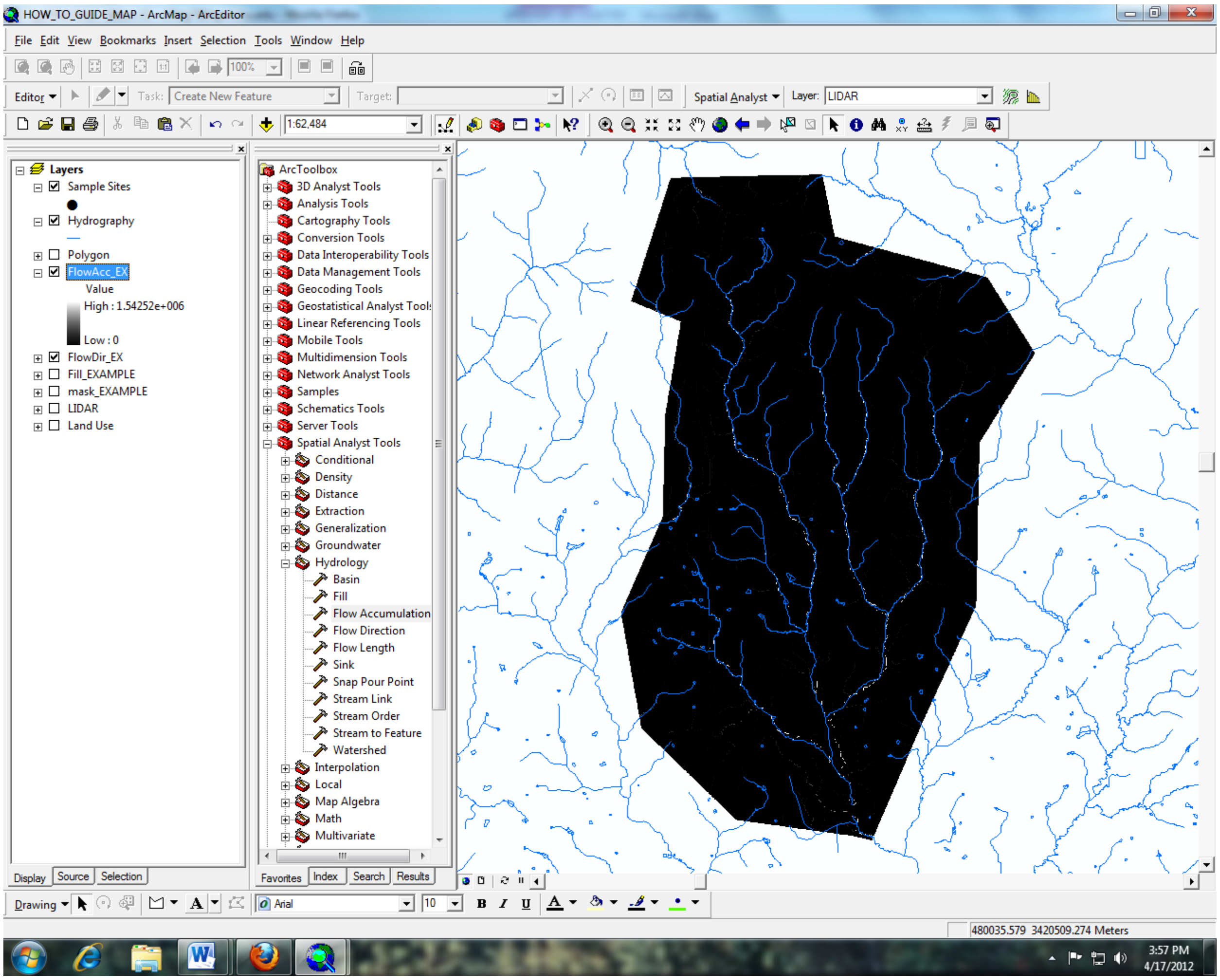
The flow direction tool assigns a number to every cell in the raster based on the direction of the topography. The product is this multi-colored raster which looks kind of useless at first but other Hydrology functions read the data to understand how to build watersheds and flow accumulation.



Step 11: Next run a flow accumulation. Navigate to “Spatial Analyst Tools”>”Hydrology”>”Flow Accumulation”. The input flow direction raster will be the flow direction raster you just created. Save the new layer in the appropriate location and click “OK”.



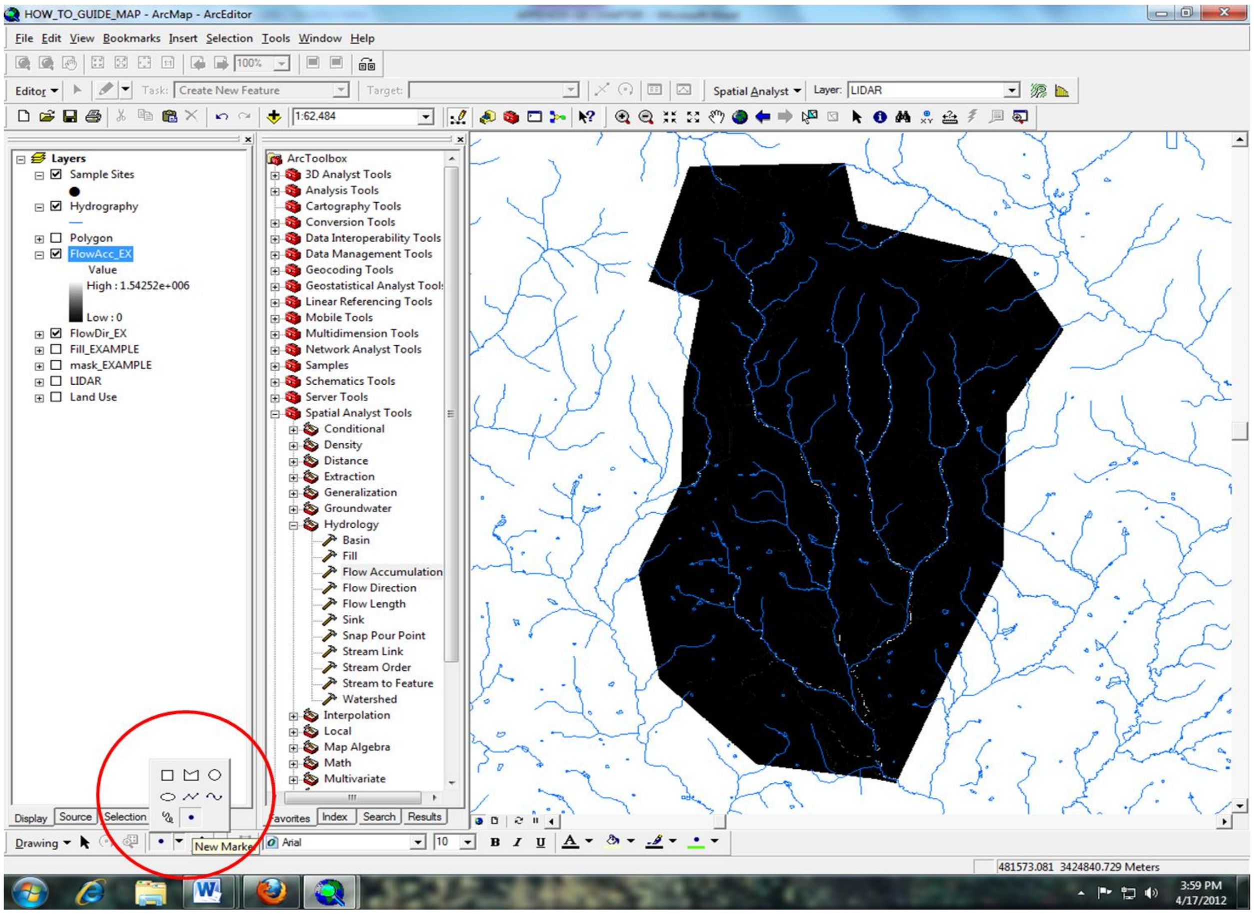
The flow accumulation raster may not appear to have any data given the scale shown in the table of contents but that is ok. If the area you are working with is a low gradient watershed you may not notice an obvious trend with this data. Zoom in to the stream to see different pixels assigned for the flow accumulation.



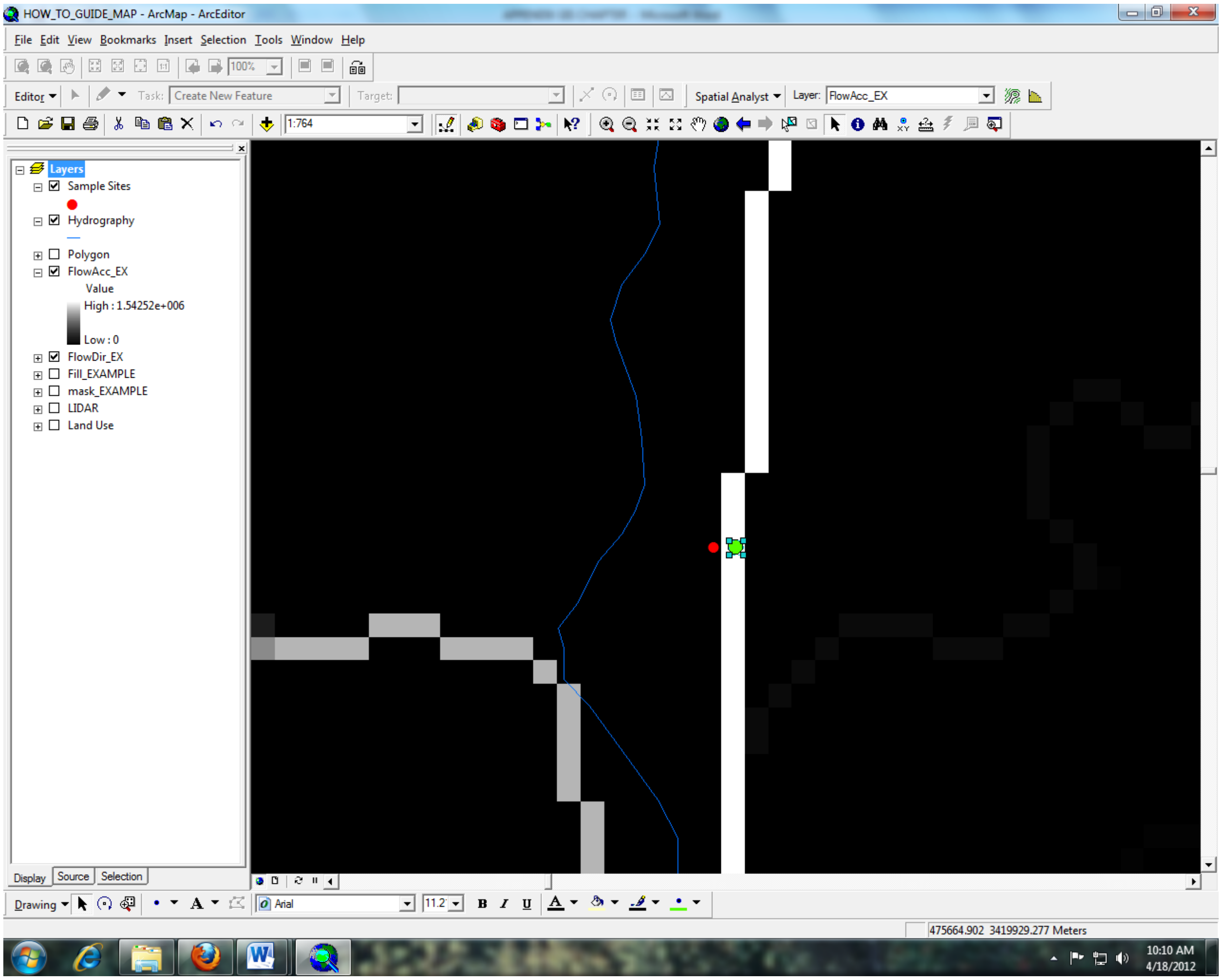
Create a New Pour Point

This is necessary to run the watershed tool in the following steps. Although the sample site is still marked by a point, it may not always line up precisely where it would need to be for this analysis. Therefor I would recommend creating a new pour point directly where it needs to be. This will ensure that you don't get errors in the following steps.

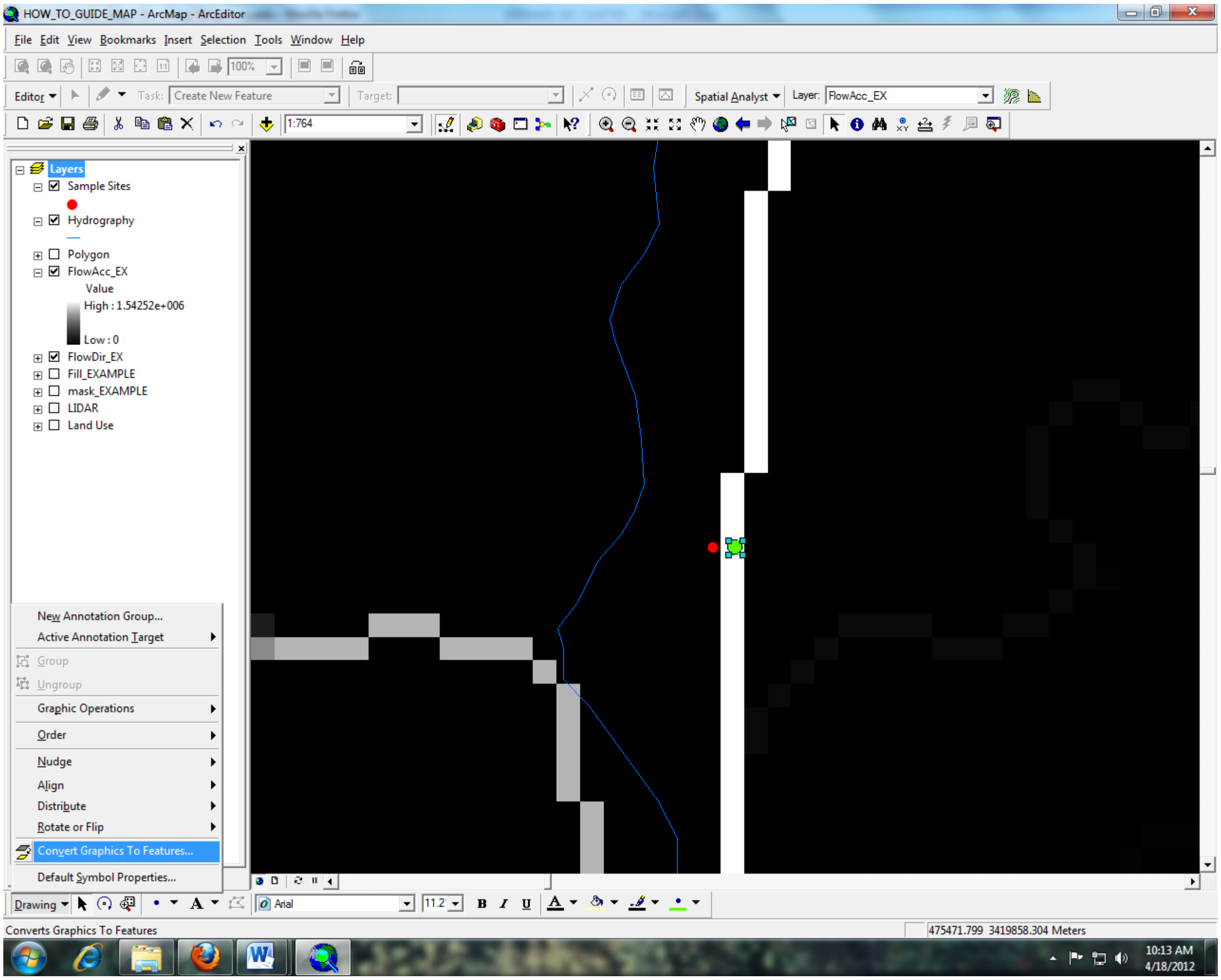
Step 1: In the drawing tools, select the point symbol to draw a new point.



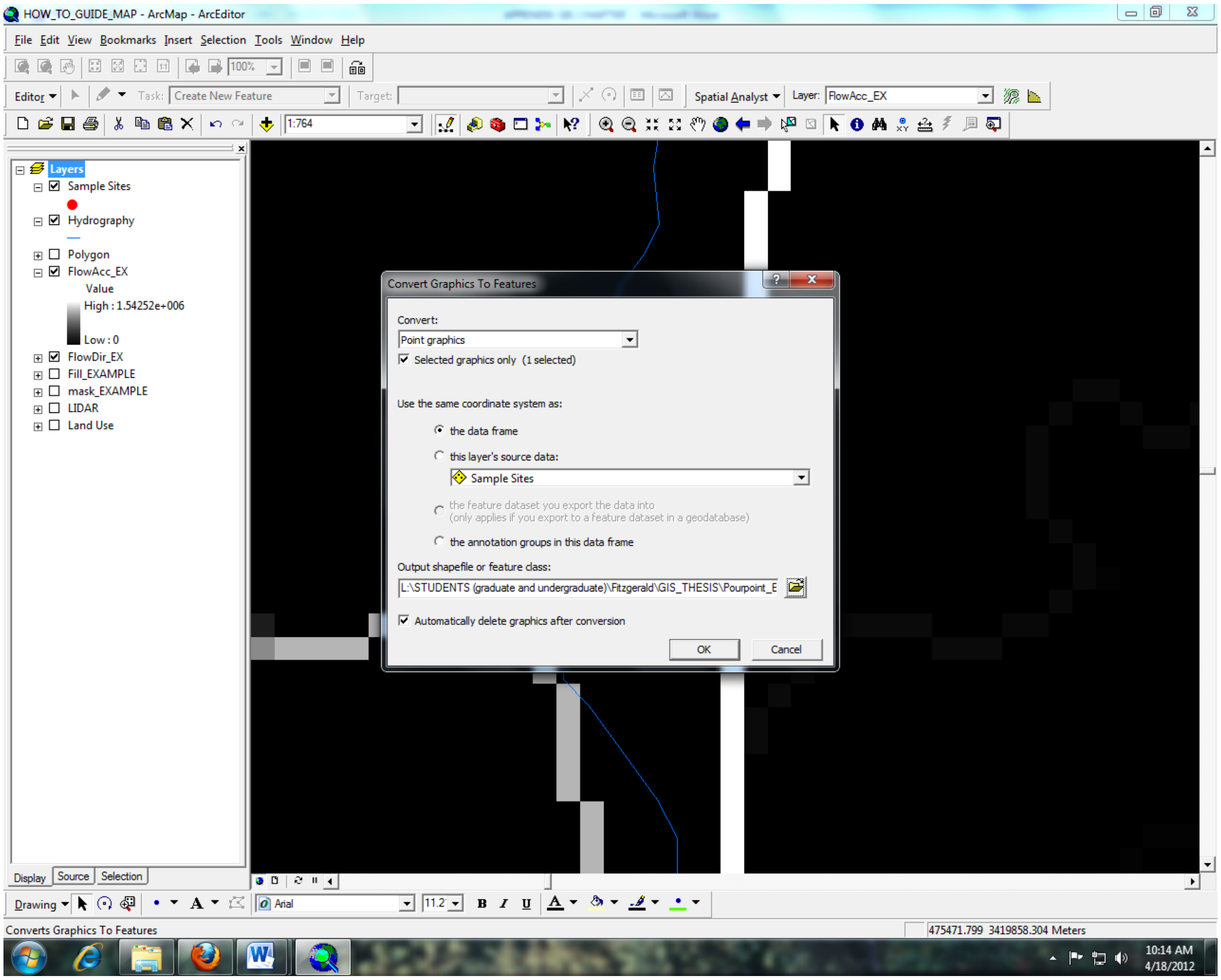
Step 2: Zoom in as close as you can before placing the point on the map. Make sure to place the point where the flow accumulation raster indicates the stream is (NOT where the hydrography stream is). This point will later be converted to a pixel within the flow accumulation raster.



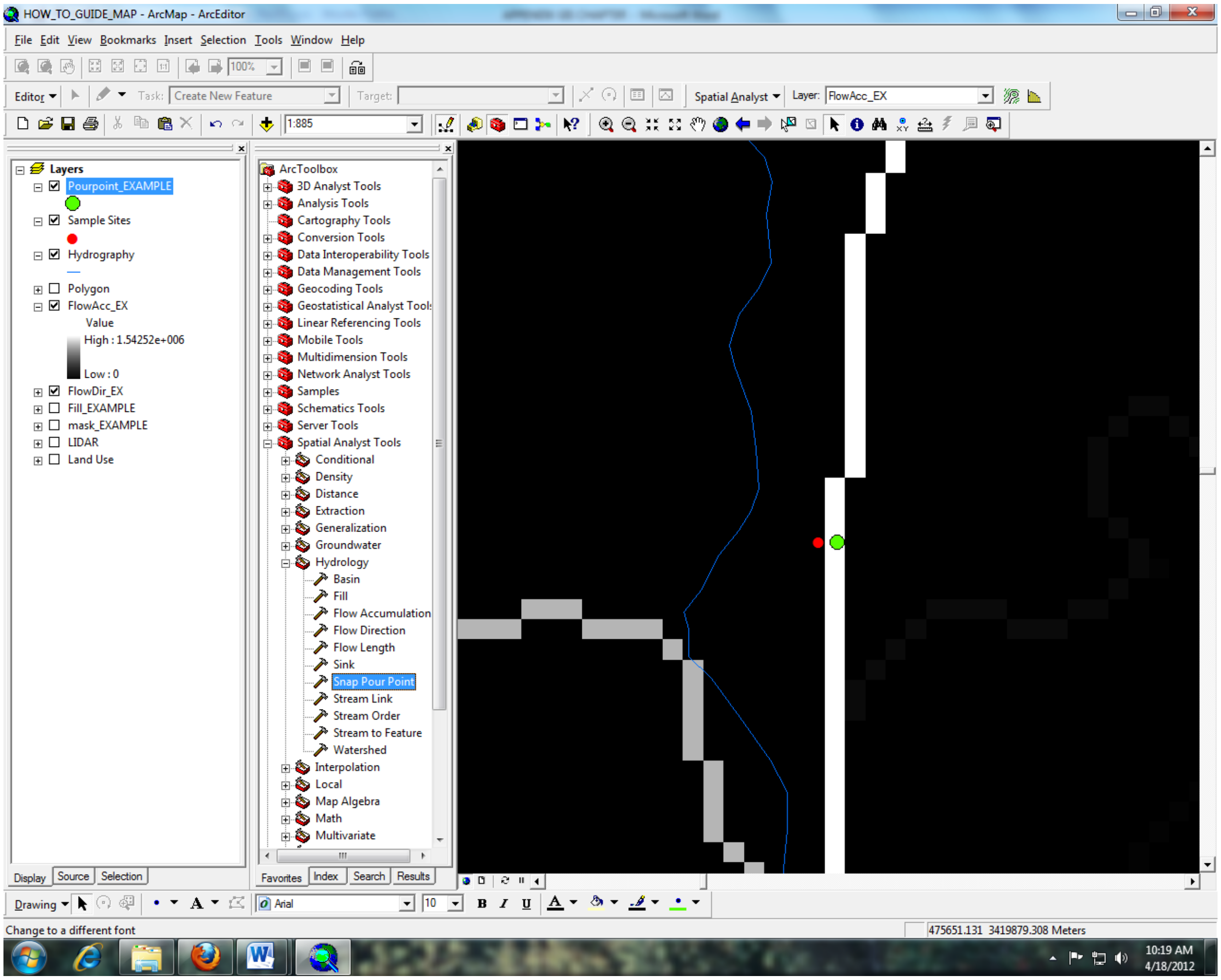
Step 3: Export this point so it becomes permanent feature. " Select Drawing">"Convert graphics to features".



