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The Three Gorges Dam: An Impact Analysis Applying Remote Sensing Techniques

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Abstract

This paper looks at the application of remote sensing and GIS for change detection of the land cover surrounding the Yangtze River since the Three Gorges Dam (the dam) began construction in 1994. The dam, located in central China, is 1.5 miles wide and more than 600 feet high. It created a reservoir hundreds of feet deep and nearly 400 miles long. The dam has been called one of the most destructive projects of our time by numerous publications due to the loss of archaeological and cultural sites, the displacement of over a million people, and its effects on the environment. The intention of this paper is twofold: to discover impacts the dam has had on land cover in the region and to provide an analysis of existing academic research on the topic.

Background and Introduction

The Three Gorges Dam is a hydroelectric dam that spans the Yangtze River by the town of Sandouping, in Hubei province, China. The Three Gorges Dam is the world's largest hydroelectric power generator; producing 20 times more energy than the Hoover Dam in the United States. It spans more than 1.5 miles across and 600 feet high, and has a reservoir that stretches more than 400 miles upstream. The $25 billion construction project began in 1994 and was completed in 2011. The Yangtze River is the third largest river in the world, stretching more than 3,900 miles across China before reaching its mouth near Shanghai (Figure 1). Historically, the river has been prone to massive flooding, overflowing its banks about once every ten years. The dam was designed to greatly improve flood control on the river and protect the 15 million people and 3.7 million acres of farmland in the lower Yangtze flood plains[1], but the social and environmental consequences of the project have been devastating.

Figure 1: The Dam site is located on the Yangtze River in Hubei province of China. It is about midway between of Hubei's province provincial capital, Wuhan City, and Chongqing City. Credit: http://en.citizendium.org

The reservoir created by the dam, nearly 400 miles long and hundreds of feet deep, has inundated more than 1,000 valuable archaeological and cultural sites, destroyed thousands of acres of the most fertile farmland in China, displaced more than 1.5 million people, and is called a contributing factor in the extinction of the Yangtze River dolphin. The waters of the Yangtze have also been polluted by submerged industrials sites that previously contained toxic materials and other industrial pollutants. Among many other ecological problems, erosion and landslides have become prevalent along the banks of the Yangtze and the risk of earthquakes has increased[2]. This region produced nearly half of the country's total crops and was some of the most fertile land in China, but it is now fast becoming an urban center.

[1] Bettwy, Mike. June 14, 2007. "NASA Satellites Watch as China Constructs Giant Dam."

[2] X.X. Lu 1, D.L. Higgitt. "Estimating erosion rates on sloping agricultural land in the Yangtze Three Gorges, China, from caesium-137 measurements." *Department of Geography, University of Durham, Science Laboratories.* 22 September 1999 http://courses.nus.edu.sg/course/geoluxx/notes/catena-paper.pdf

Remote sensing is one approach to better understand and evaluate the impacts of dam construction on the region. The impacts of the dam have been observed on the ground and from the air using resources such as the NASA-built Landsat satellites, NASA's Tropical Rainfall Measuring Mission, and NASA's Terra and Aqua satellites. Satellite imagery can be used to assess the region prior to the start of the project, provide an overview of the dam's construction, and analyze land cover changes post-construction of the dam. Satellites can also be used to determine how changing land cover and land use influences climate and the environment.

Figure 2: Two deep holes and a trash way hole open for sluicing the mounting flood water at the Three Gorges Dam. Credit: http://english.people.com.cn/90001/90783/91300/6691772.html

One such study, completed by NASA in 2006 using information from the Terra and Aqua satellites, revealed that the land use change associated with the dam's construction has increased precipitation in the region[3]. The study found that land use changes also reduced rainfall in the region immediately surrounding Three Gorges Dam after the dam's water level abruptly rose in June 2003 (Liguang Wu, NASA). Researchers also found that the dam affected rainfall over a larger area than expected; a 62-square-mile region rather than 6 miles. Now that the dam is fully operational, it is predicted that regional temperature and precipitation changes will increase even more due to size of the reservoir. Figure 3 shows the reservoir in 1987 and 2006.

Figure 3: Images of the Three Gorges location in 1987 and 2006. Credit: NASA

This study will also use Global Land Survey (GLS) orthorectified imagery from 1987 and 2006 to assess the impacts the Three Gorges Dam has had on its surrounding environment. A review of existing academic research on the topic is provided to understand how remote sensing has been used in the past for change detection and environmental risk calculations in the region.

[3] Bettwy, Mike

Analysis and Methodology

Remote sensing is an integral analysis tool with many important applications, particularly helpful in asssesing changes, risks, and impacts from the Three Gorges Dam. This study uses Global Land Survey (GLS) orthorectified imagery from 2005 and 1987 EarthSat Orthorectified GeoCover data to understand the impacts the Three Gorges Dam has had on its surrounding environment. Imagery files were downloaded from Global Land Cover Facility (GLCF) using the Earth Science Data Interface; the GLCF's web application for searching, browsing, and downloading data from their online holdings. A map search was completed for available Landsat ETM+ and TM imagery, Global Land Cover data from AVHRR, and ASTER imagery for the Three Gorges Dam region (Figure 6). The search resulted in 10 images; two images from 1987, six from 2000, and two from 2006. USGS Landsat TM Orthorectified imagery from 1987 and 2006 were chosen for this analysis; both images are from the NASA Landsat Program. Orthorectification corrects for relief displacement and terrain distortion, which cause the tops of vertical objects in the image to look displaced from their bases[4]. Distortions would potentially interfere with future classification efforts.

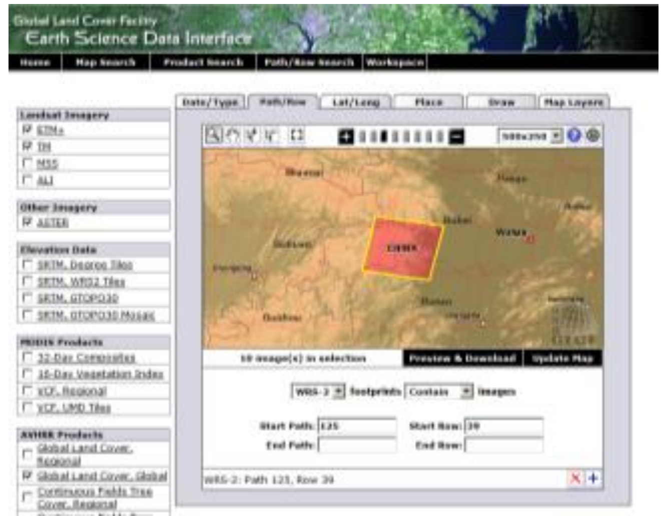

Figure 4: GLCF Search Window.
Source: http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp

The imagery was downloaded as zipped .TIF files, with each band as a separate file. IZarc was used to unzip each file and the files were moved to a new folder. Each individual .TIF file, or band, was then opened in ArcMap where the Composite tool was used to combine bands 1-5 and 7 from each time period into stacked images that could be used for analysis in both ArcMap and MultiSpec.

Results and Discussion

Data analyses performed include an aerial imagery comparison using ArcMap, a change detection analysis, an image classification using MultiSpec, and an NDVI analysis. Each of these analyses is described in more detail below.

Aerial Image Comparison

A comparison of the two aerial images from 1987 and 2006 in ArcMap reveals that the Three Gorges Dam has certainly had an impact on the surrounding land uses (Figure 7). These images are both displayed using Bands 3-2-1 to show true color and to understand the land cover and uses. The reservoir created from the Three Gorges Dam is very clear in the 2006 image. In 1987, the Yangtze River remains unobstructed and there are no major visible tributaries. By 2006, there was development around the dam site and the water levels had risen to increase the size of the tributaries flowing to the north and south from the Yangtze River. This visual comparison proves that change did occur, and remote sensing analysis techniques will allow for a deeper look at how the region has truly been affected.