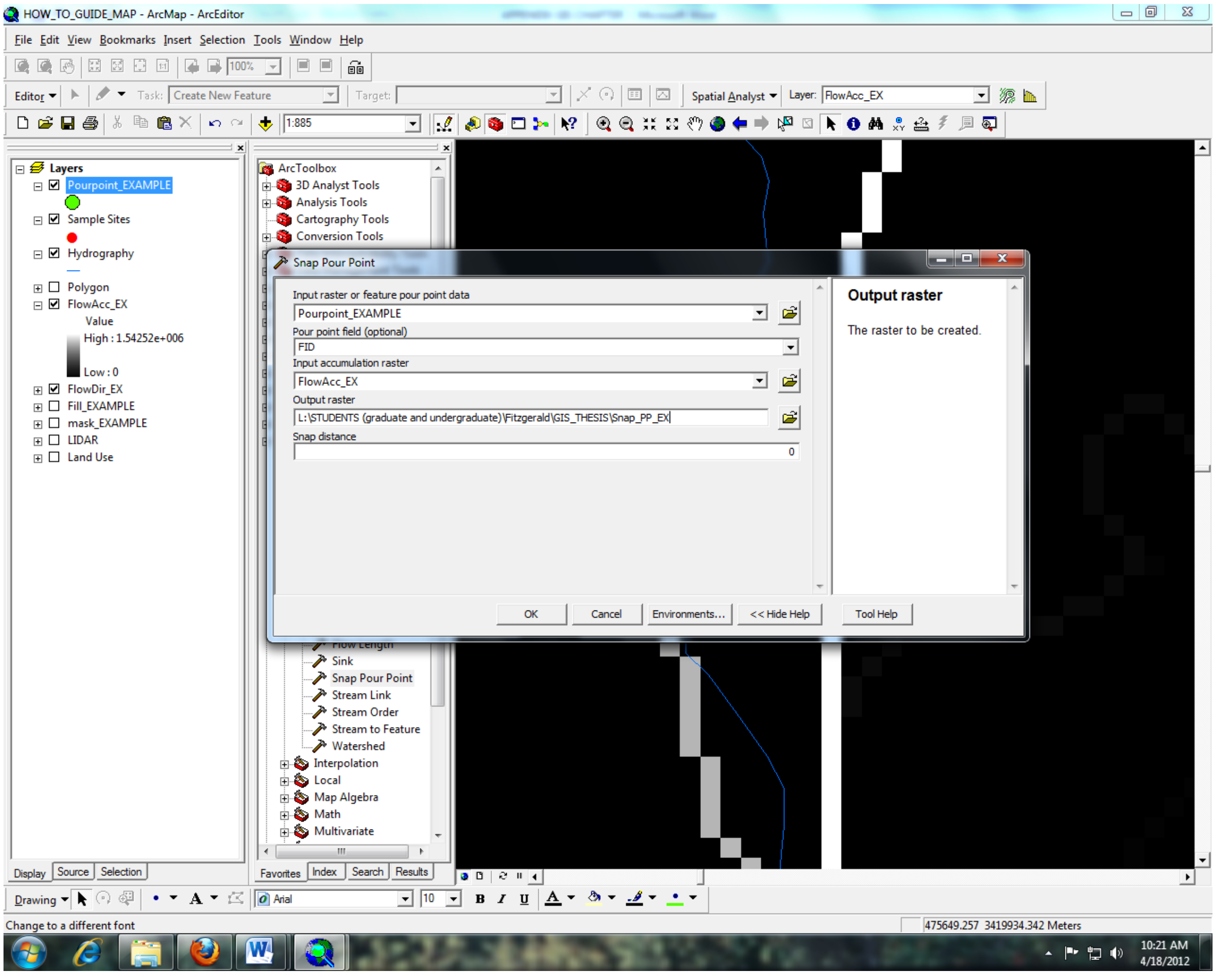
Step 4: Save the pour point in the appropriate location. Check the box to delete the graphic after conversion, click “OK”, and export the layer to the map.



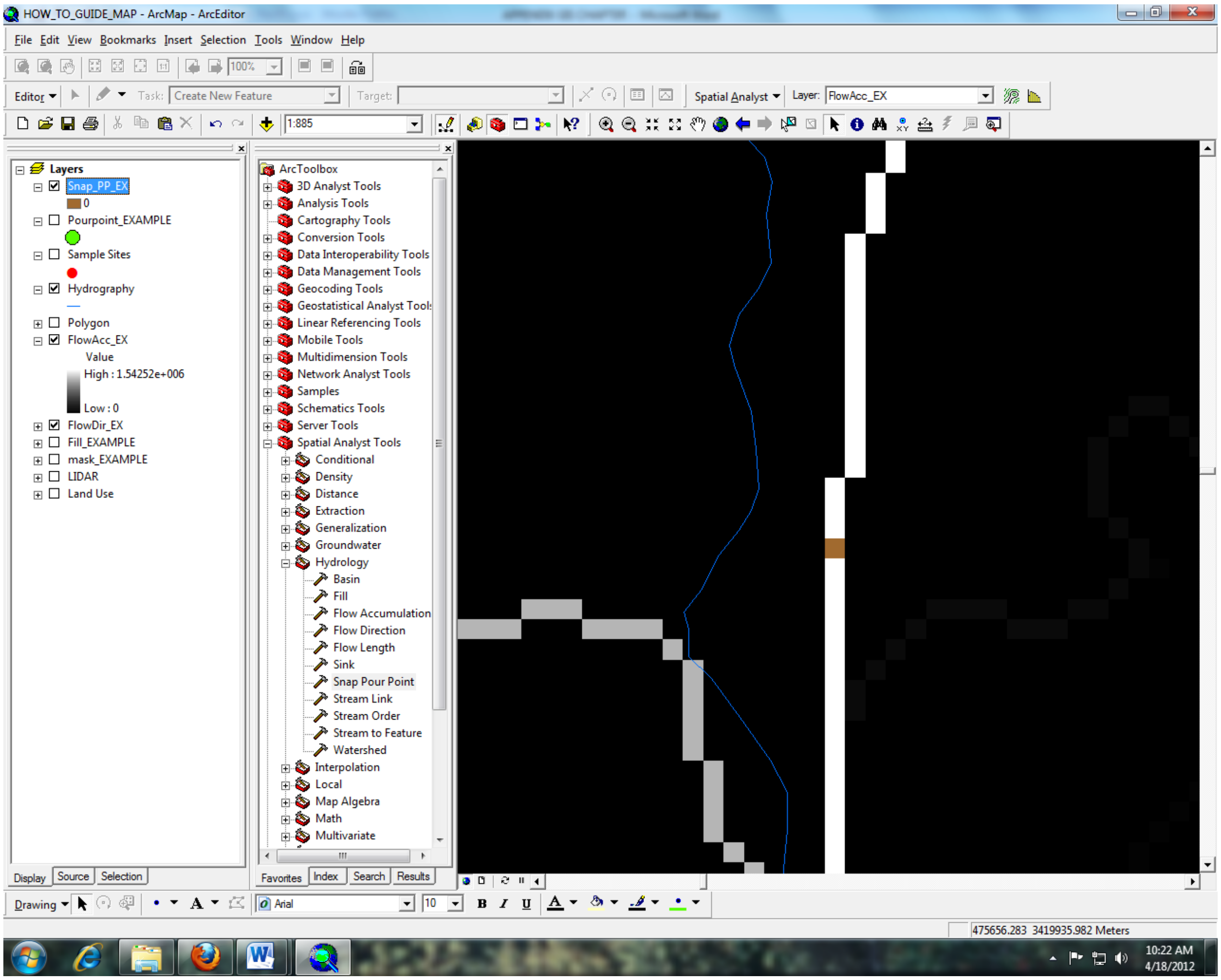
Step 5: To move the pour point to the correct location select "Spatial Analyst Tools">"Hydrology">"Snap Pour Point".



* Although the “Pour Point Field” box says “optional” you should choose the proper identification field for your pour point to ensure that ArcMap takes the proper actions

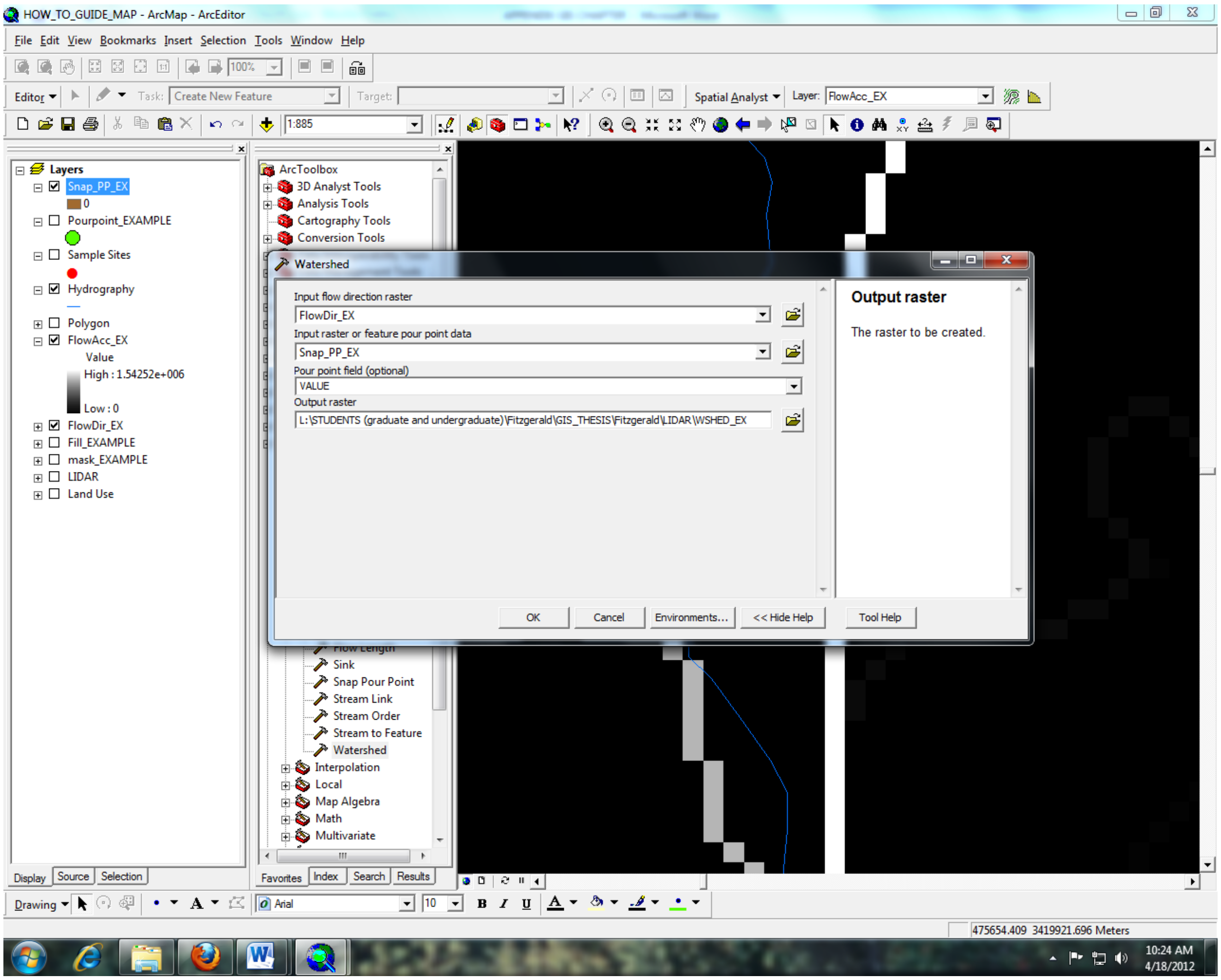


The final snapped pour point

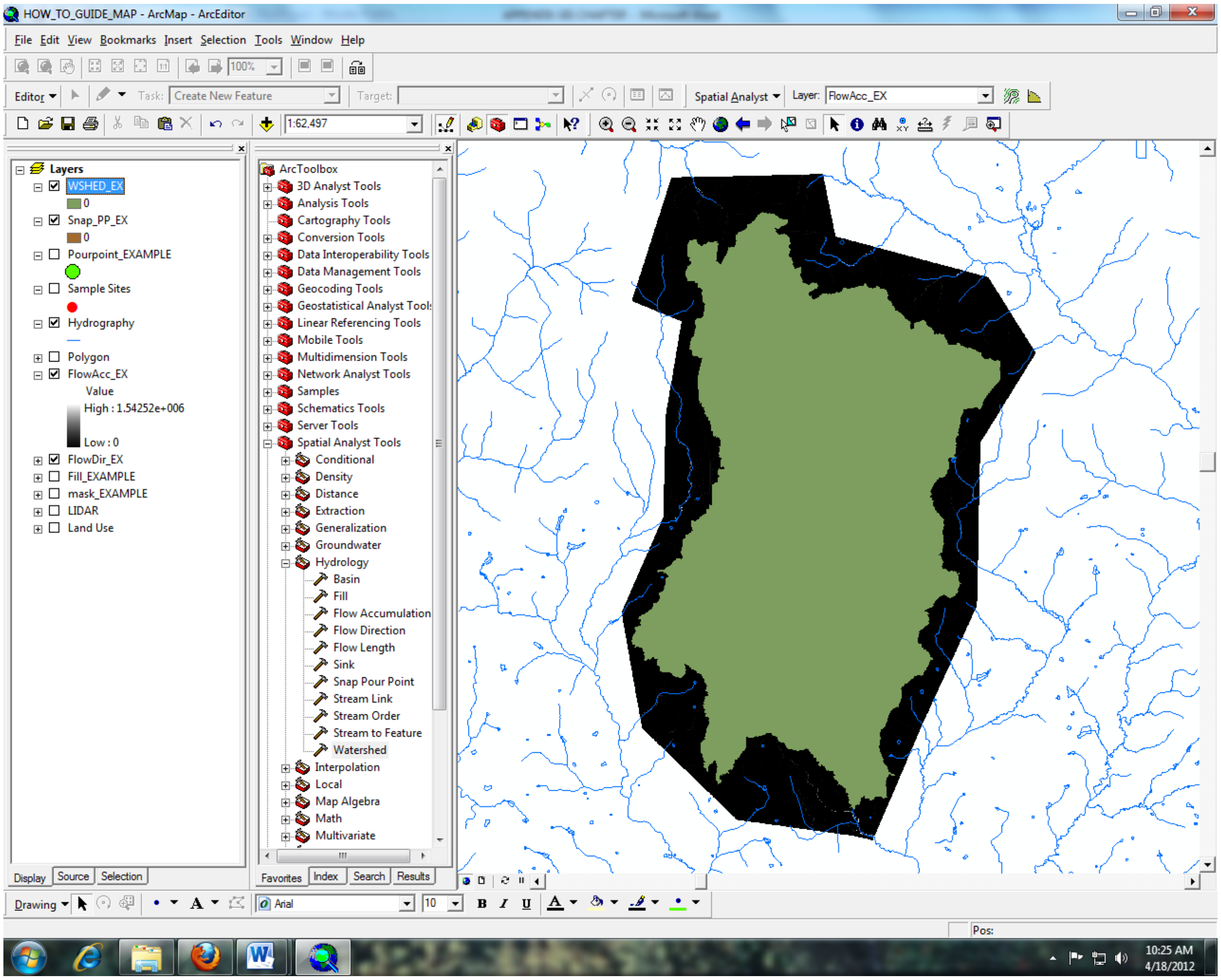


Creating the Real Watershed

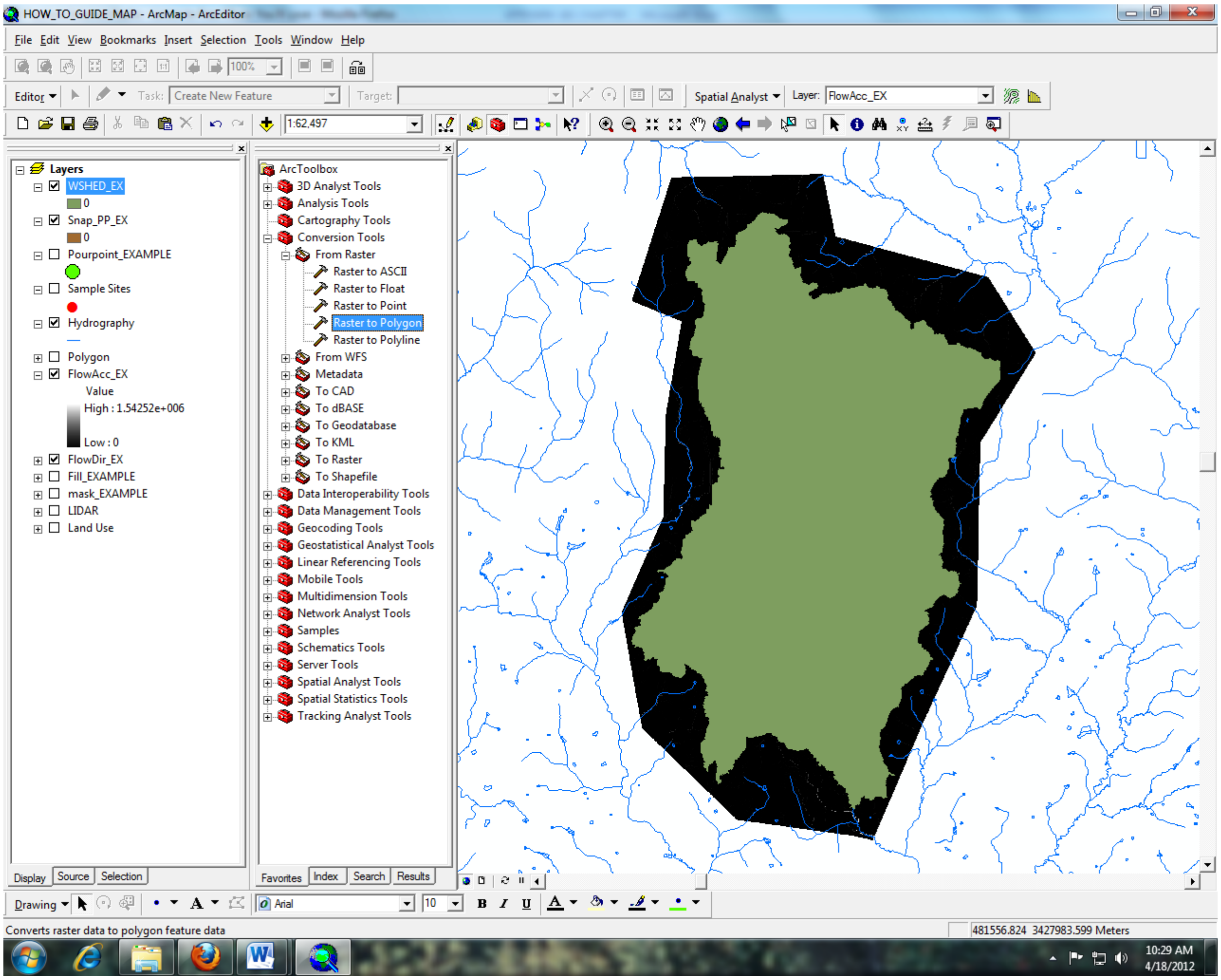
Step 1: Select "Spatial Analyst Tools">"Hydrology">"Watershed". The inputs are the flow direction raster and the snapped pour point. Name the output watershed appropriately and click "OK".



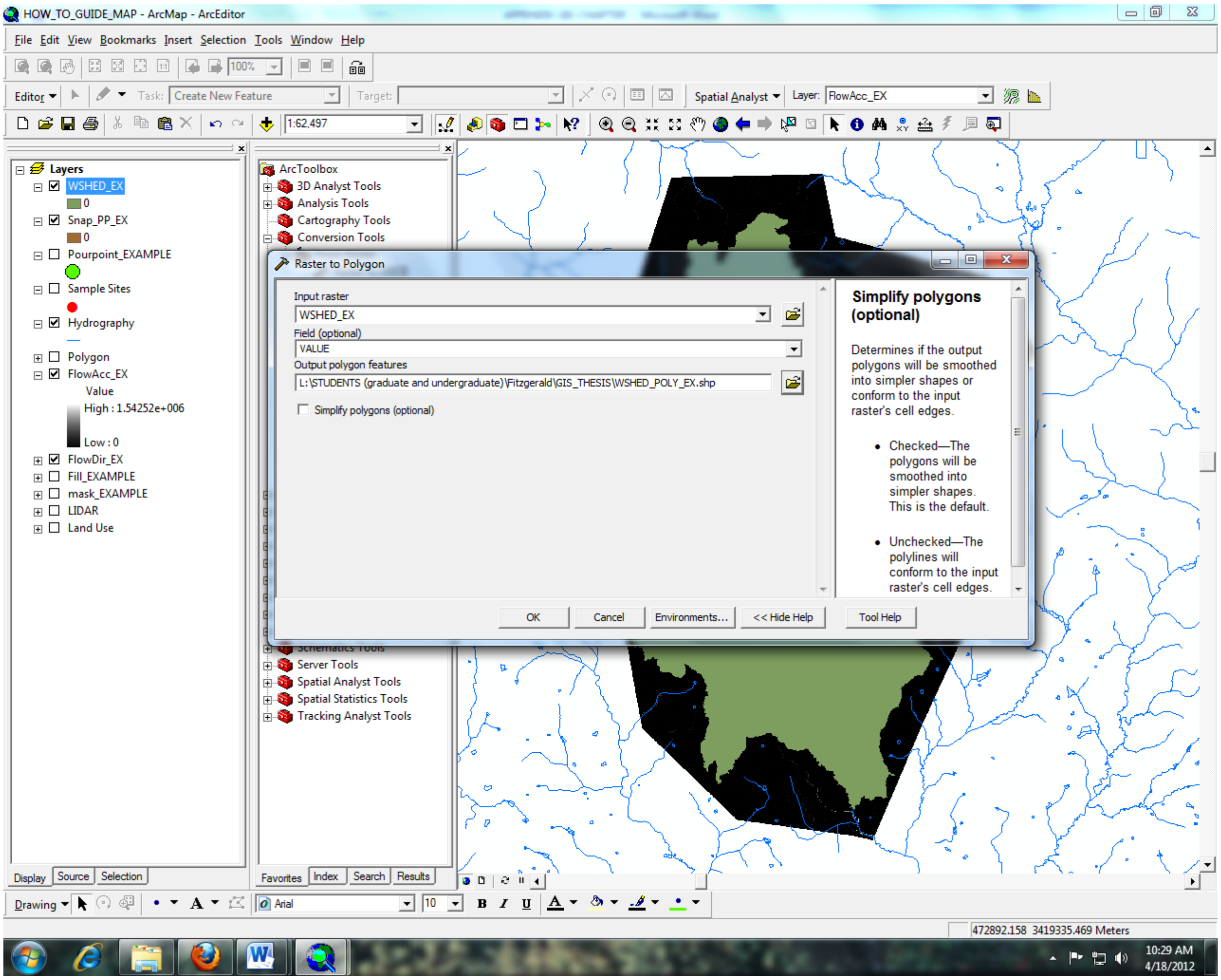
This step produces an upstream watershed for your sample site. This new watershed will be used to calculate landuse metrics, etc.



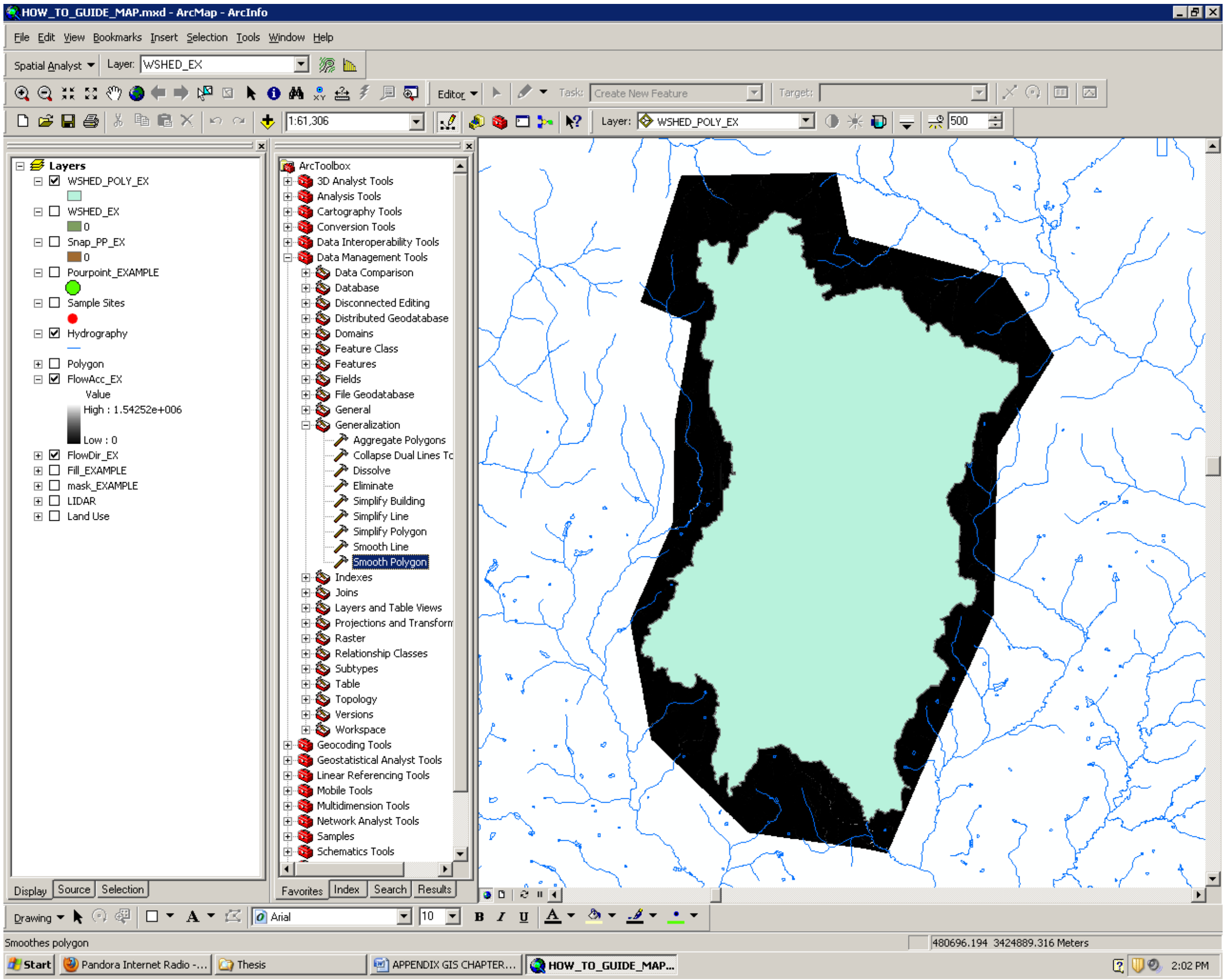
Step 2: Convert the watershed raster to a polygon. “Conversion tools”>”Raster to Polygon”



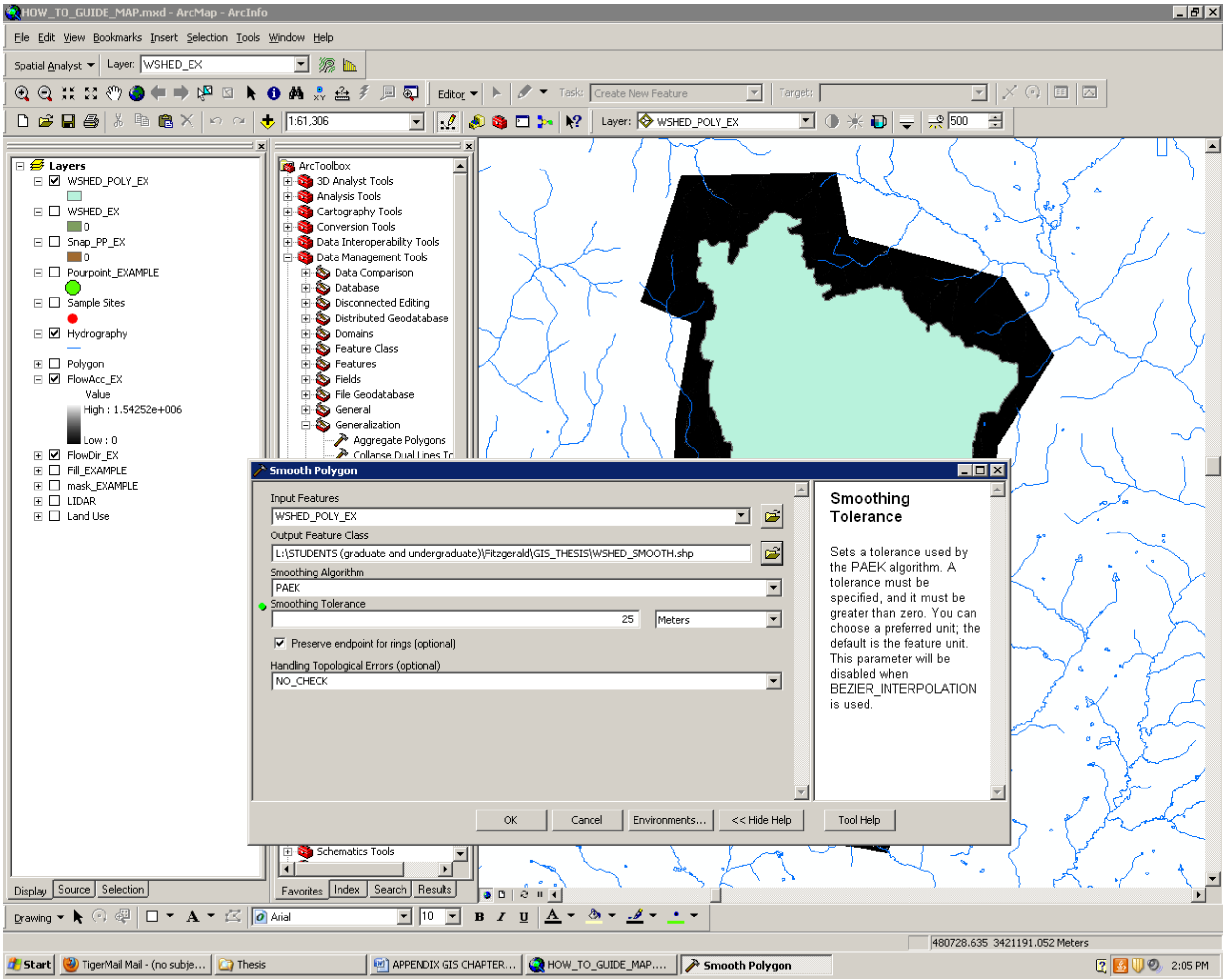
Step 3: Select the appropriate layers and execute



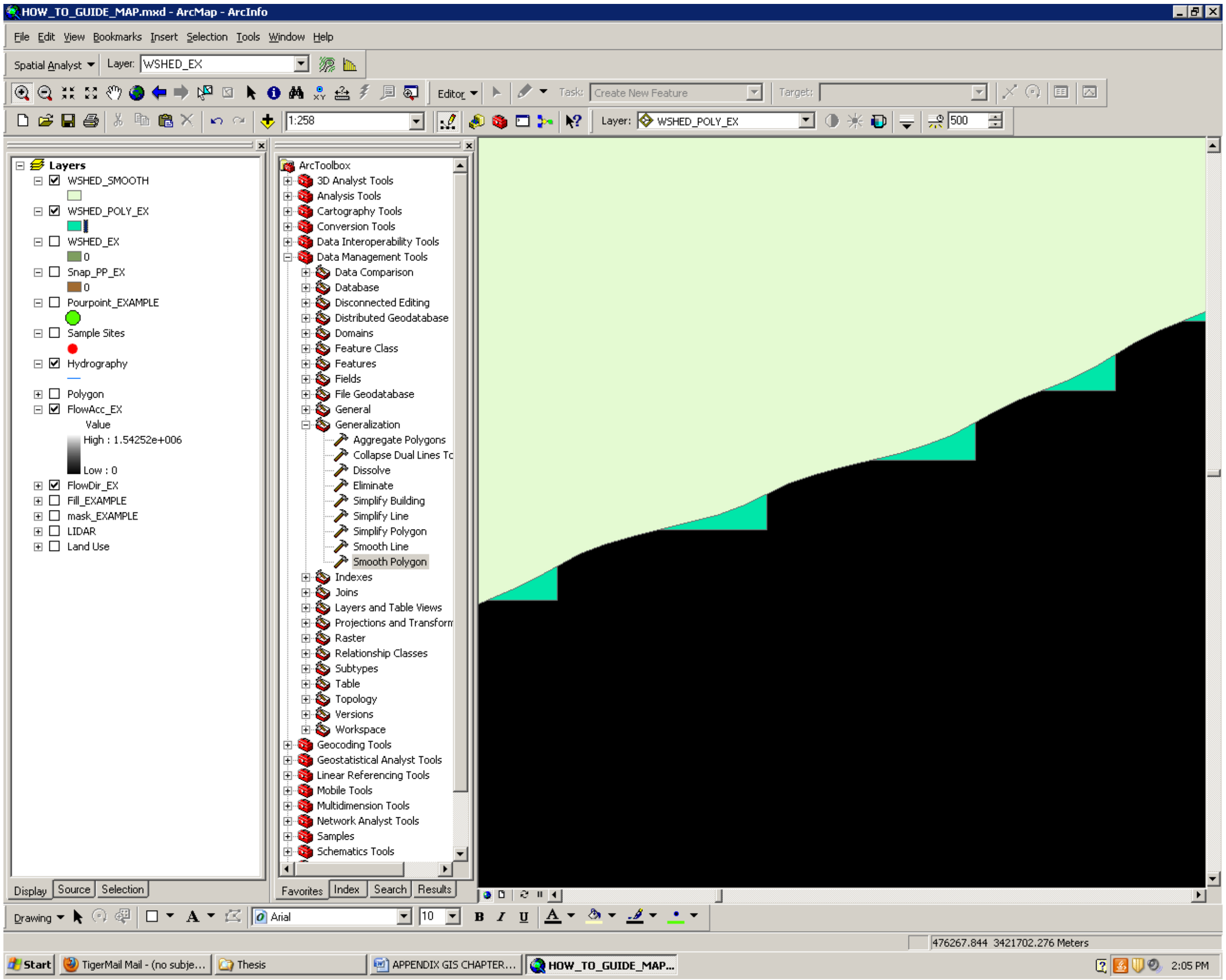
Step 4: Smooth the new watershed polygon. Select "Data Management Tools">"Generalization">"Smooth Polygon".



Polygon smoothing will provide a cleaner edge that makes raster calculations and extractions mathematically simpler and slightly more acurate.

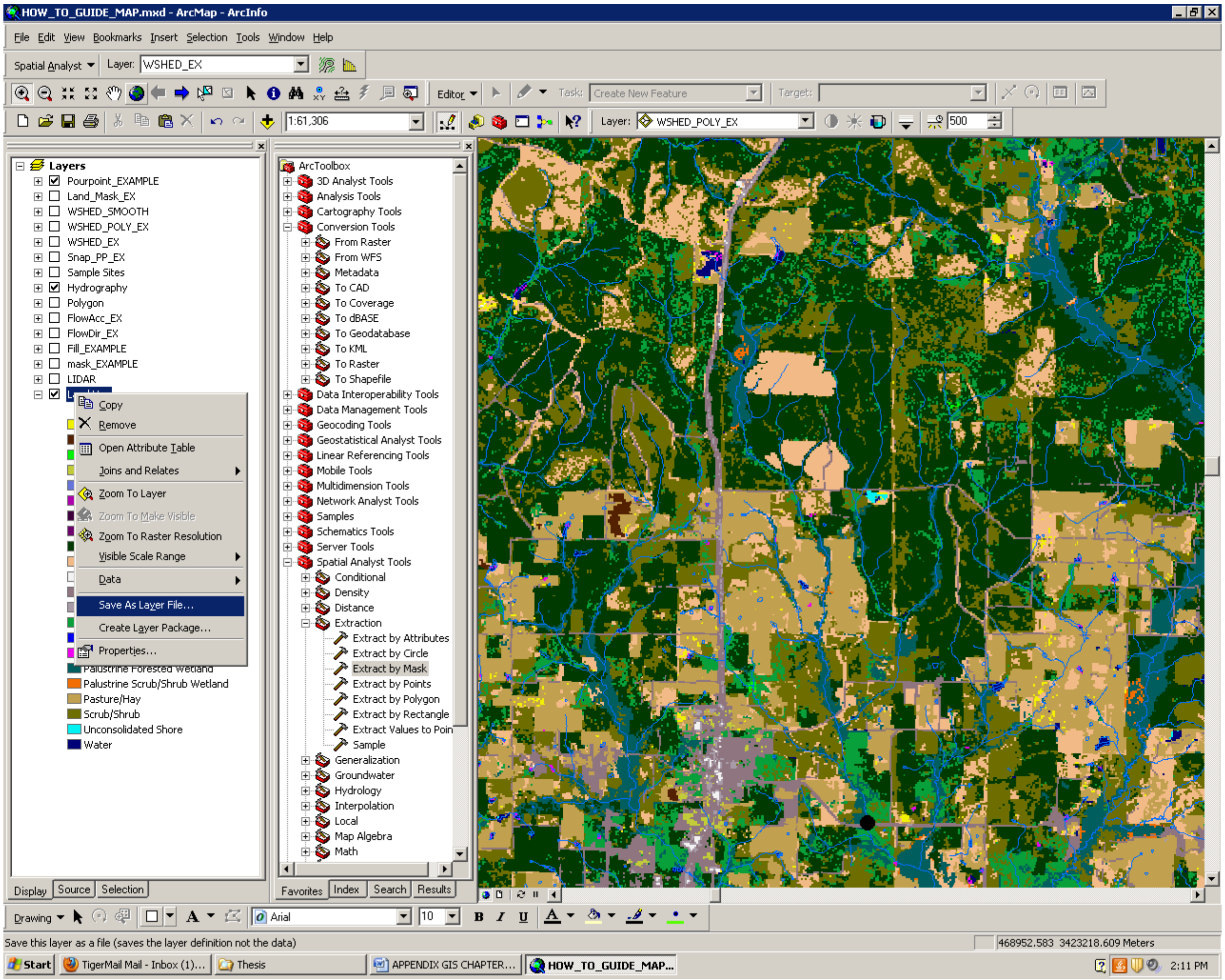


Zoom in close to the polygon edge to see the product of polygon smoothing.

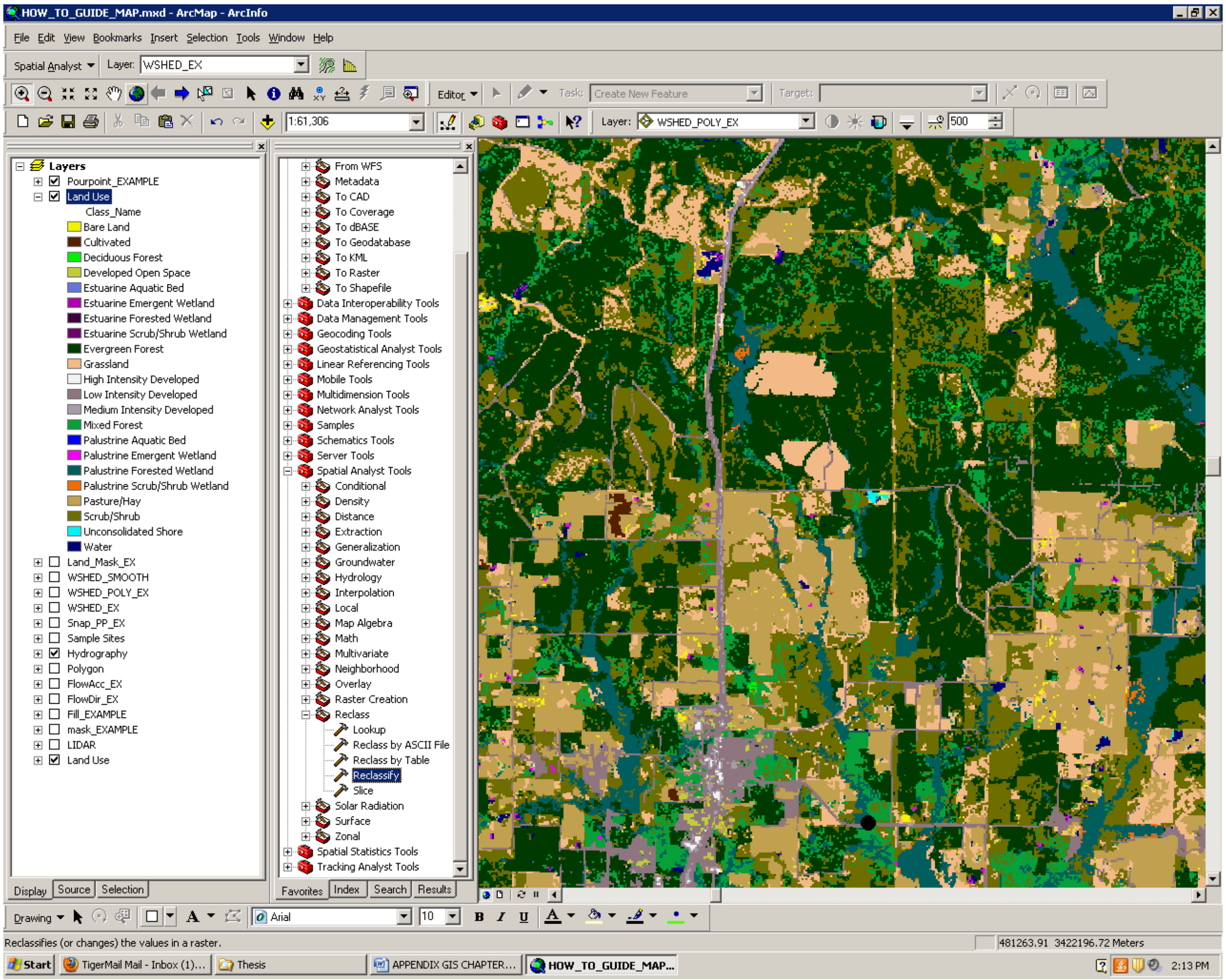


Reclassifying Landuse Raster

Step 1: Add Landuse raster to the map (if you have not already).

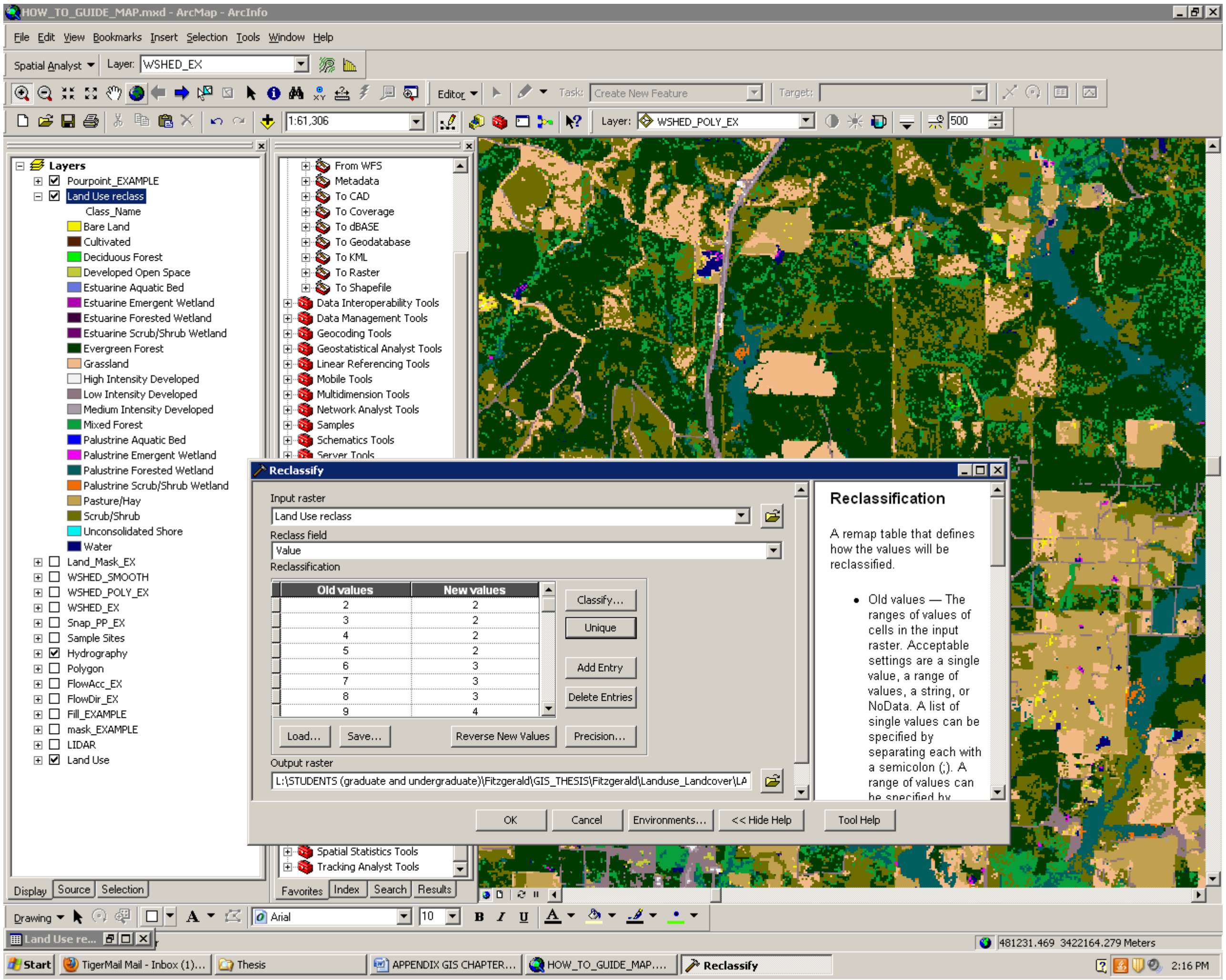


Step 2: Reclassification will depend on your indivdual objectives but in this case, I reclassified land into one of six categories: Developed, Agriculture, Forested, Palustrine, Estuarine, and Water. In ArcToolbox go to “Spatial Analyst Tools”>”Reclass”>”Reclassify”. The input raster will be the land use layer.

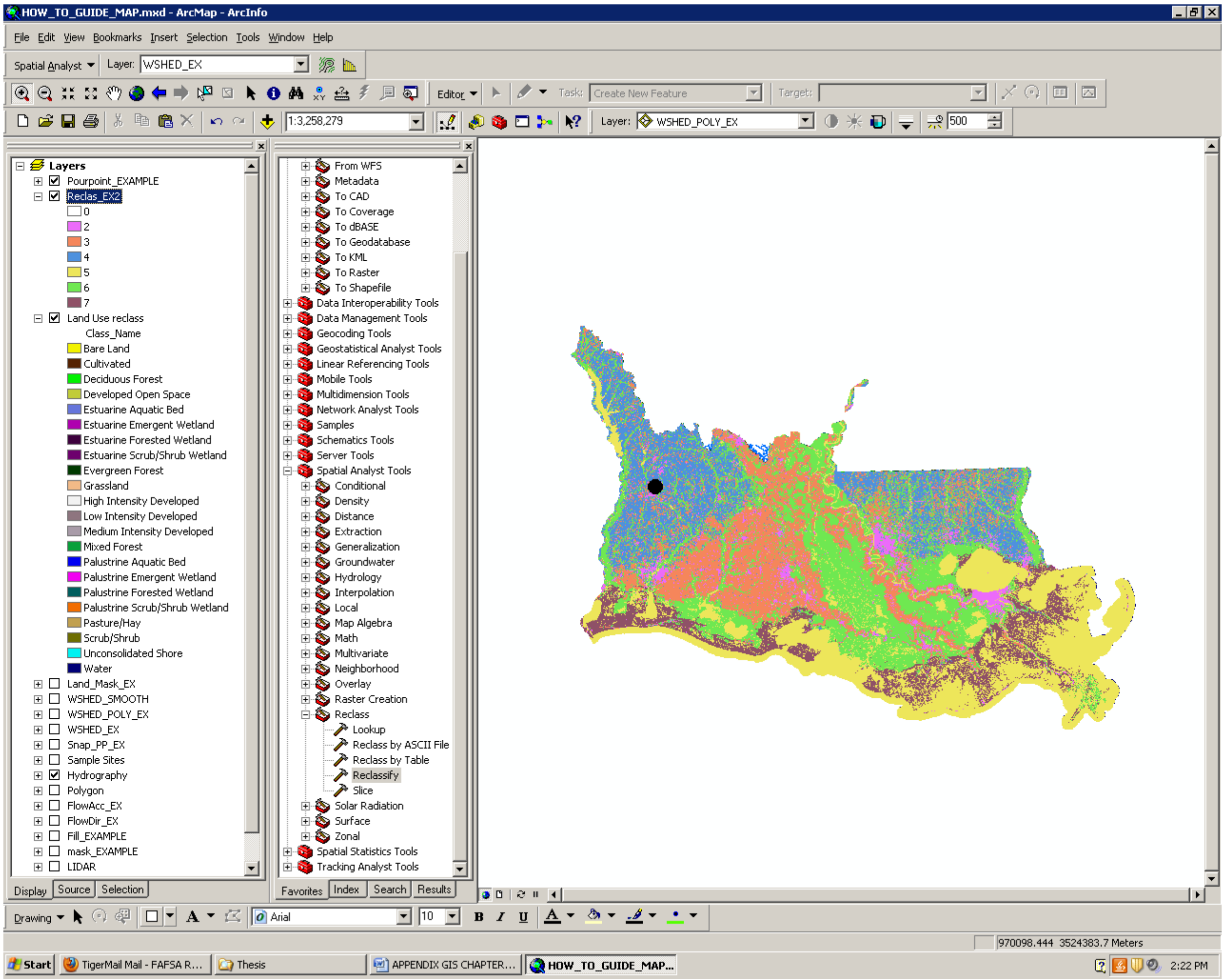


In this instance, I reclassified based on “Value” found in the attribute table.