4 Lillesand, Kiefer and Chipman. Remote Sensing and Image Interpretation. 6th Edition. 2008.

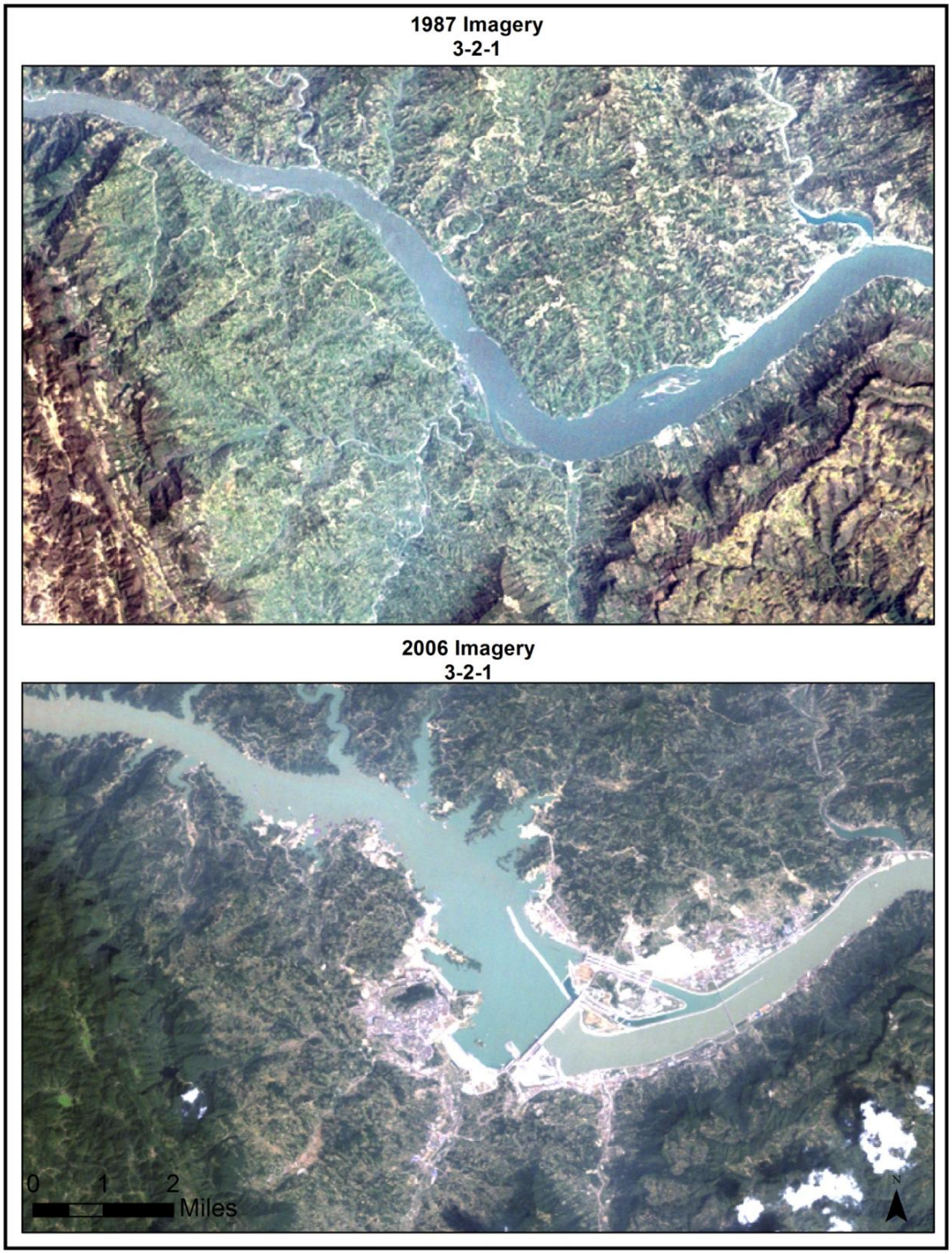

Figure 5: Imagery Comparison using ArcGIS

Change Detection

A quick glance at Figure 7 will tell an analyst that the Three Gorges Dam has had an impact on the environment. Change detection provides detailed information for identifying and assessing long term changes in land cover and land use, rates of desertification, and short term phenomena such as snow cover or floodwater. Change detection involves the use of multitemporal data sets to discriminate areas of land cover change between dates of imaging[5]. This analysis uses change detection to provide information about how the construction of the Three Gorges Dam changed the surrounding landscape over nineteen years.

This change detection analysis uses data acquired by the same sensor that were recorded using the same spatial resolution, spectral bands and viewing geometry in order to improve the accuracy and reliability of the results. The change detection process can also be influenced by any environmental factors that change between the two imagery dates, but these factors are not considered in this paper. To begin the analysis, the ArcGIS Composite tool was used to create a new raster containing the six reflective bands from the 1987 TM image (bands 1-6) followed by the six reflective bands from the 2006 TM image (bands 7-12). A new display was then created using single bands from each year. Figure 8 shows a 3-color RGB map using bands 9-3-9, the red bands from both time periods. In this display, areas of change show up as either green or red, while areas of little change show up as black, grey, or white. This image supports the hypothesis that the region has undergone a great deal of change in the area surrounding the Three Gorges Dam in the 19 year period from 1987 to 2006.