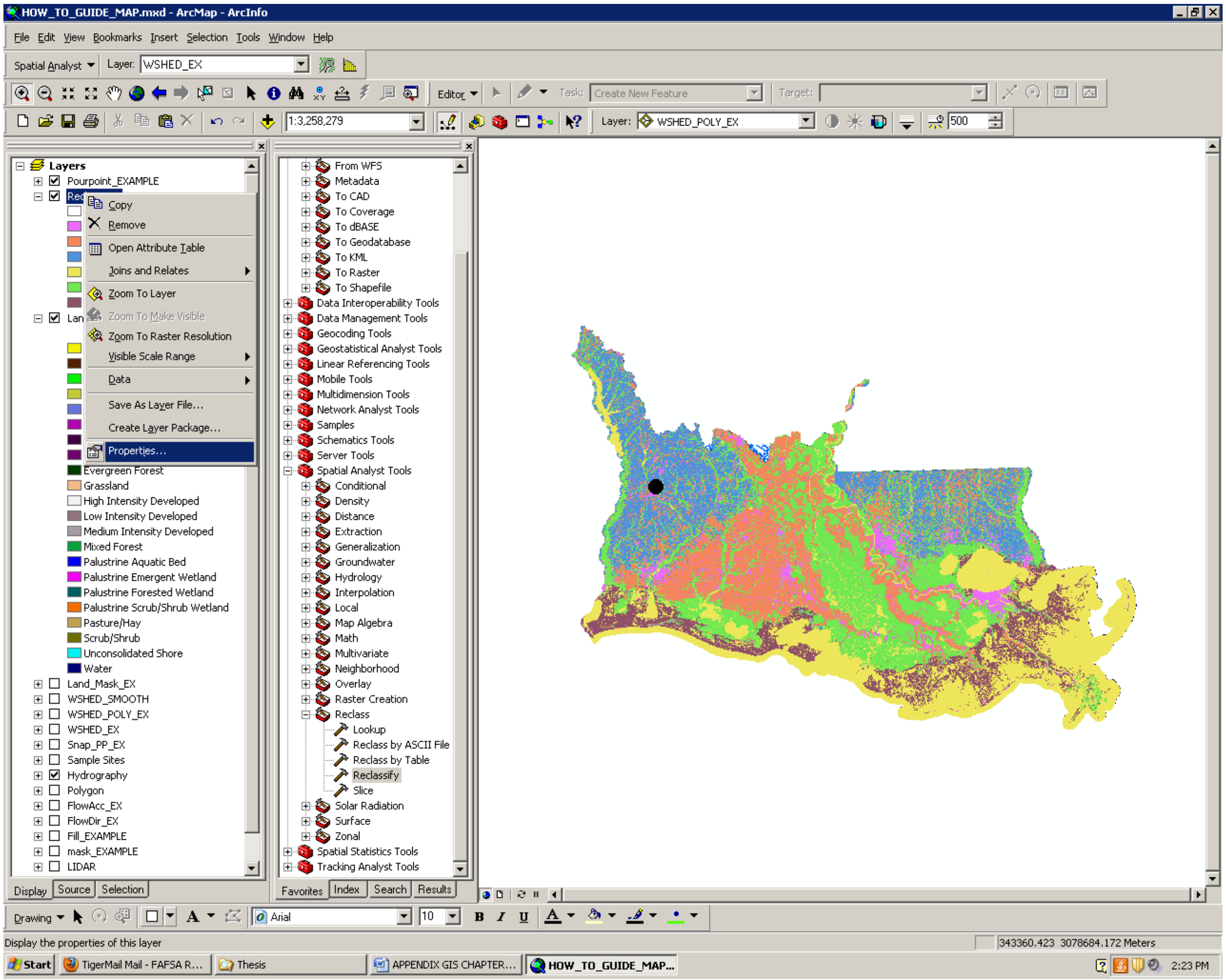
For example, values 2, 3, 4, 5, and 20 I combined into a single “Developed” category, setting them all to a value of “2”. Set the values in the “new value” column appropriately if you are trying to reduce your land use categories. (This is optional. If you prefer to have a multitude of specific land classes, do not reclassify).



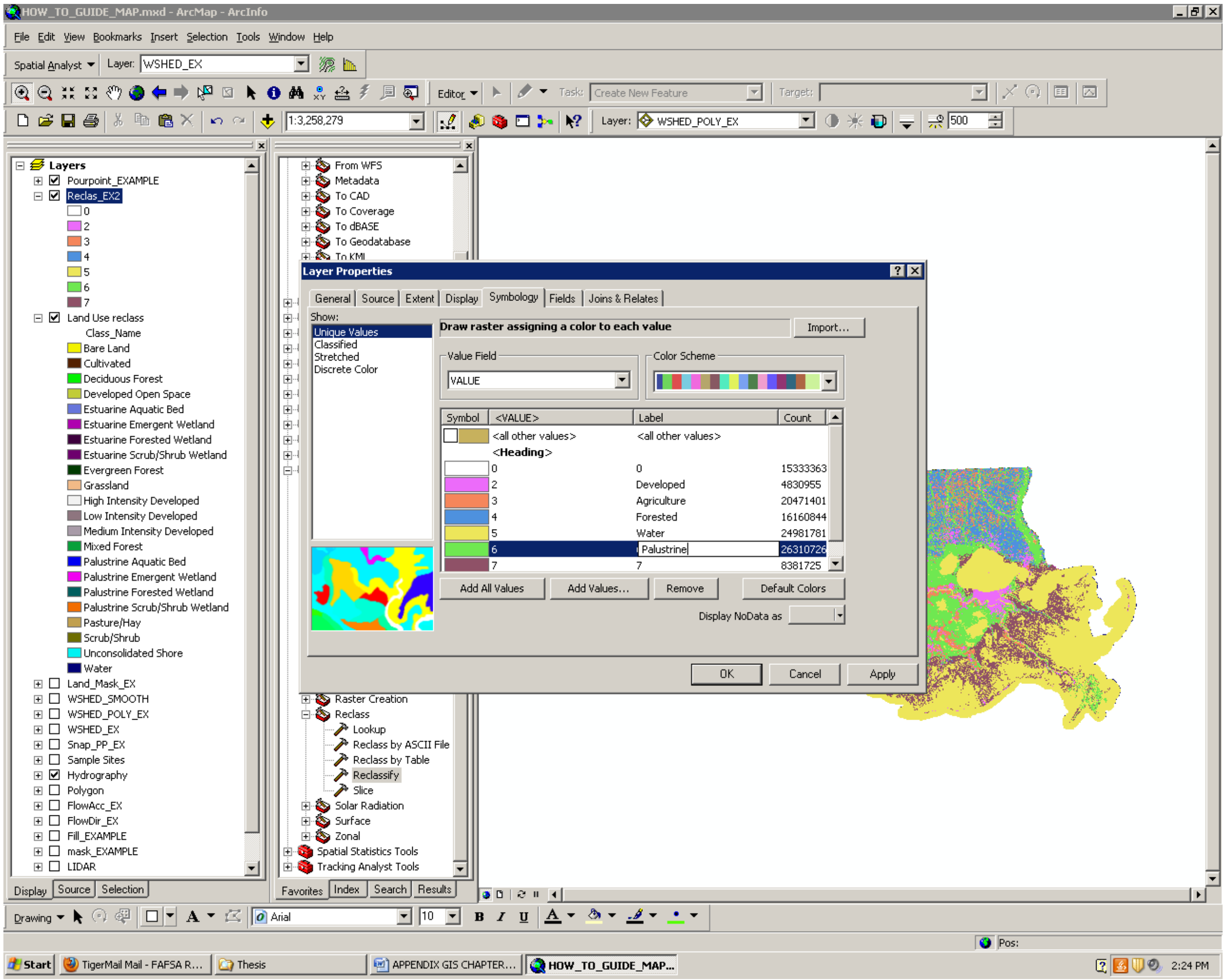
After reclassifying, you should get a map that looks something like this:



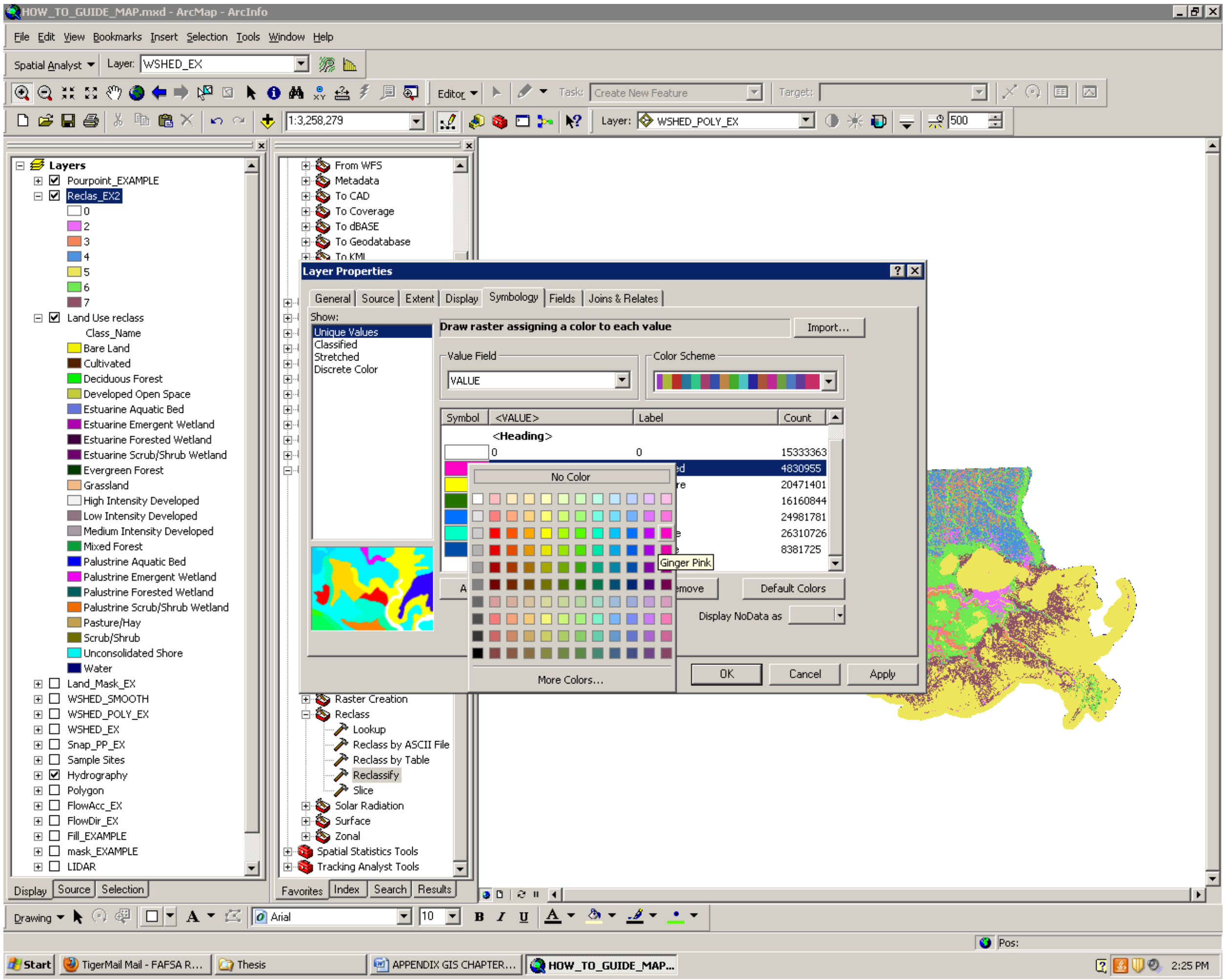
Step 3: You will notice that each color does not have a corresponding land use in the attribute table. You have to double-click the layer and manually add them in. Choose "Properties">"Symbology".



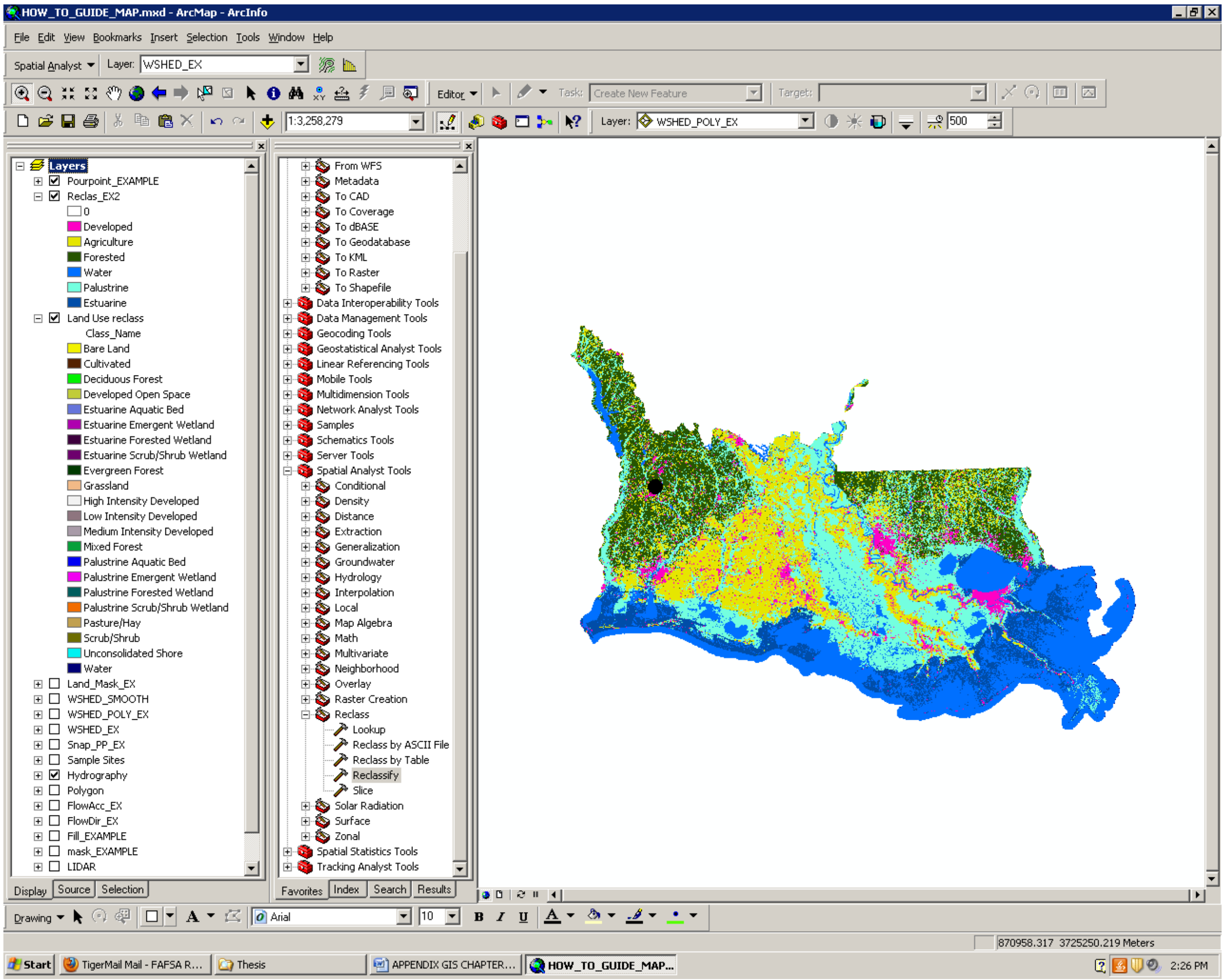
Step 4: Manually change the display captions.



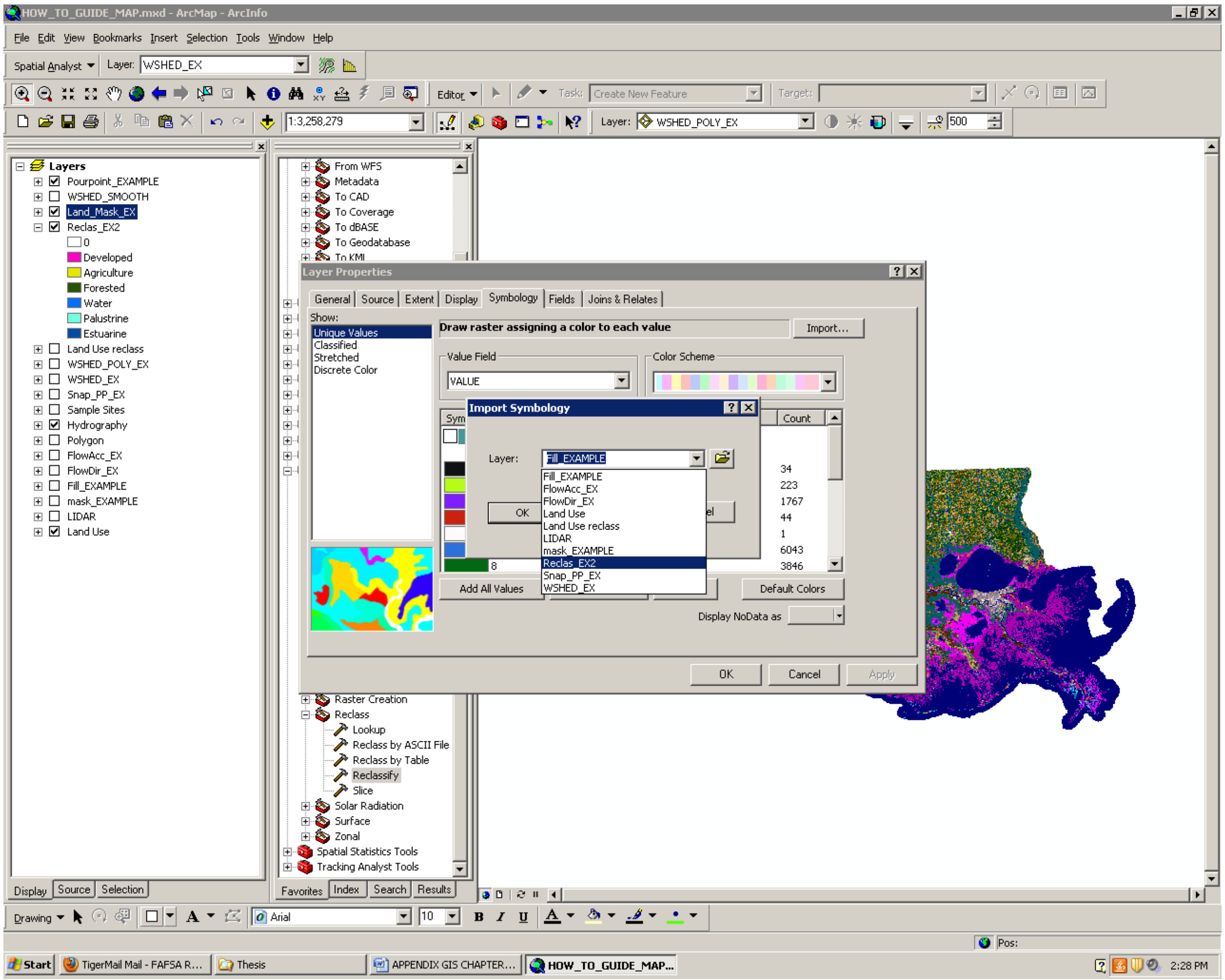
Step 5: Now select the colors to appropriate for your maps.



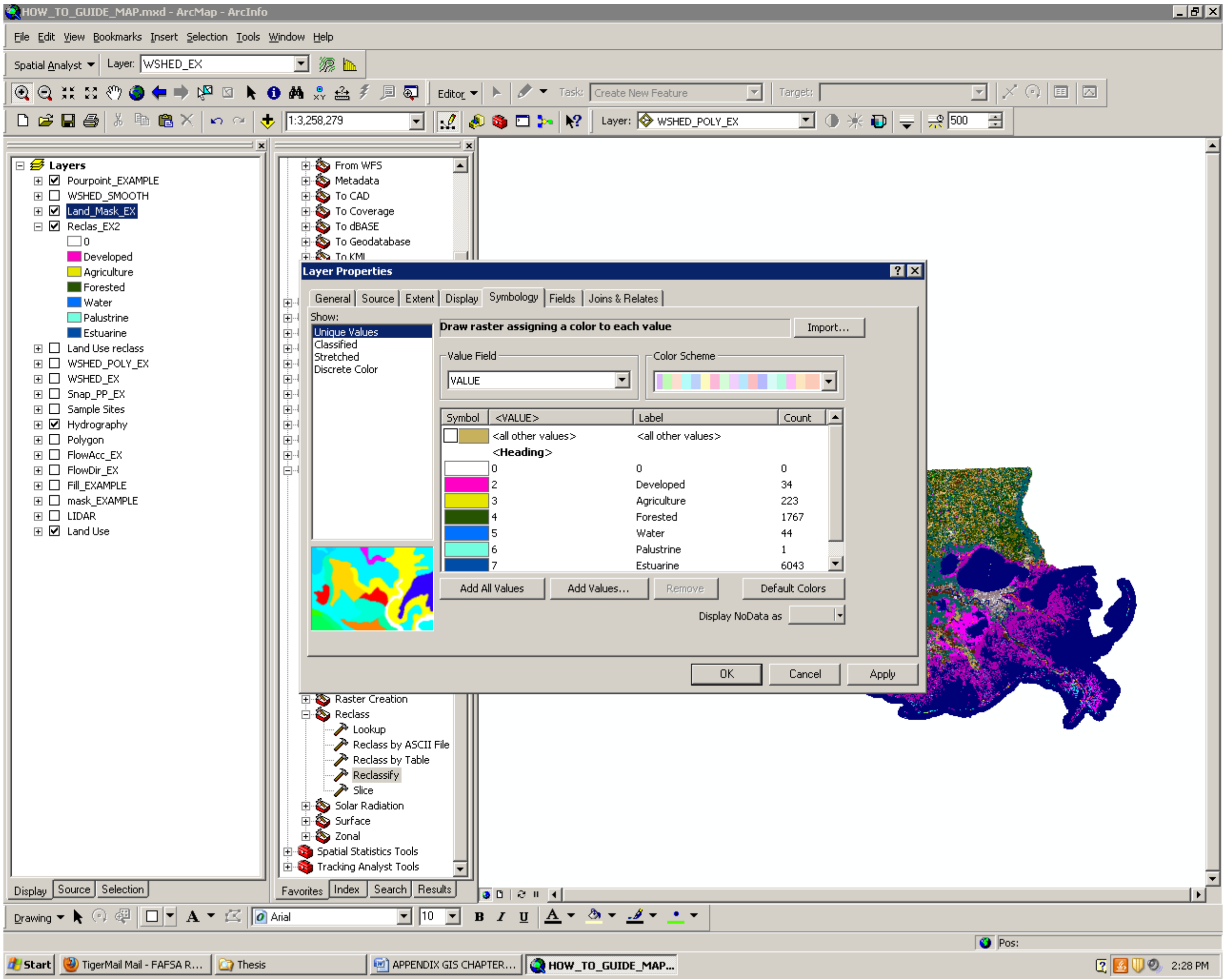
The finished product will look different from the beginning of the step as seen below.



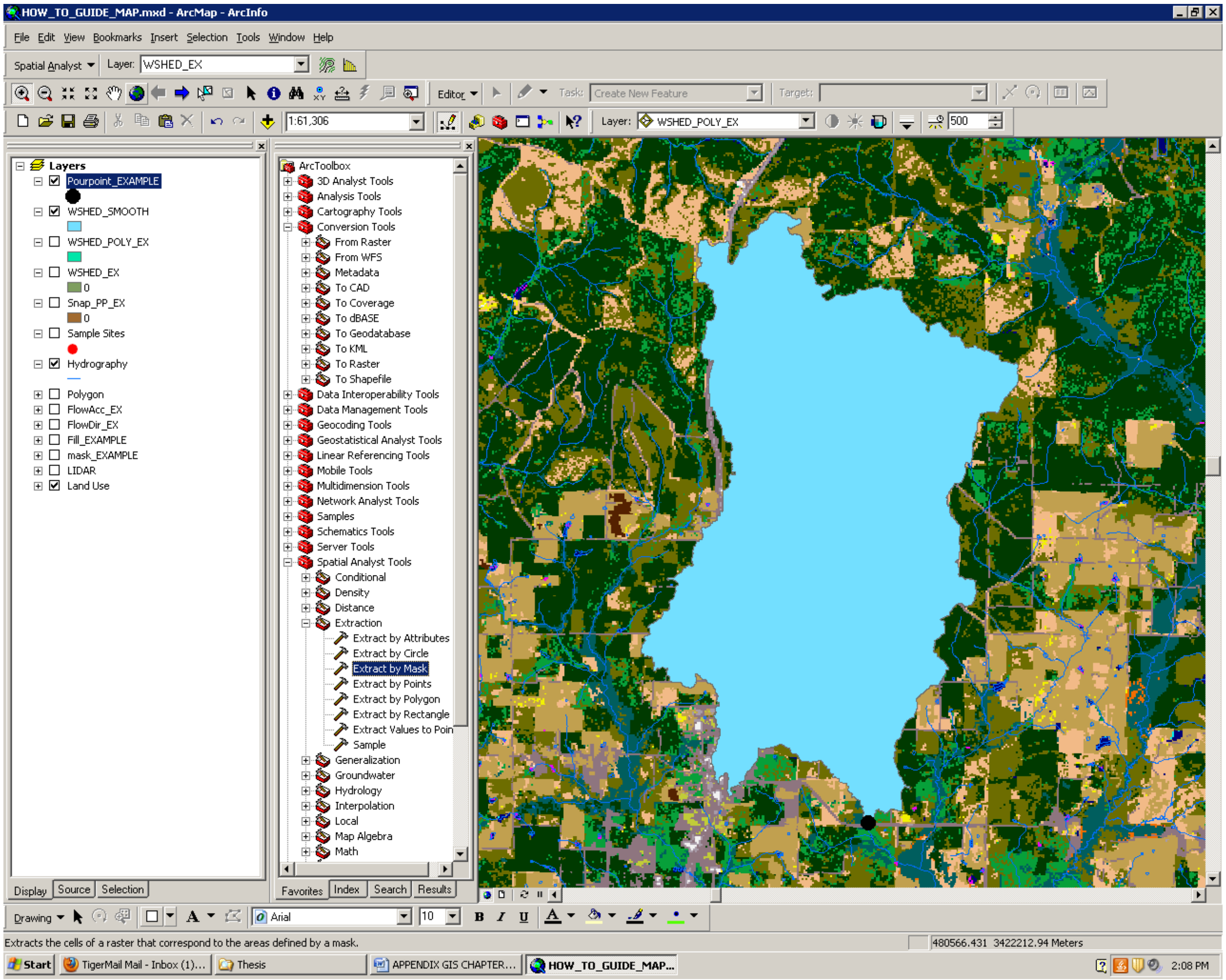
TIP If reclassifying multiple rasters to the same symbology it is possible to import the symbology from another file. Simply click the “Import” button and navigate to the appropriate file and choose the proper identifying field such as FID, ID, Value, or another field you have created that will hold the same values as the file you are modifying.



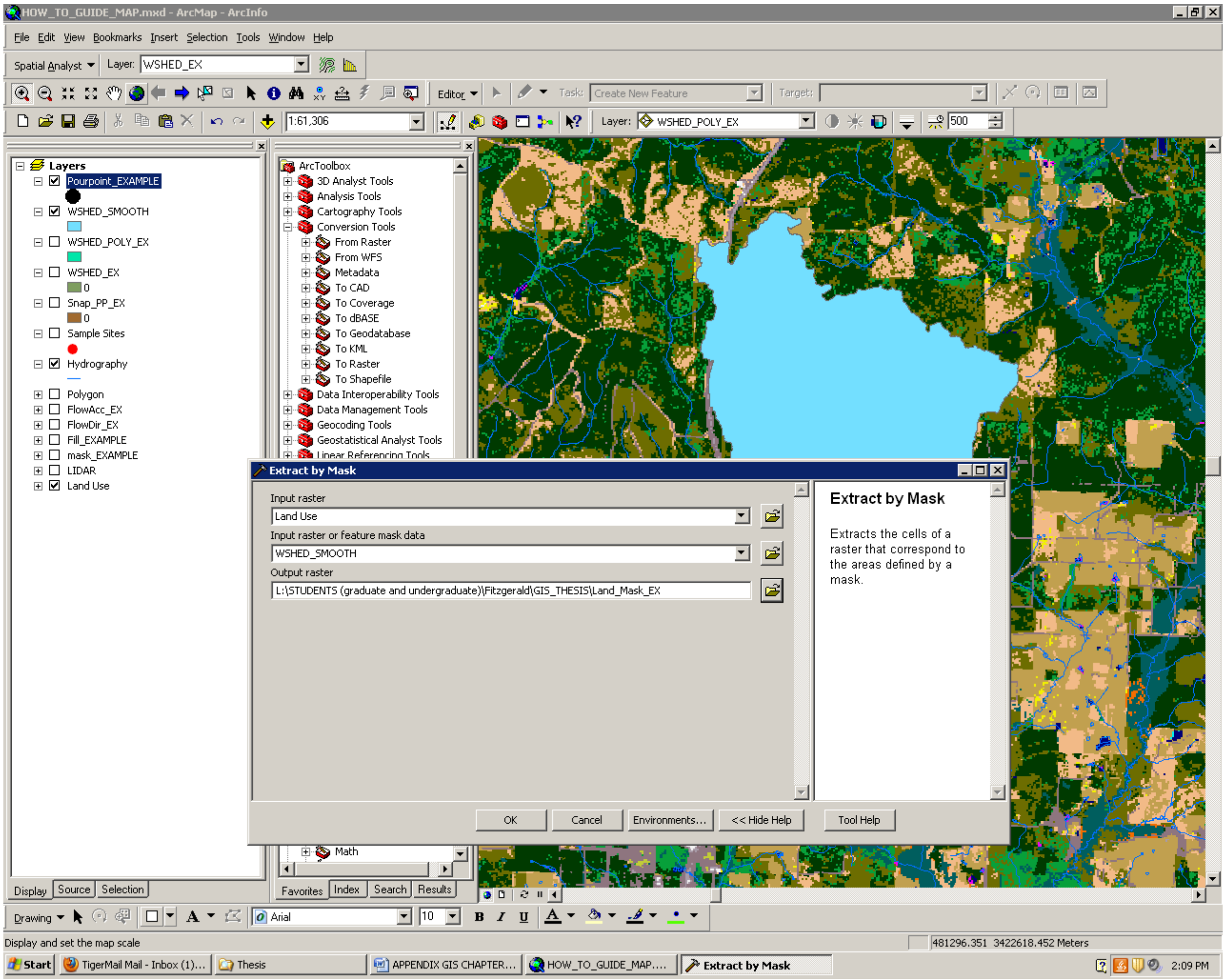
Once the Import is complete, the two layers should look and display identically.



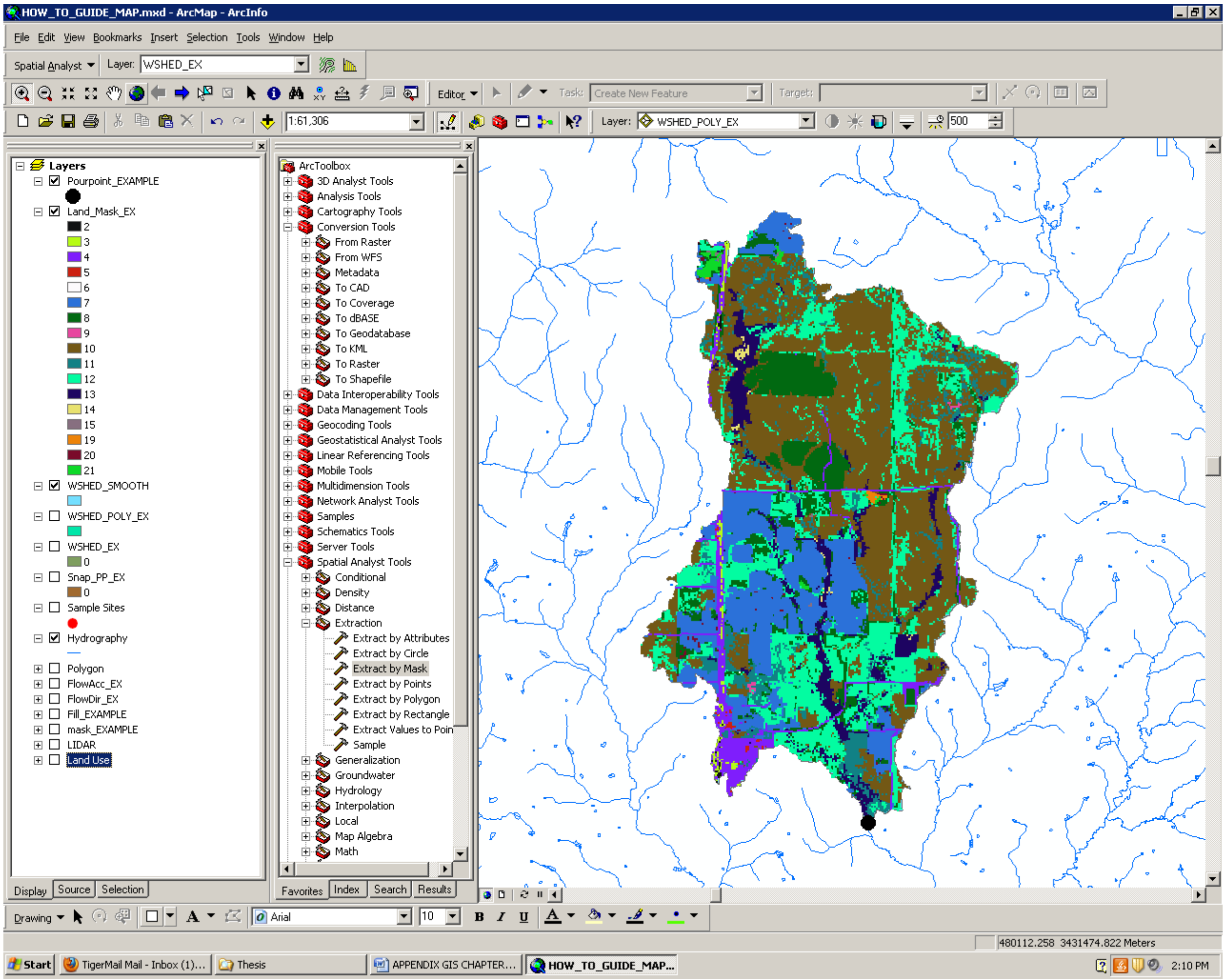
Step 6: Extracting reclassified landuse to the smoothed watersheds you created. Select “Spatial Analyist Tools”>”Extraction”>”Extract by Mask”.



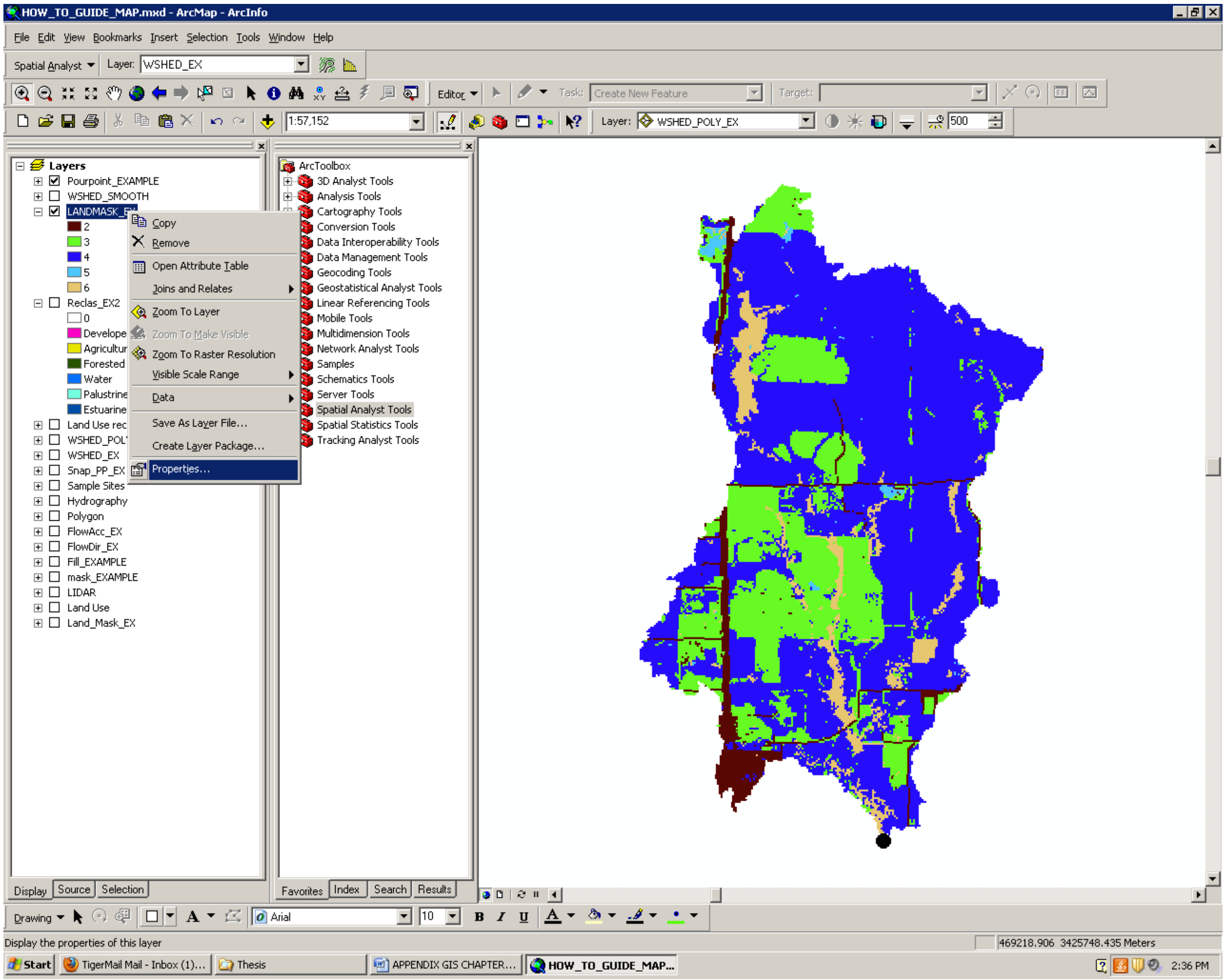
Extracting by mask is necessary because you cannot clip a raster to the form of another raster, or shapefile. The watershed polygon is used to create a snapshot of the land-use raster data.



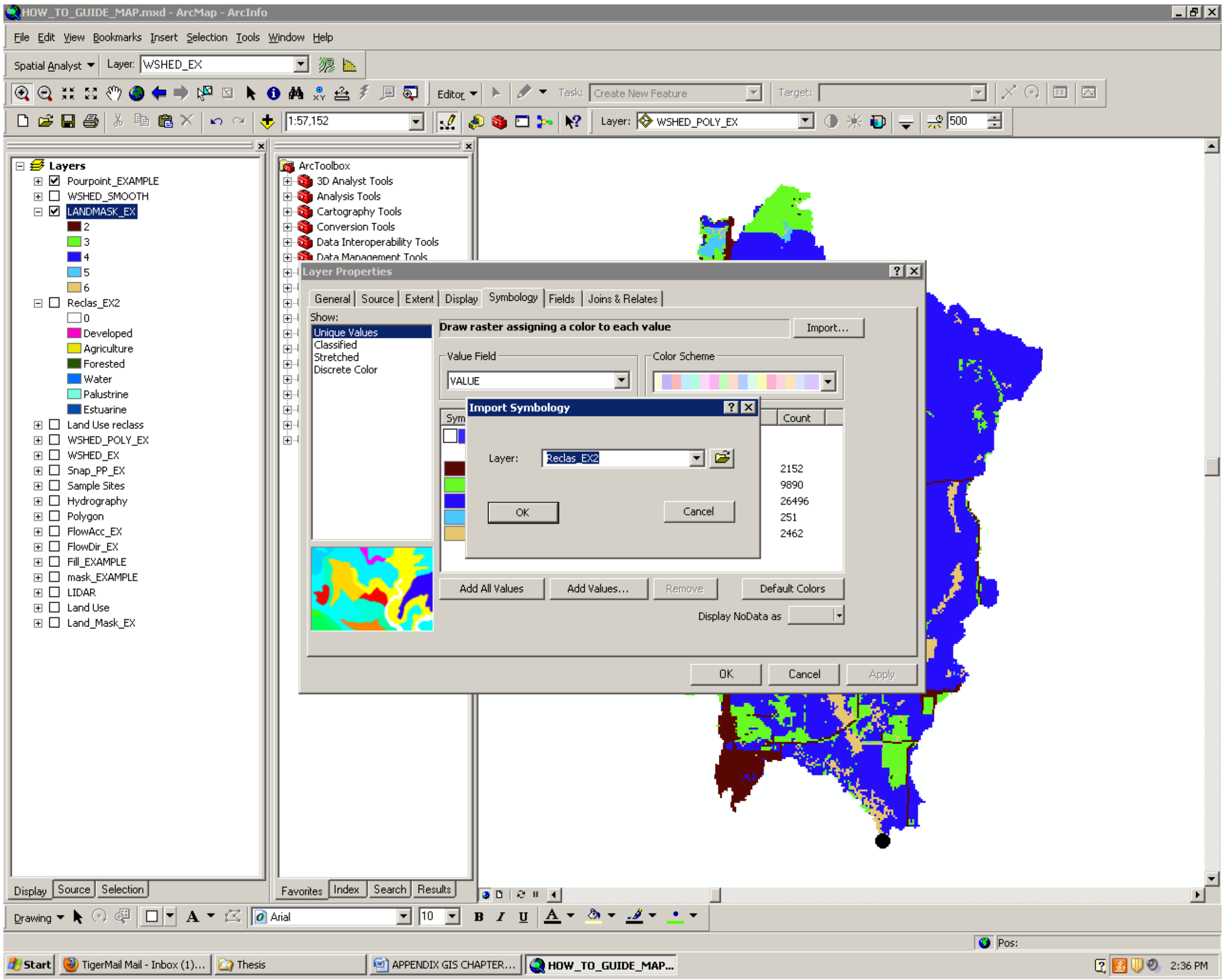
The new raster extraction is the land-use data only within the watershed polygon. The color scheme associated with the new watershed land-use may not be the same as with the NLCD classification. This can be changed in the next step.



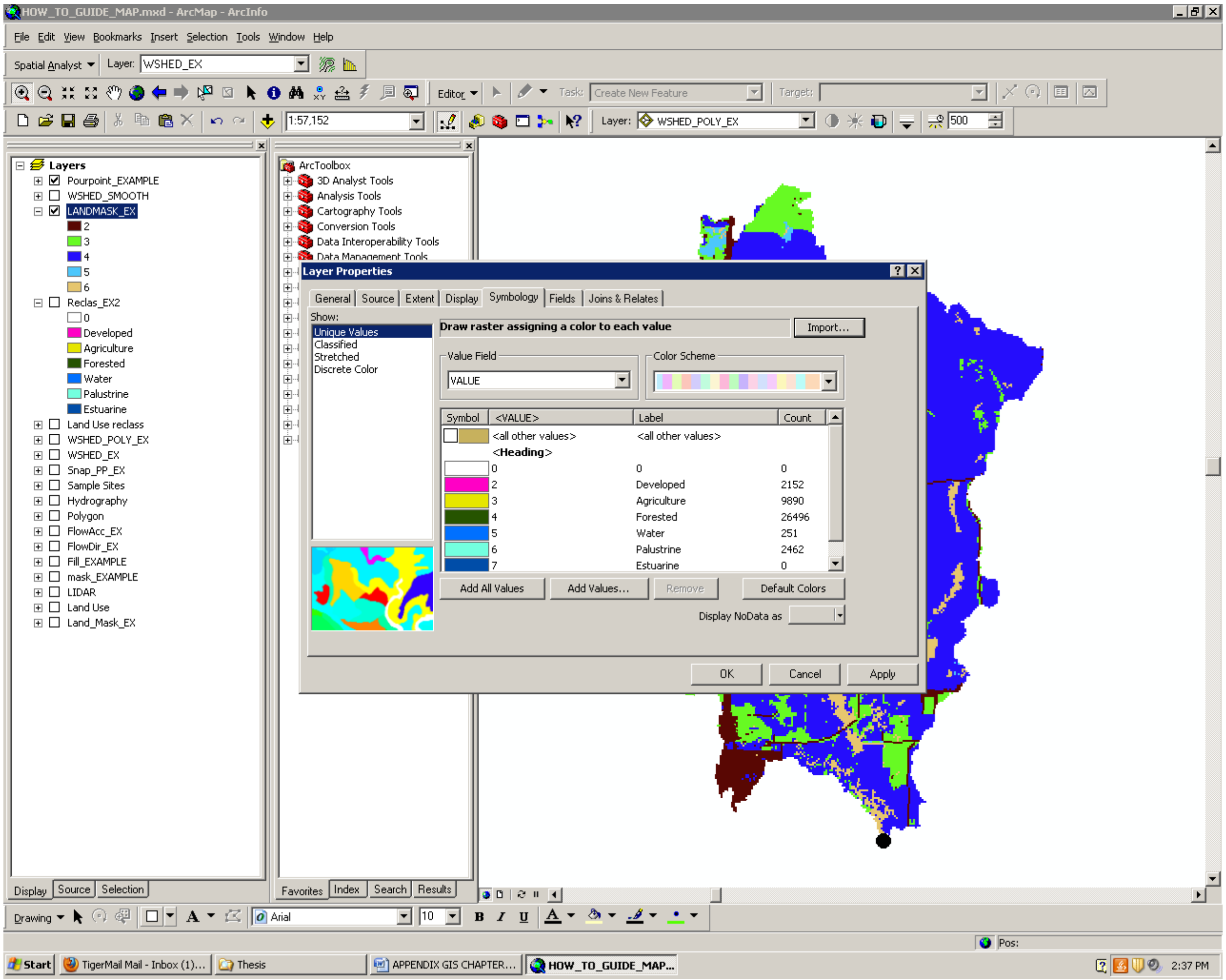
Step 7: Reclassify the new watershed land-use to the same symbology as the above land-use raster. Go to “Properties”>”Symbology”



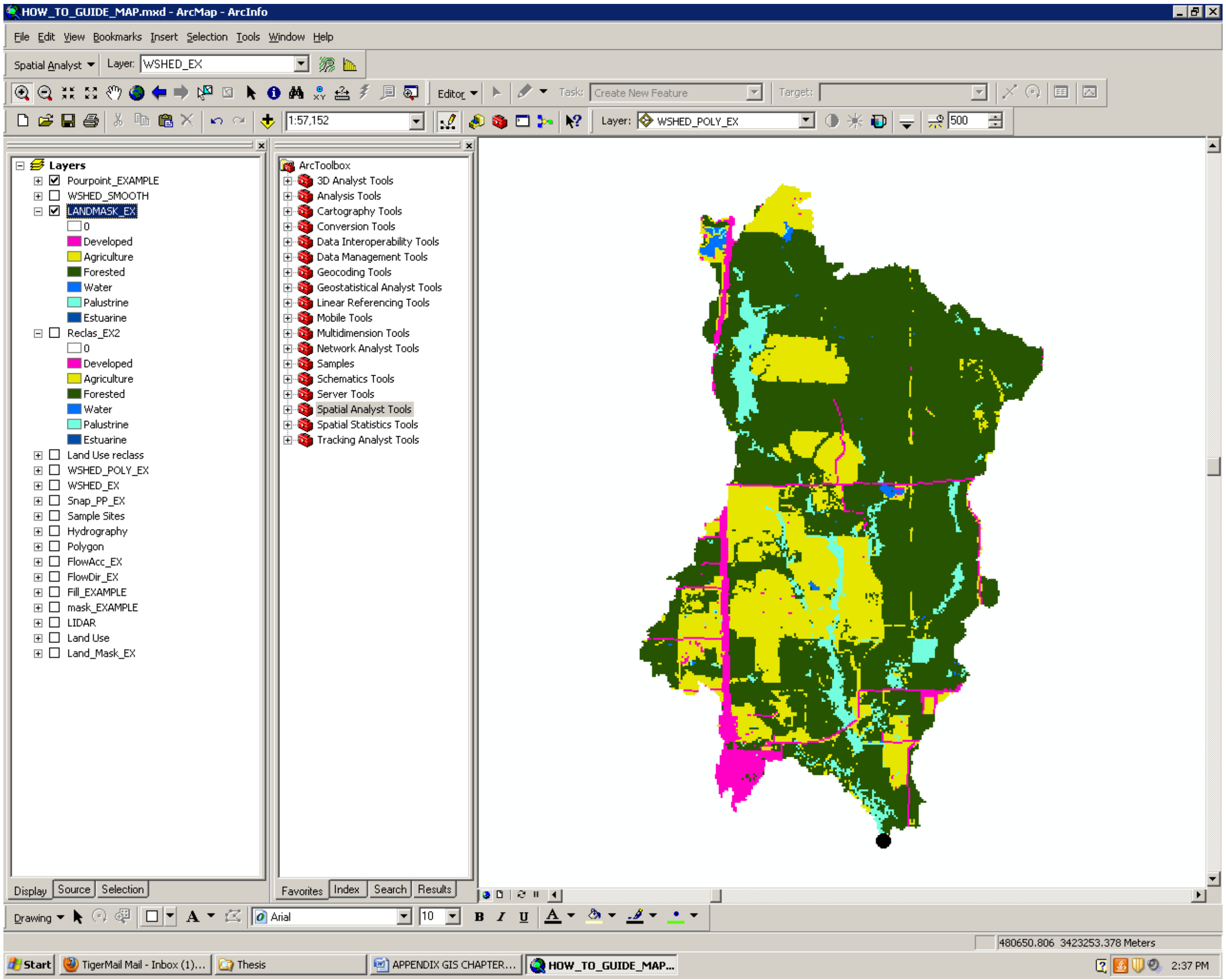
Step 8: Click "Import" and select the appropriate file to import.



Again, you will see the appropriate symbology has been assigned to the watershed land-use.

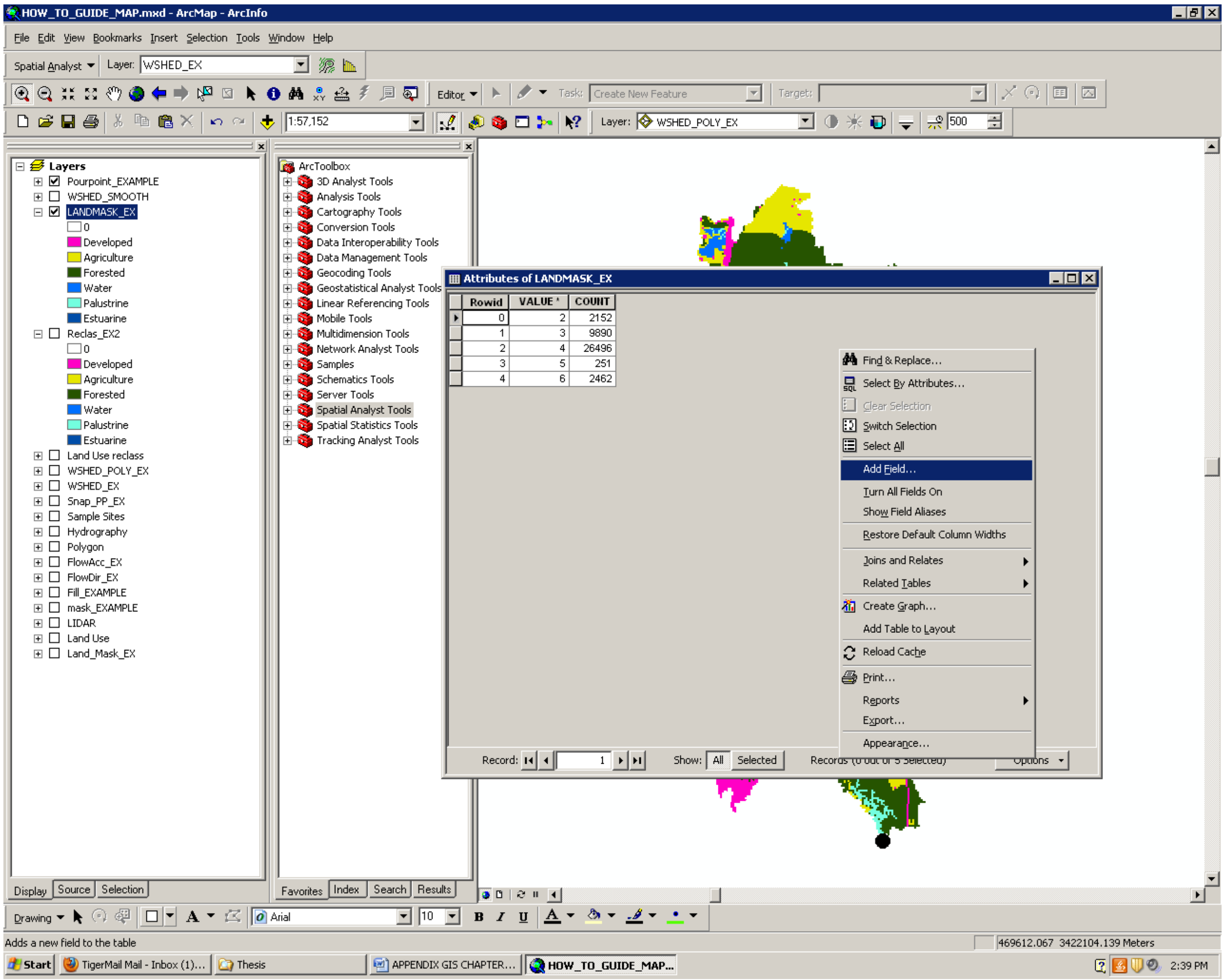


The final product.

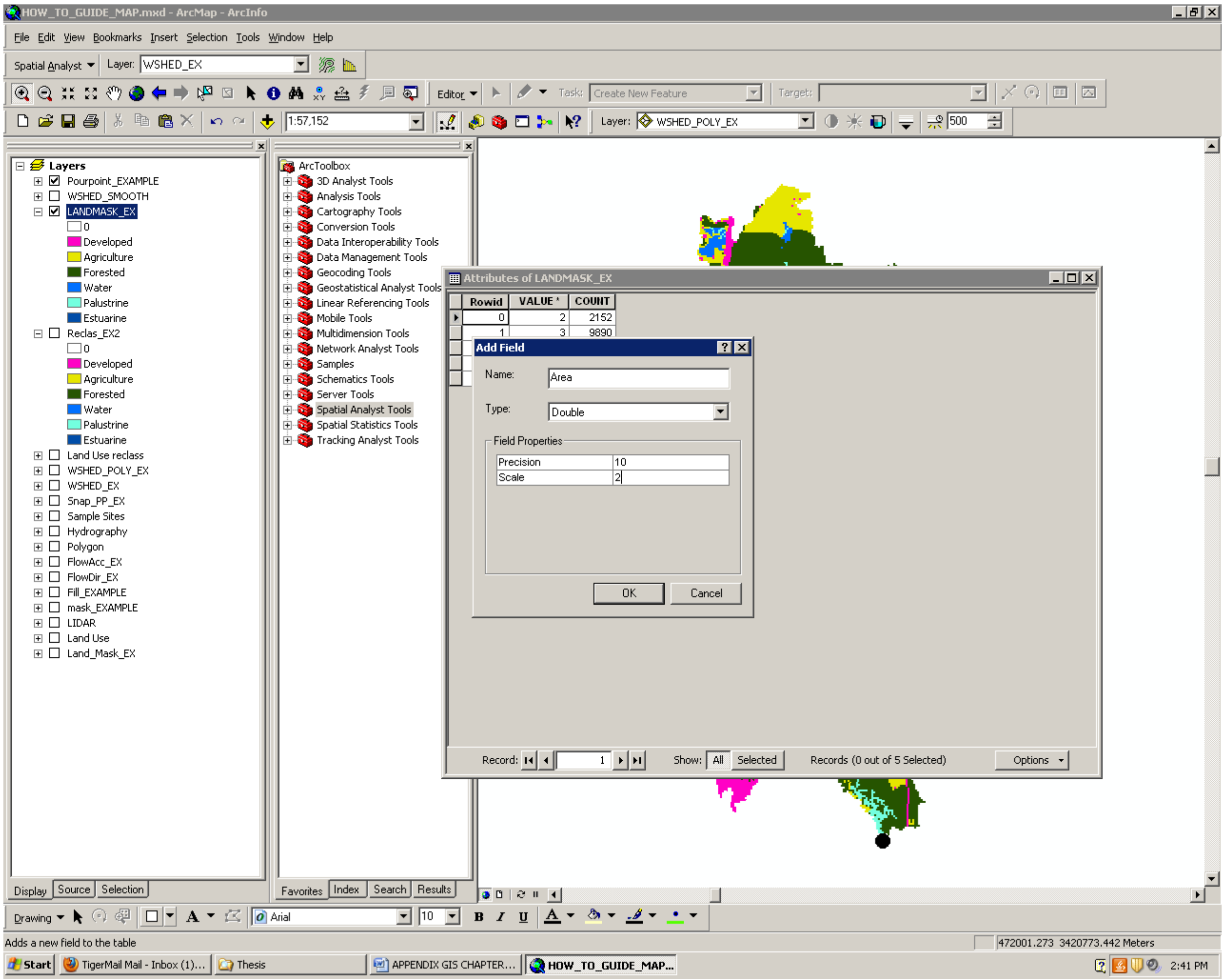


Calculating Land Use Area

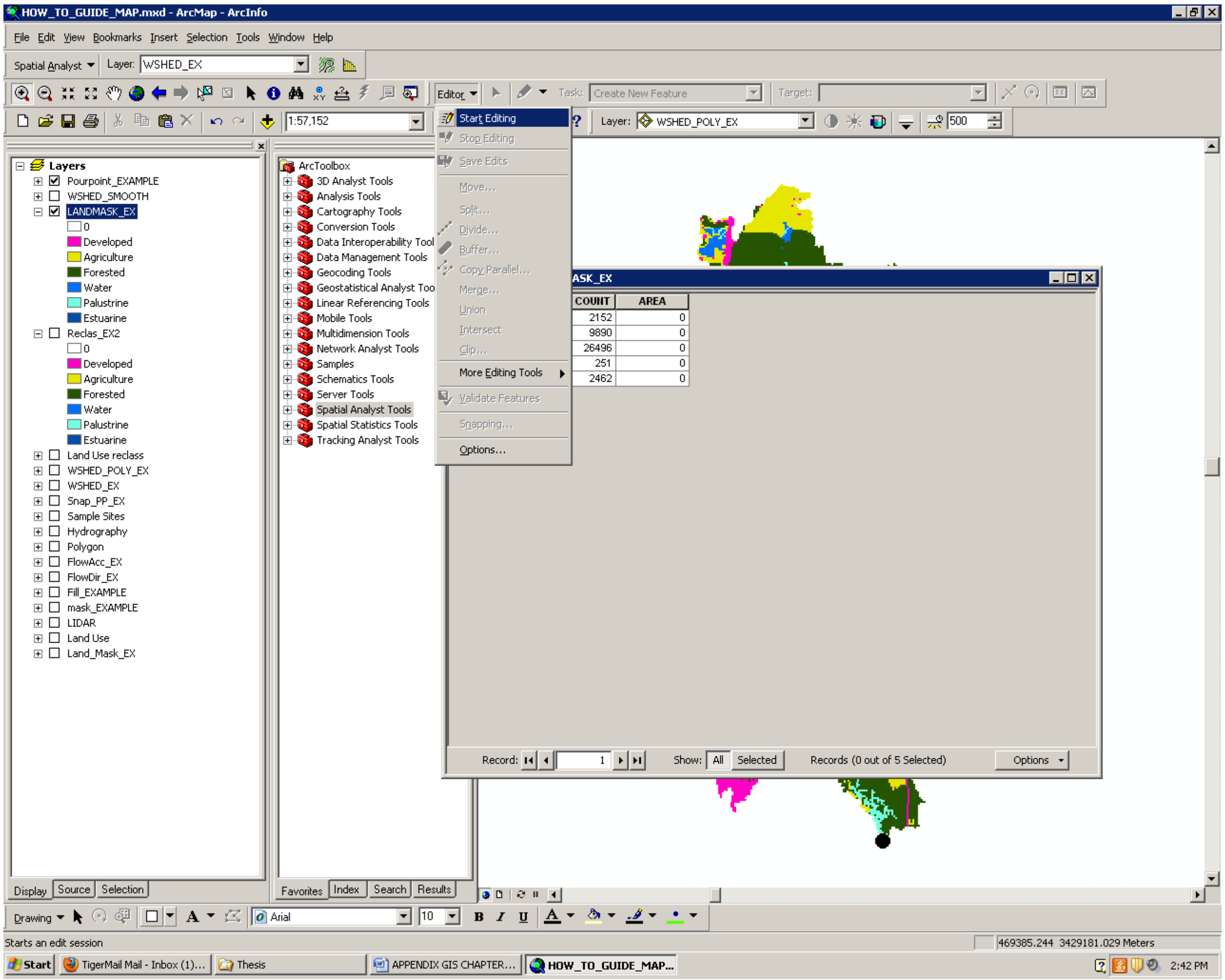
Step 1: Now it's time to calculate the area in each land use type. Open the attribute table of the watershed you're working with. Don't be alarmed if it doesn't have every one of the land classes labeled. It only shows the ones that are actually present. Click "Options">"Add Field"> and create a new field called "Area".



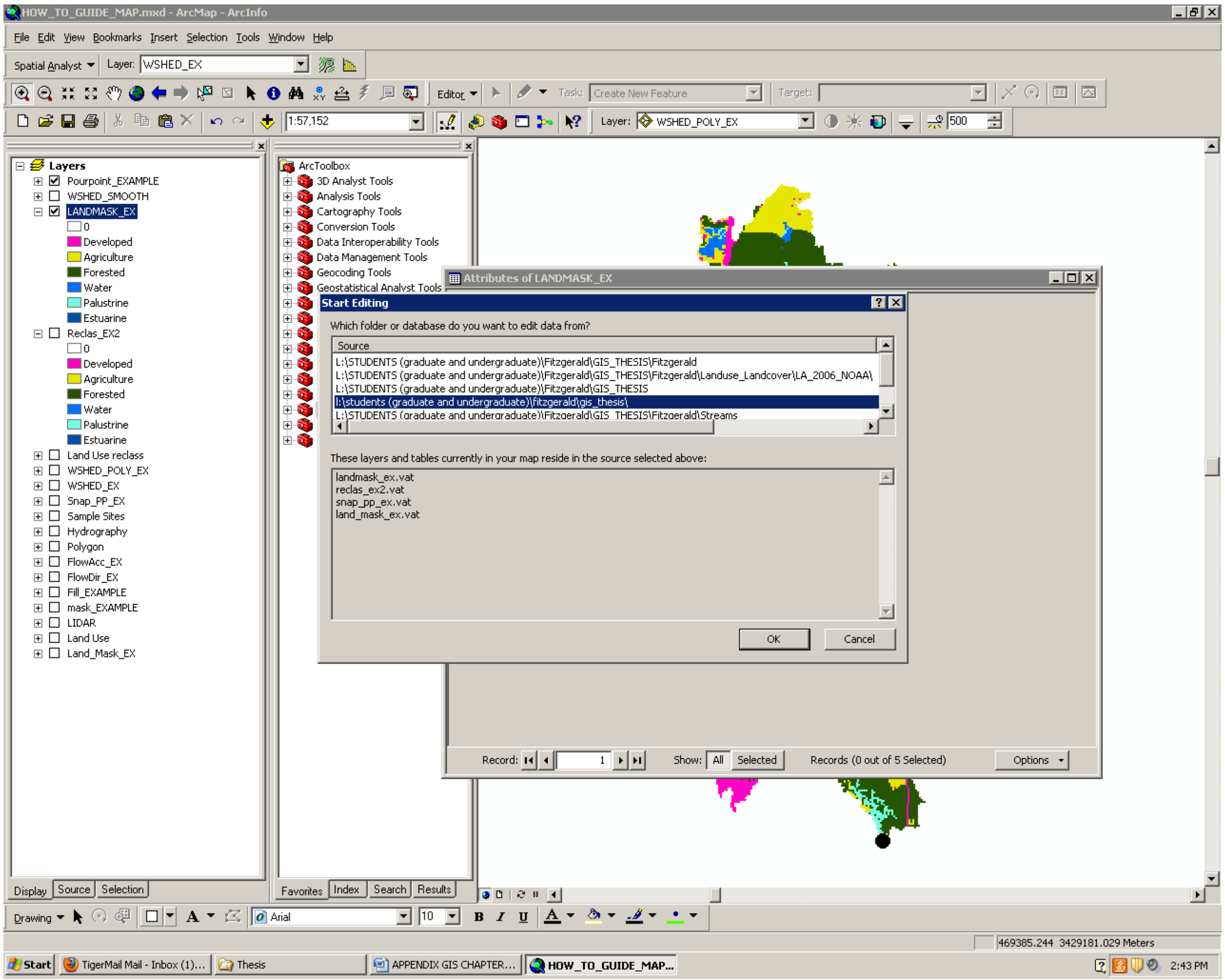
Step 2: Set as “Double” with a precision of 10 and a scale of 2. Click “OK”



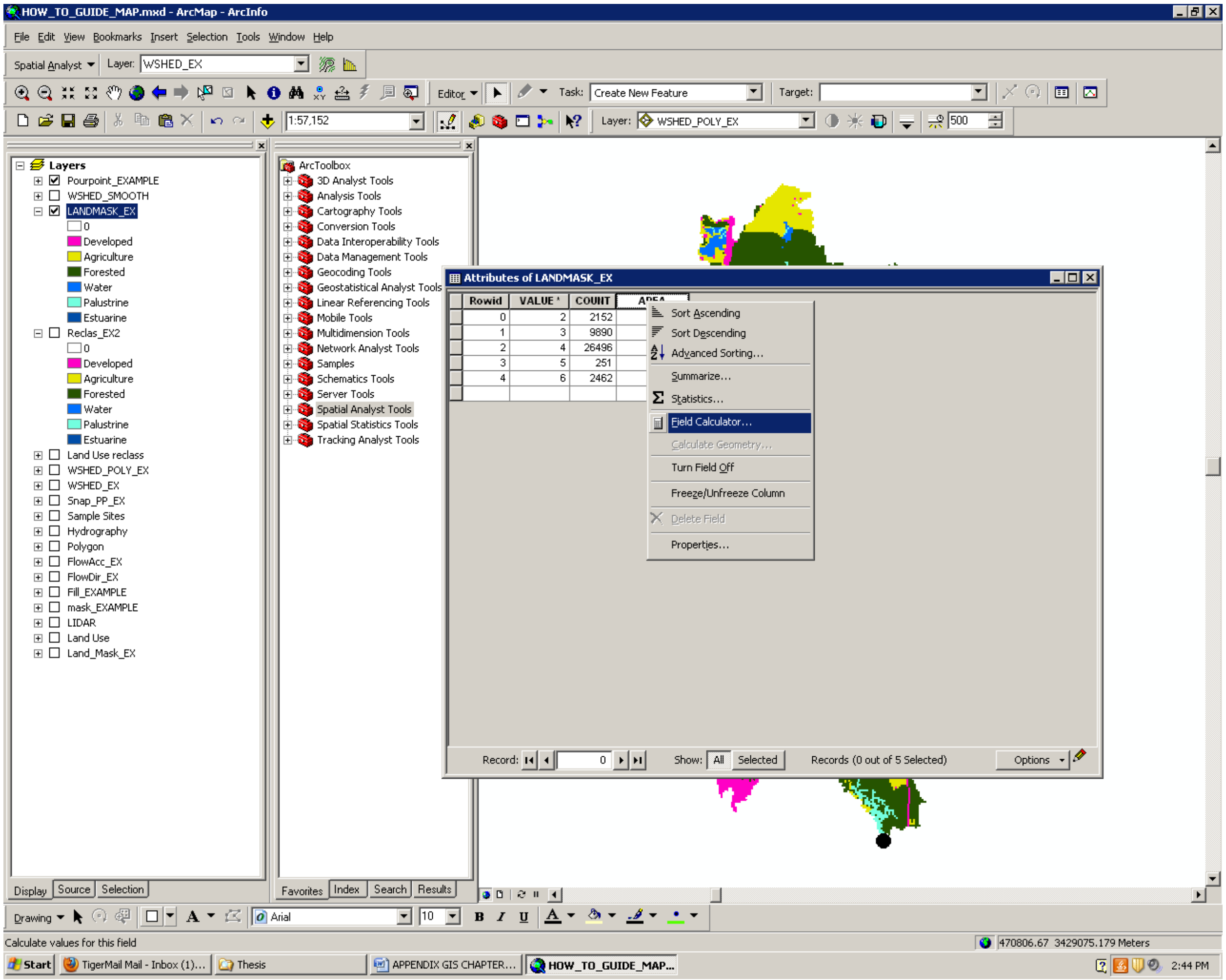
Step 3: Click “Editor”>”Start edits”



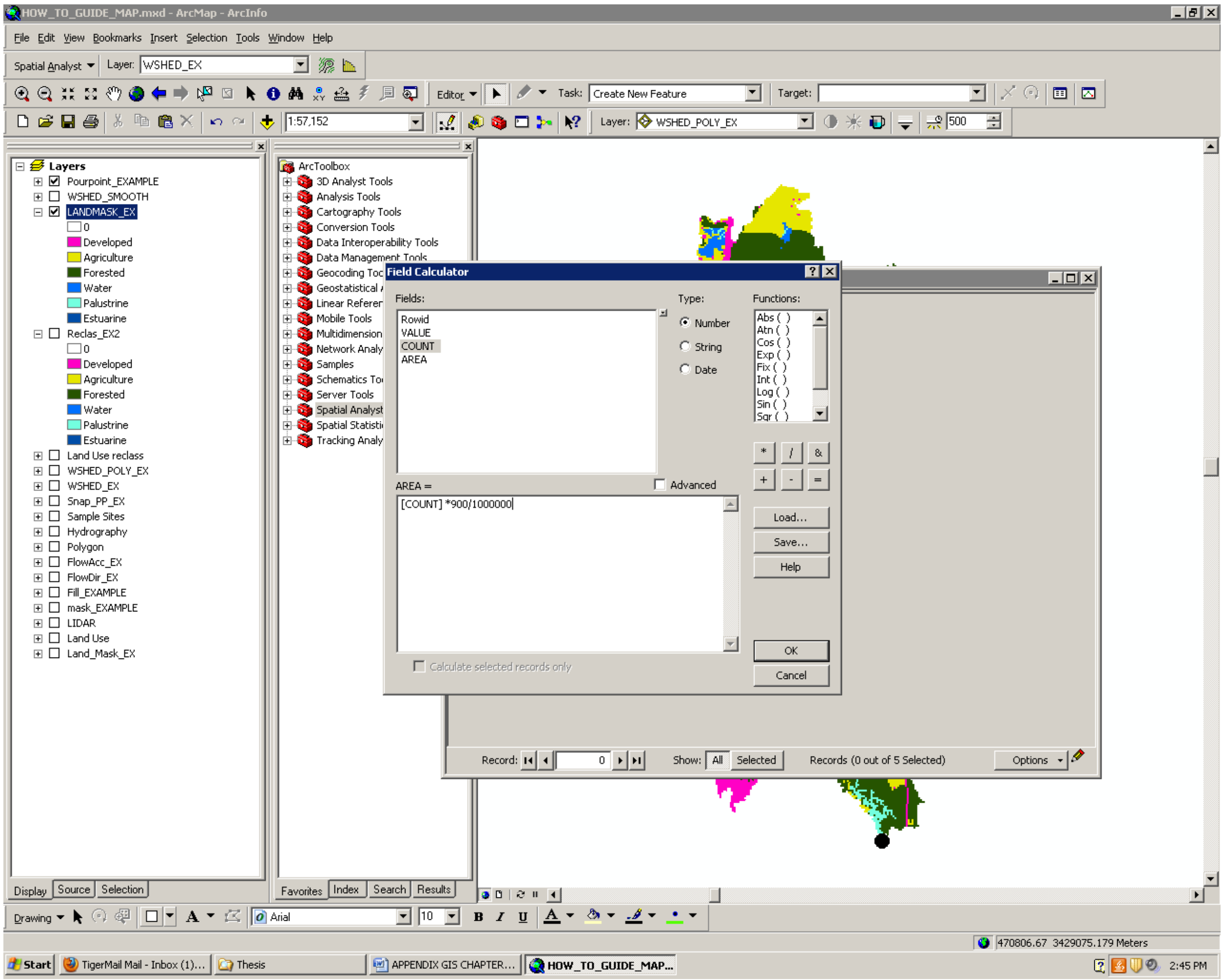
Step 4: Select the file path that contains the land use layer you're working with.



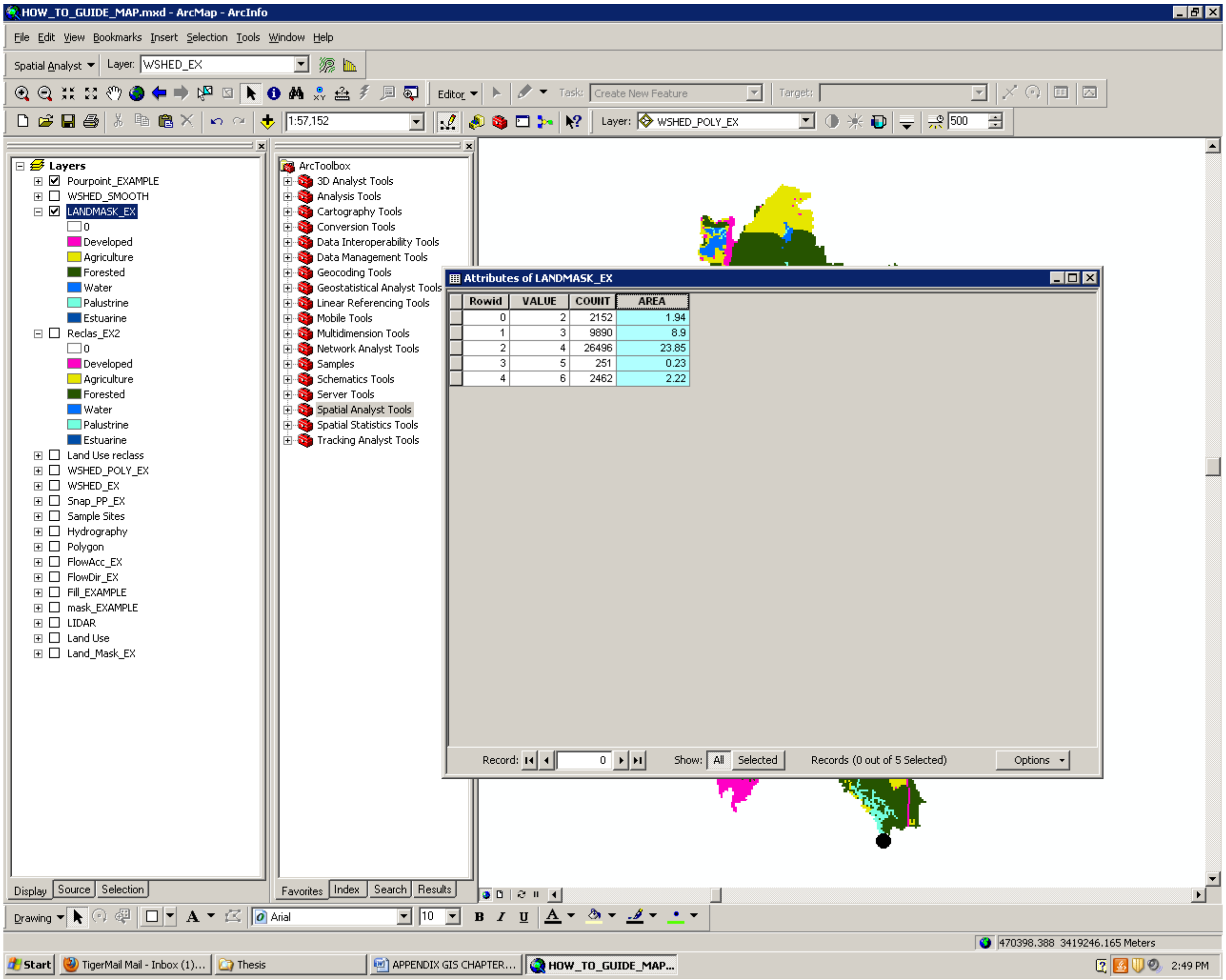
Step 5: Click "OK". Right-click on the field called "Area" and click field calculator.



Step 6: For this project we are calculating land use in km². Here you need to know the exact pixel size of your raster data. In this instance each pixel represents a 30x30-m area (standard for NLCD land-use rasters). You will need to convert from 30x30-m to km² so the conversion factor in this case is (Pixel Count)*900/1,000,000. Once calculated, be sure to click the editor and save edits, then stop editing.

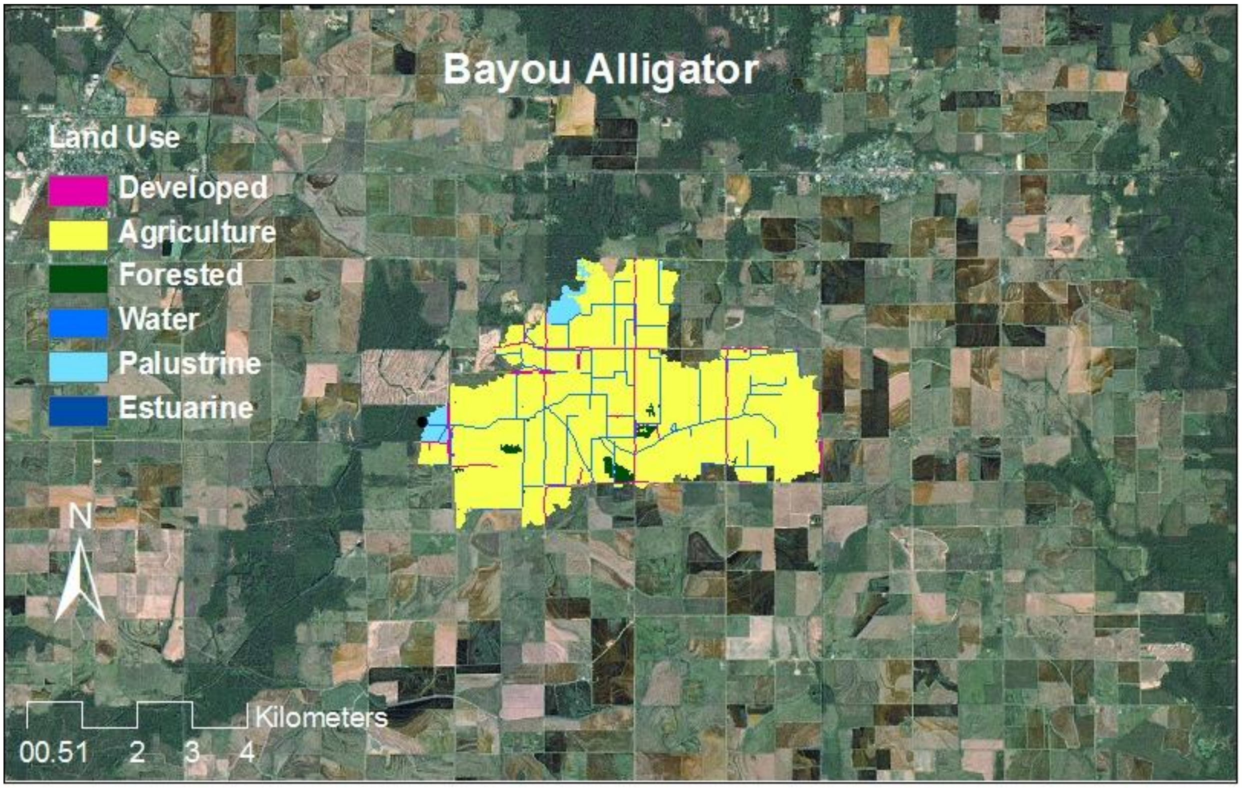


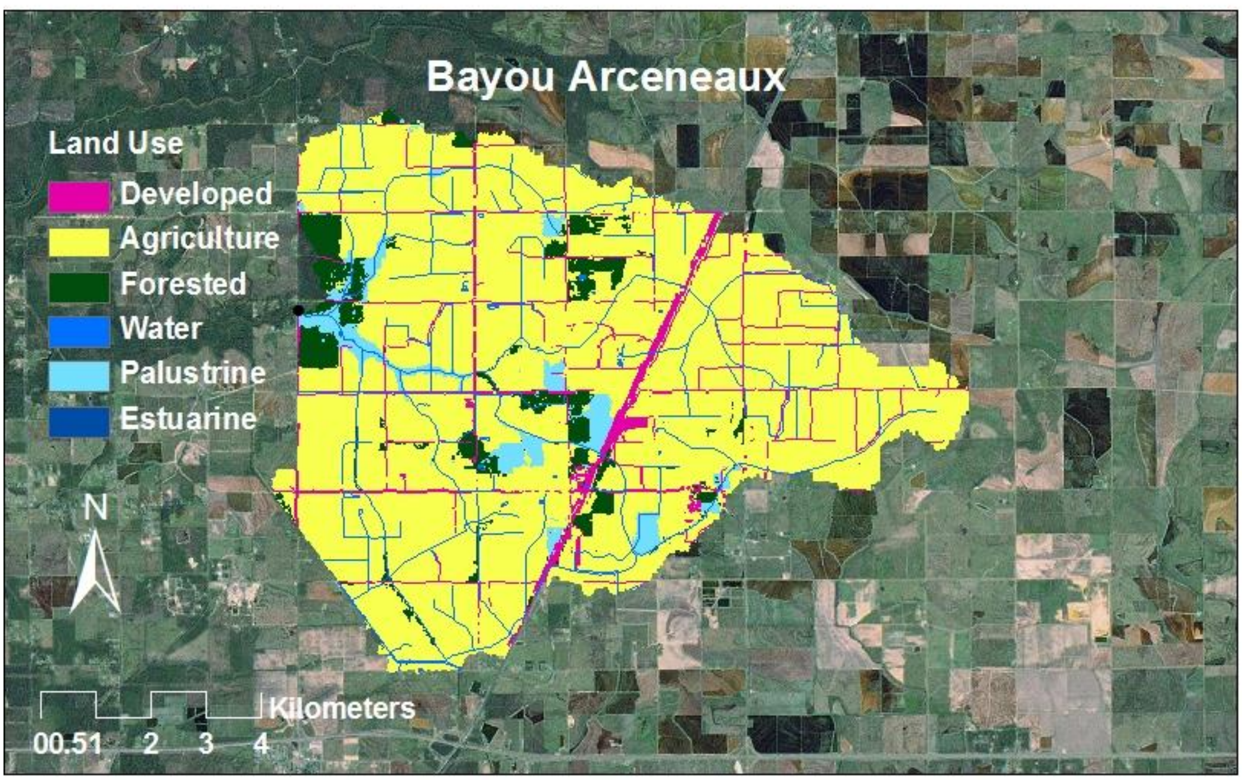
When you open the attribute table, you'll notice the land use values but not the corresponding labels. I ran into some trouble here and you can manually add in the corresponding land use names if you would prefer but I brought the area values into excel and typed out the land use names once rather than doing it for each attribute table in ArcMap. If you do want to add the land use names to the attribute table, add a field to the attribute table, enable an edit session and type them in. Again, be sure to save your edits.

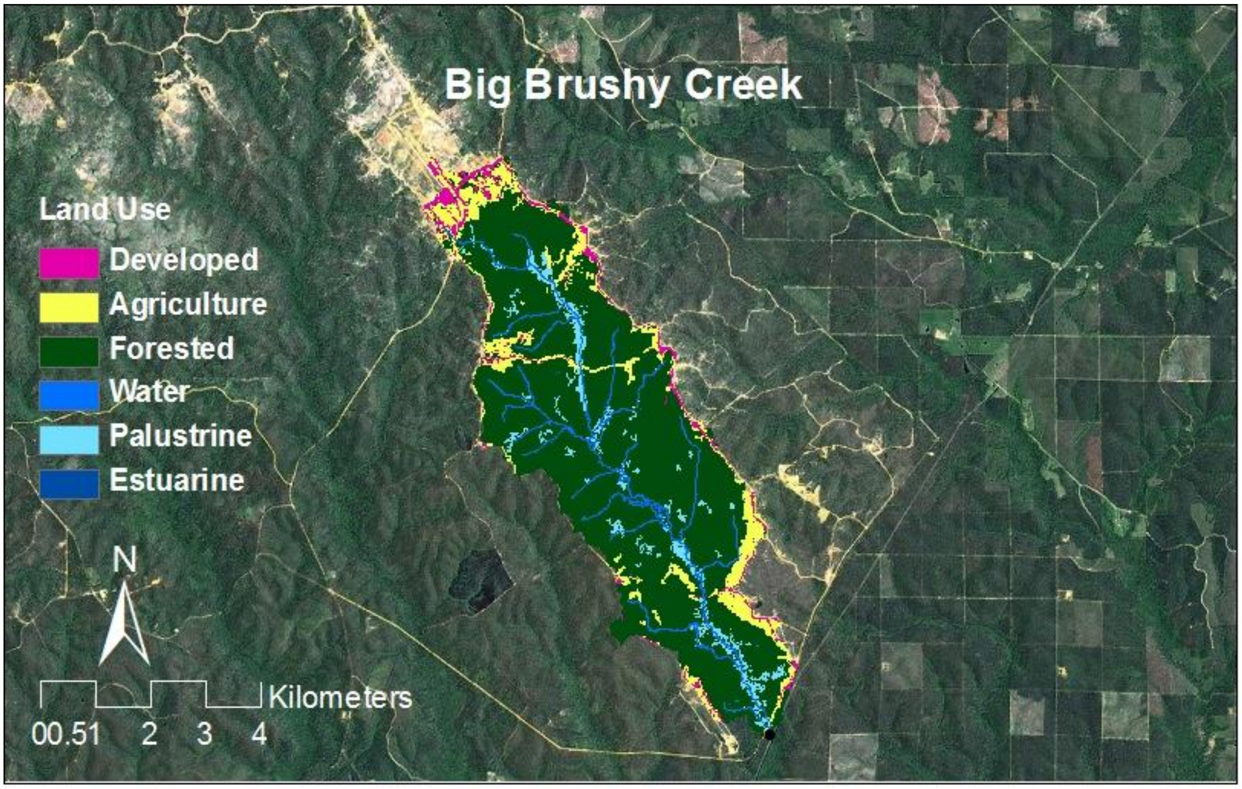


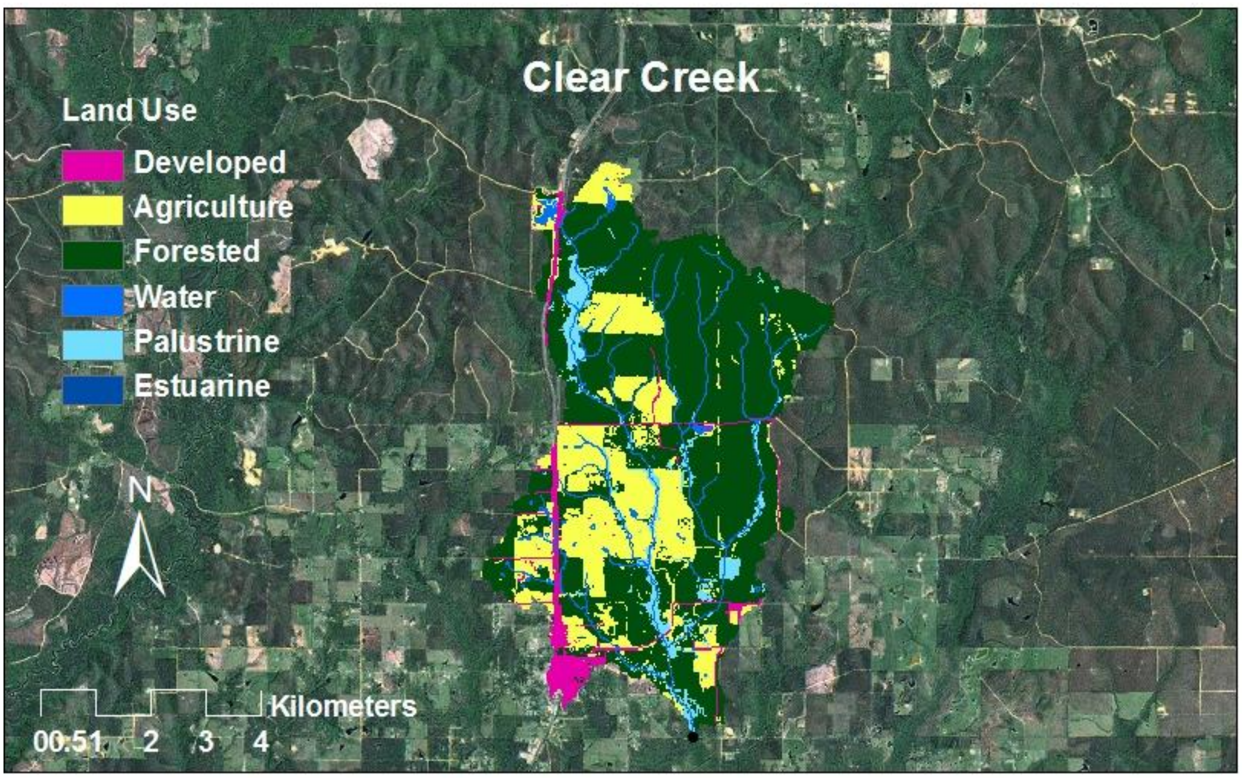
At this point you can delete old layers from the map such as the pour points, flow directions, etc. That's it! Where you go from here is up to you.

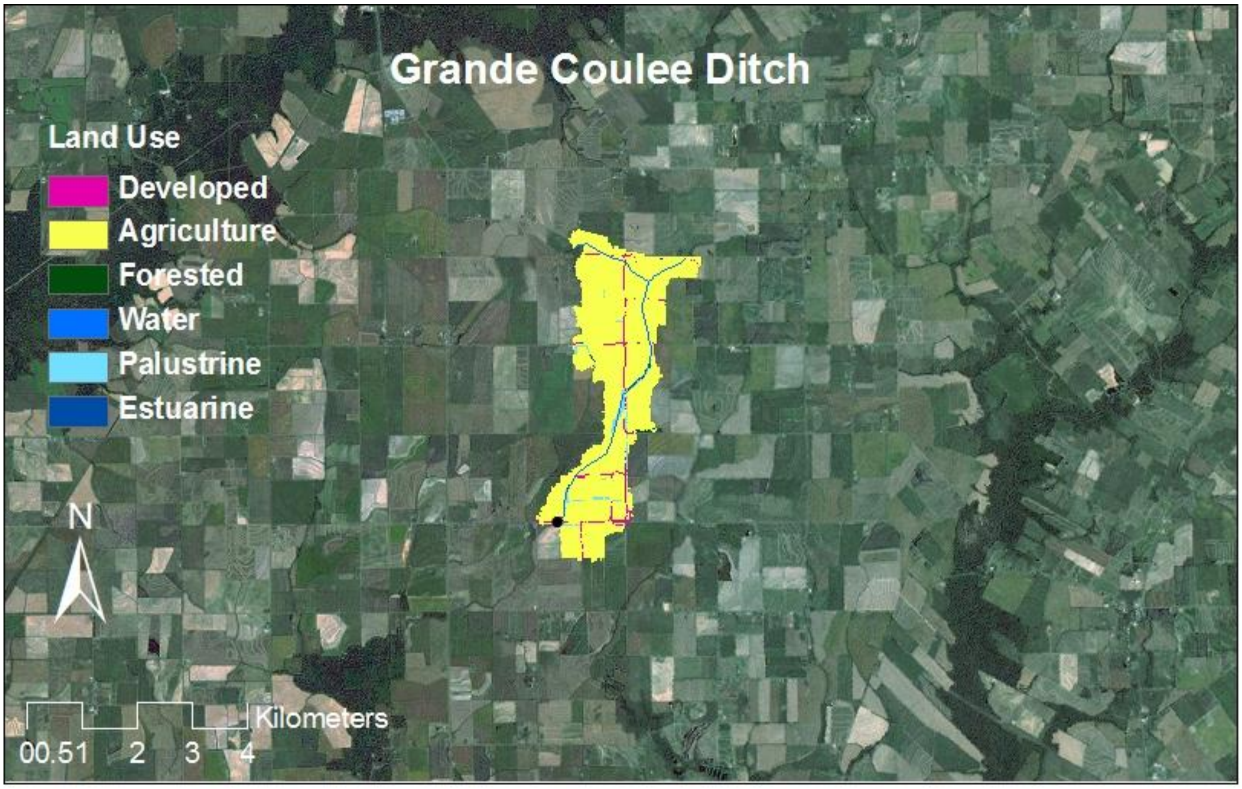
APPENDIX D. LAND COVER MAPS FOR EACH SAMPLED STREAM IN THE CALCASIEU AND MERMENTAU RIVER DRAINAGES

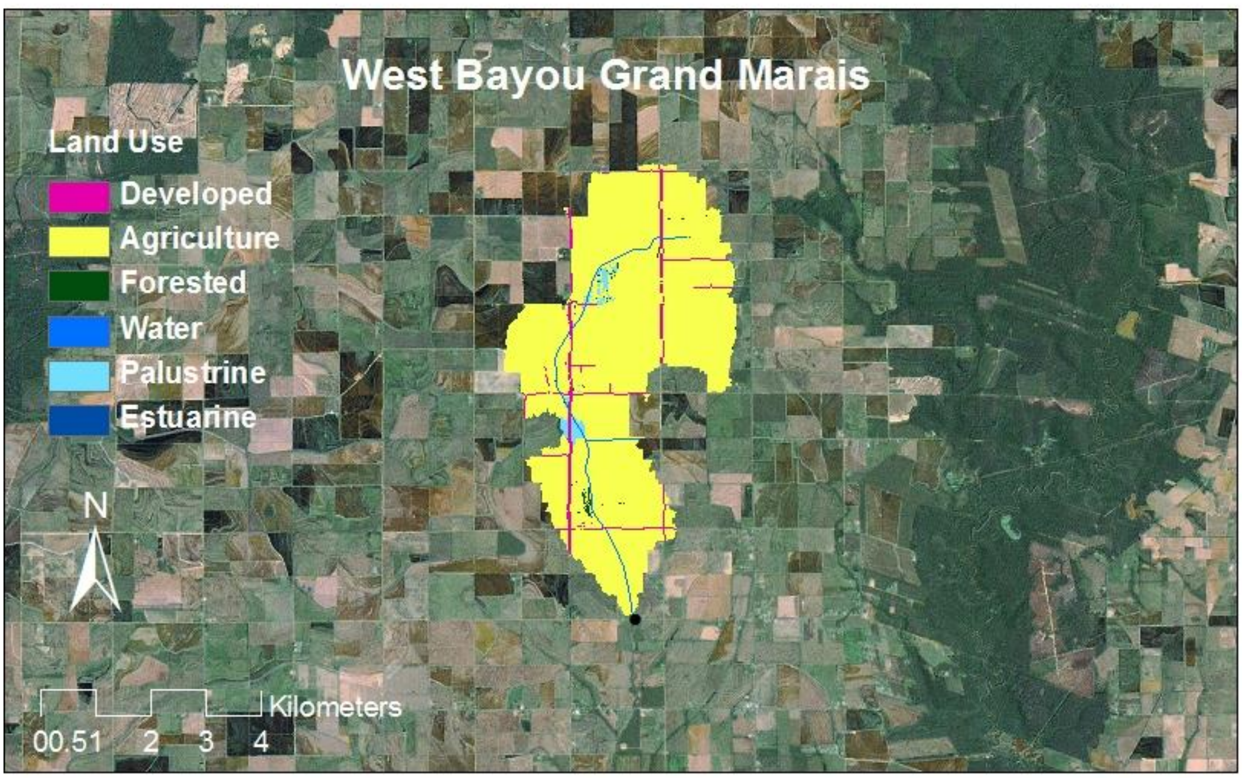


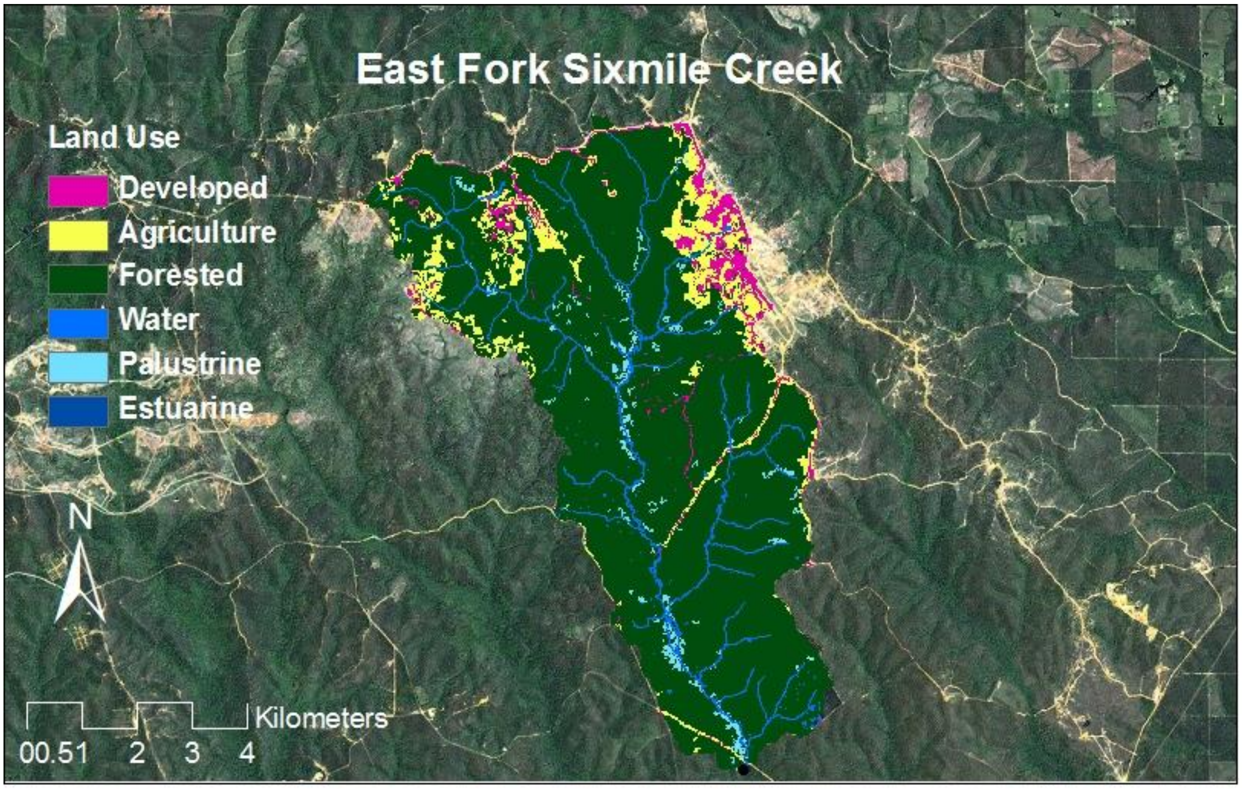


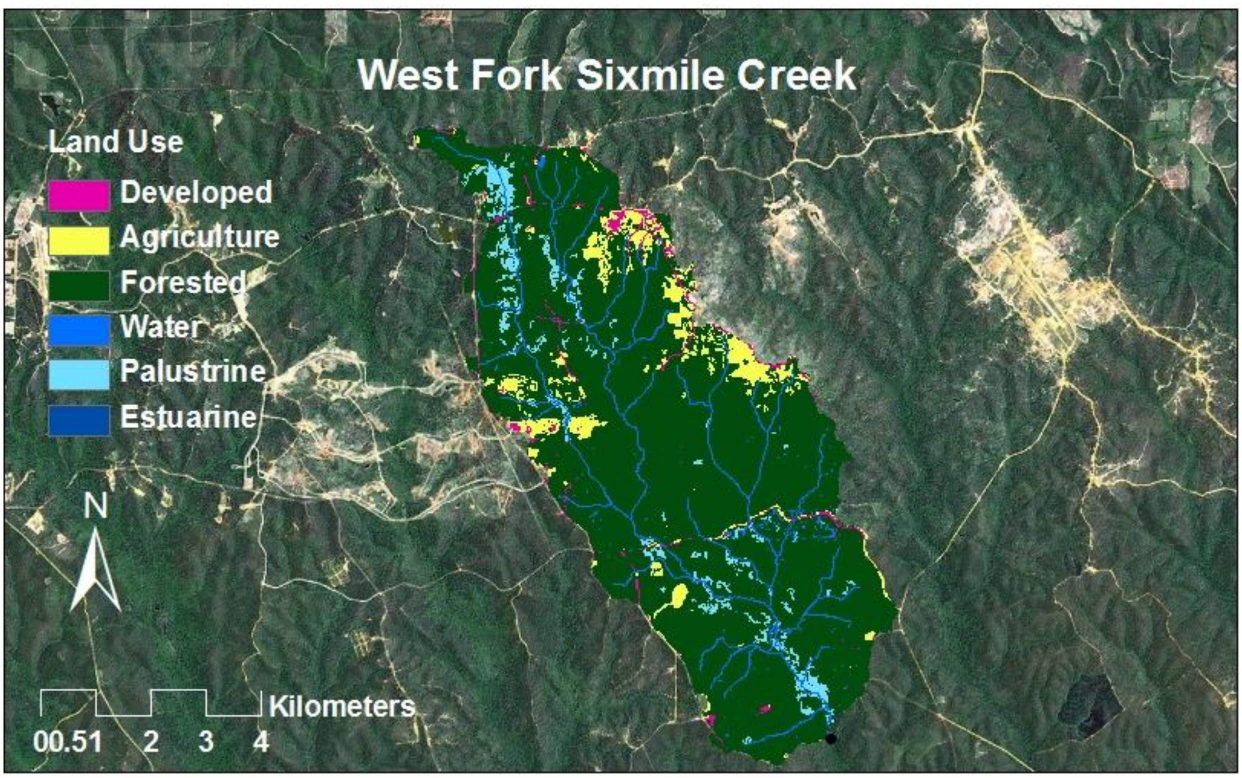

Big Brushy Creek
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
0 0.5 1 2 3 4

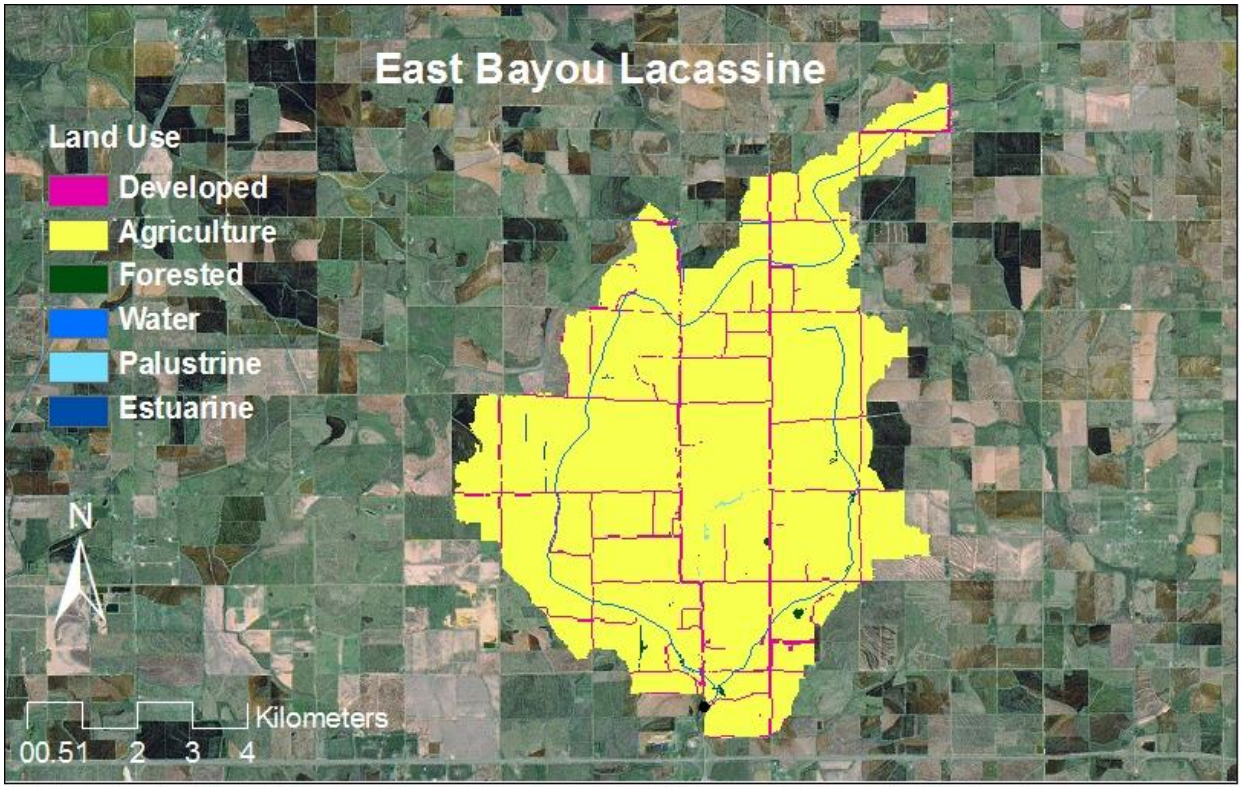

Clear Creek
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
0 0.5 1 2 3 4

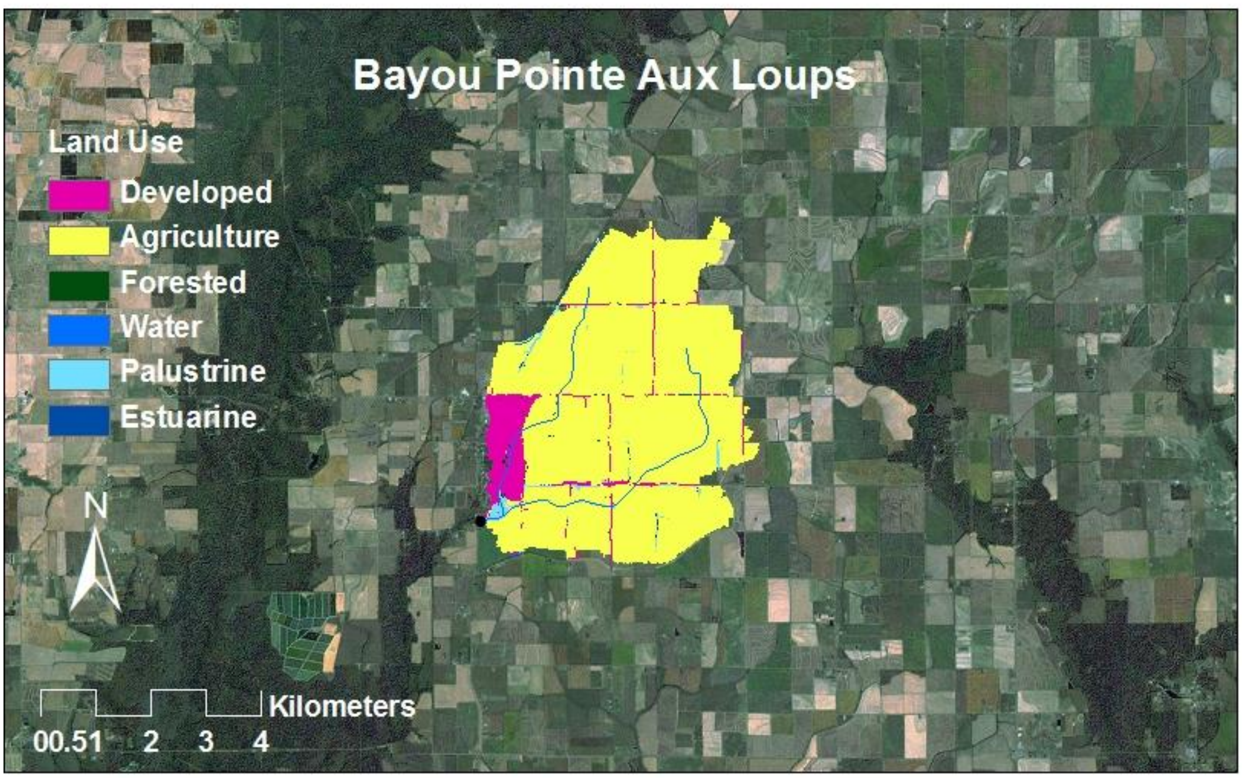

Grande Coulee Ditch
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
00.51 2 3 4

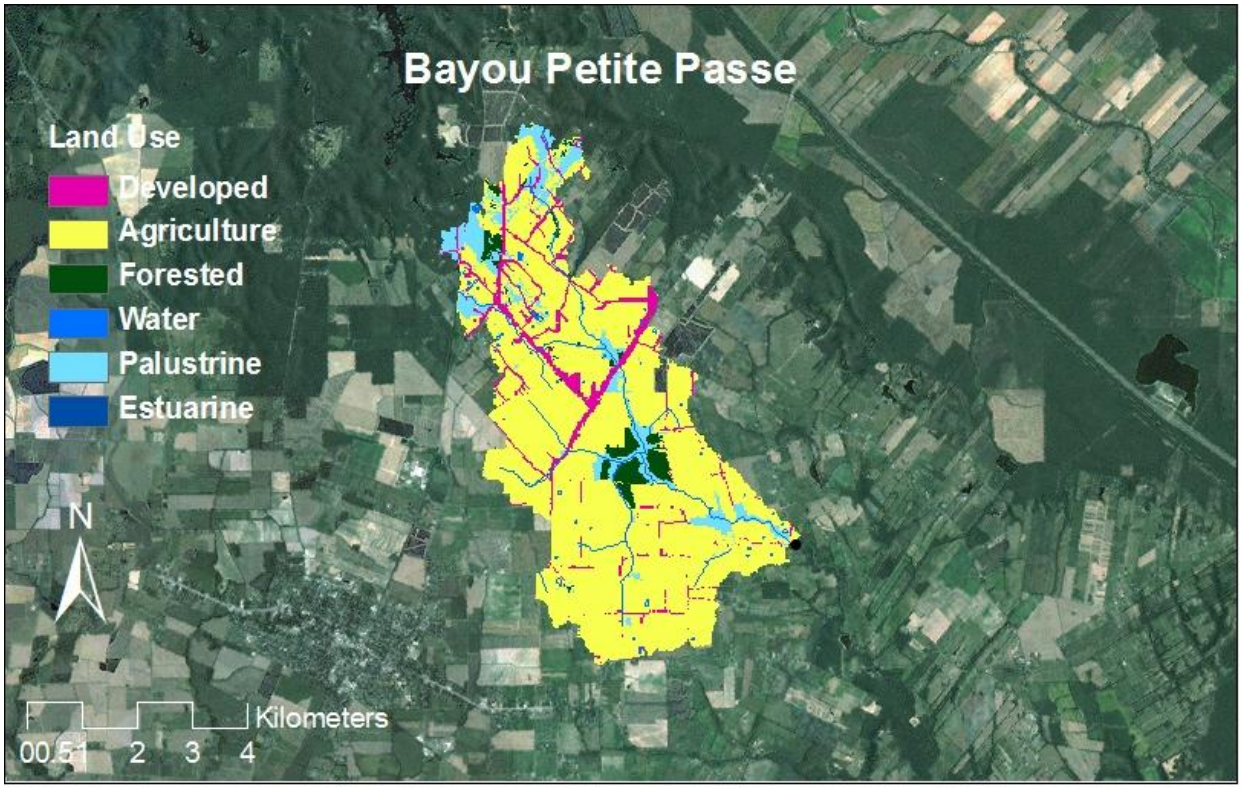

West Bayou Grand Marais
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
00.51 2 3 4

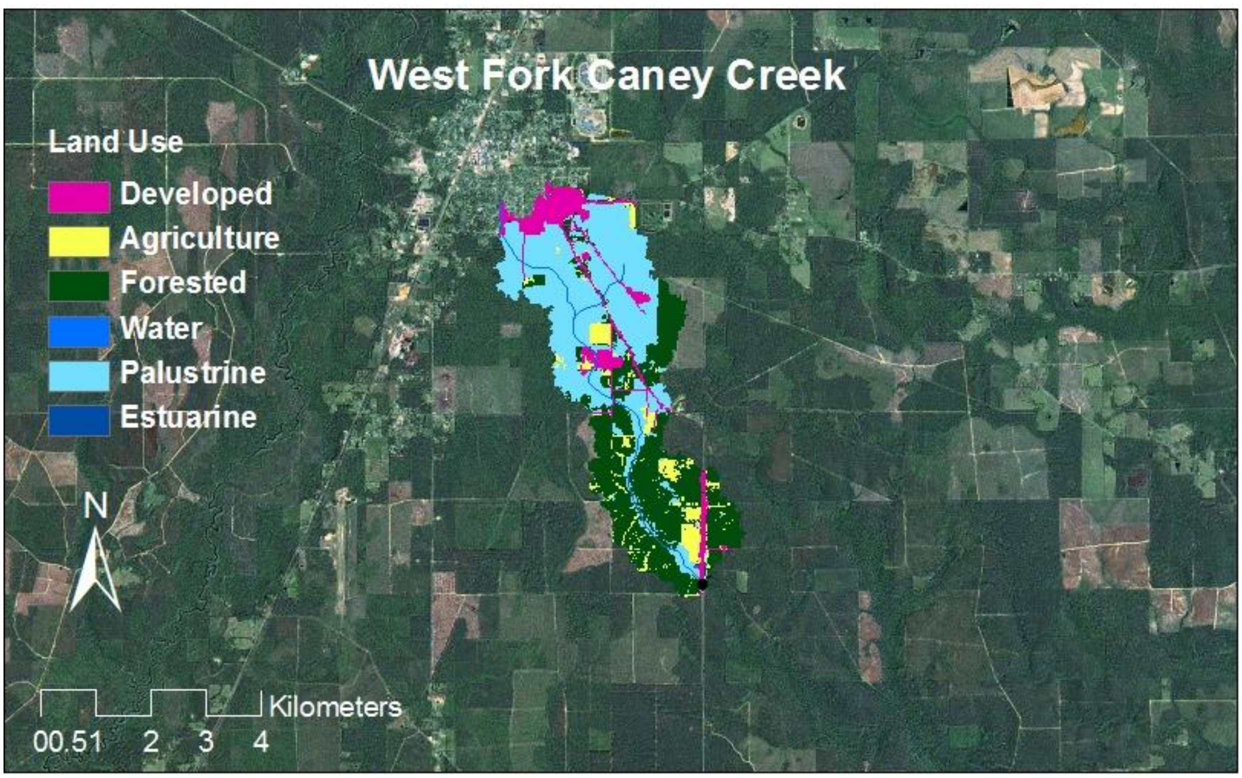

East Fork Sixmile Creek
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
00.51 2 3 4

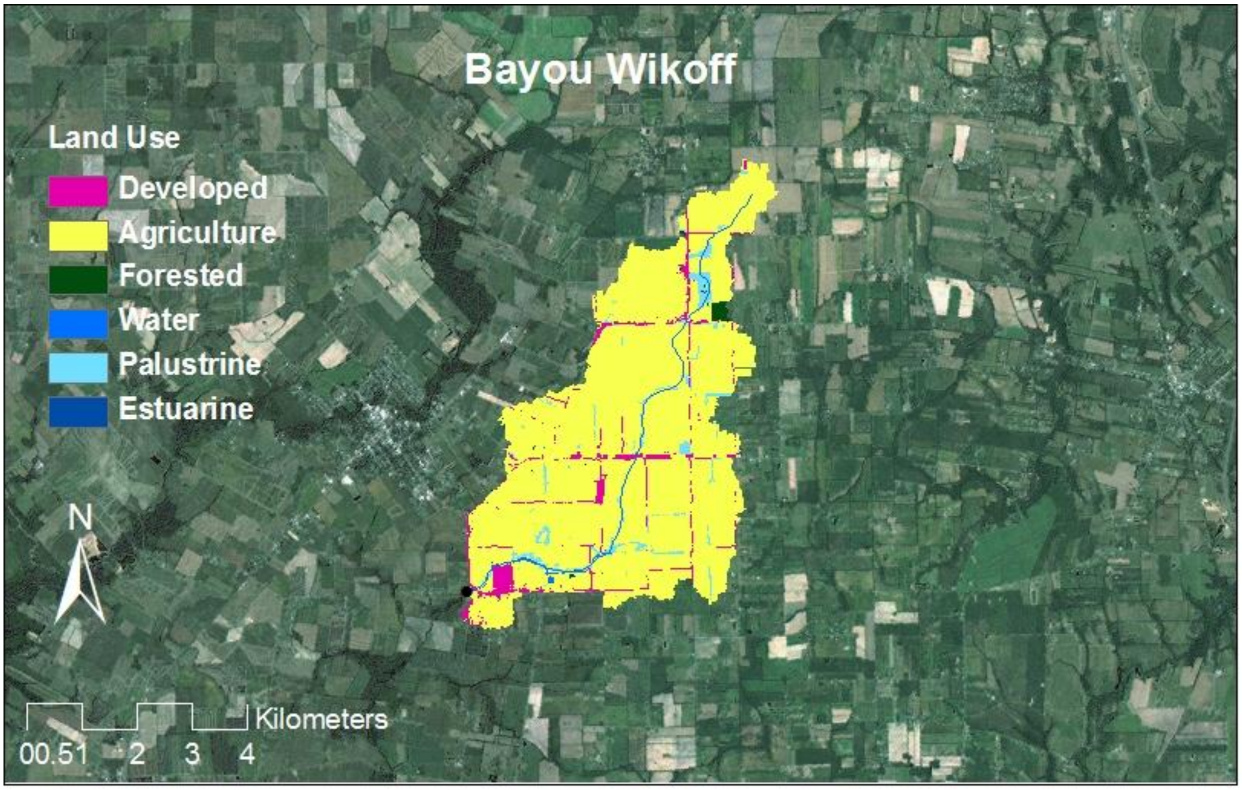

West Fork Sixmile Creek
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
00.51 2 3 4


East Bayou Lacassine
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
00.51 2 3 4


Bayou Pointe Aux Loups
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
00.51 2 3 4


Bayou Petite Passe
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
0 0.5 1 2 3 4


West Fork Caney Creek
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
0 0.5 1 2 3 4


Bayou Wikoff
Land Use
Developed
Agriculture
Forested
Water
Palustrine
Estuarine
N
Kilometers
0 0.5 1 2 3 4

VITA

Alexandra Marie Fitzgerald was born August 10, 1988, in Charlottesville, Virginia to Roger Fitzgerald and Melinda McKean. Alexandra grew up in Staunton, Virginia and graduated from Fort Defiance High School, Fort Defiance, Virginia in June, 2006. Alexandra graduated cum laude with a Bachelors of Science from Virginia Polytechnic Institute and State University, Blacksburg, Virginia in May, 2010 with a double-major in Fisheries and Wildlife sciences and a minor in Biology. Alexandra enrolled in the Master of Science program at Louisiana State University in August, 2010 beginning a thesis titled "Effects of Varying Land Use on Headwater Stream Fish Assemblages and In-Stream Habitats in Southwestern Louisiana" under the direction of Michael Kaller and William E. Kelso.