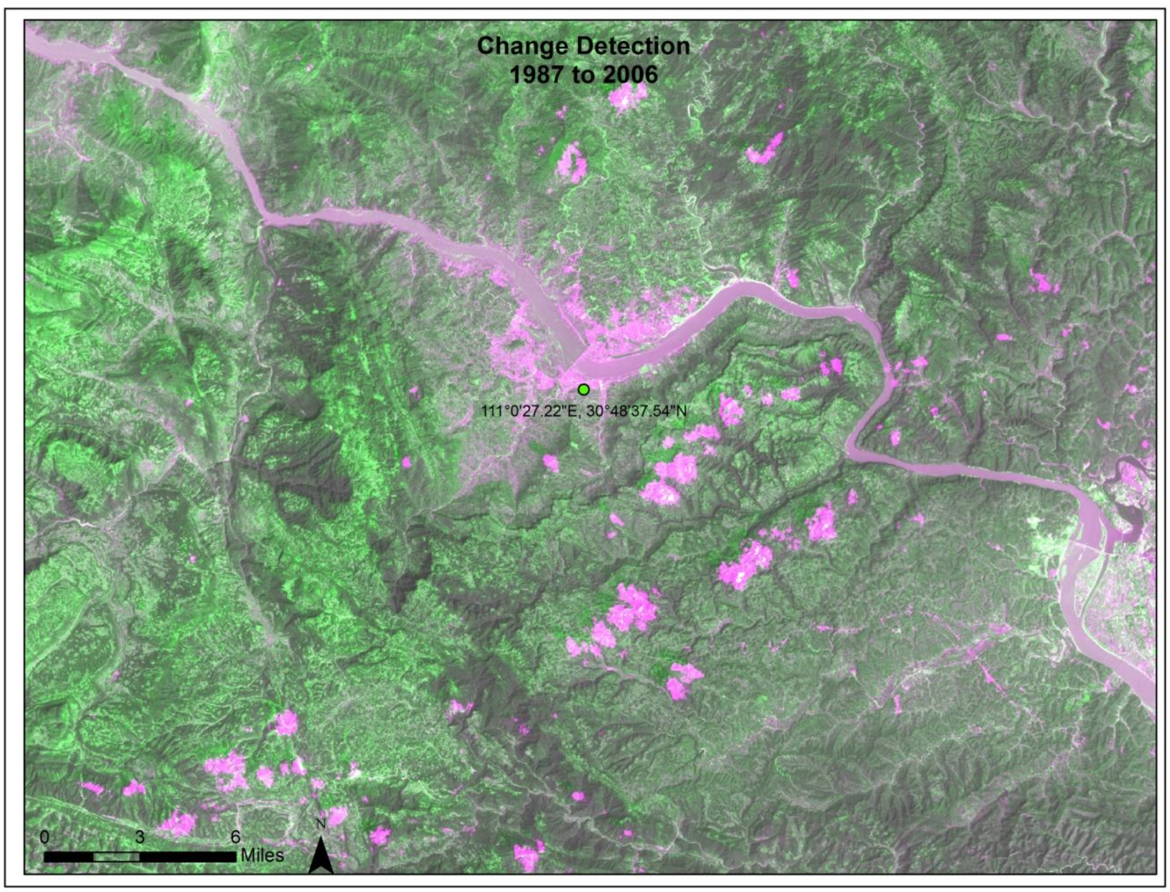

Figure 6: 9-3-9 Change Detection Results using ArcMap

[5] Ibid.

To better understand the degree of change for the region, a second analysis was performed using the ArcGIS Spatial Analysis toolbox. The raster calculator was used to create a new raster that would display the areas of greatest change. The following formula was used:

2006 image – 1987 image = new image

The result of this calculation is shown in Figure 9, which calculated the difference in value for each of the pixels between 1987 and 2006. The reservoir resulting from the dam construction is shown as red in this image, verifying that this area resulted in a high degree of change. Google Earth imagery was consulted to better understand the other areas of change, shown in blue. These areas appear to be villages that have developed in the mountains, potentially by people who were displaced from the plains and fields by dam construction.

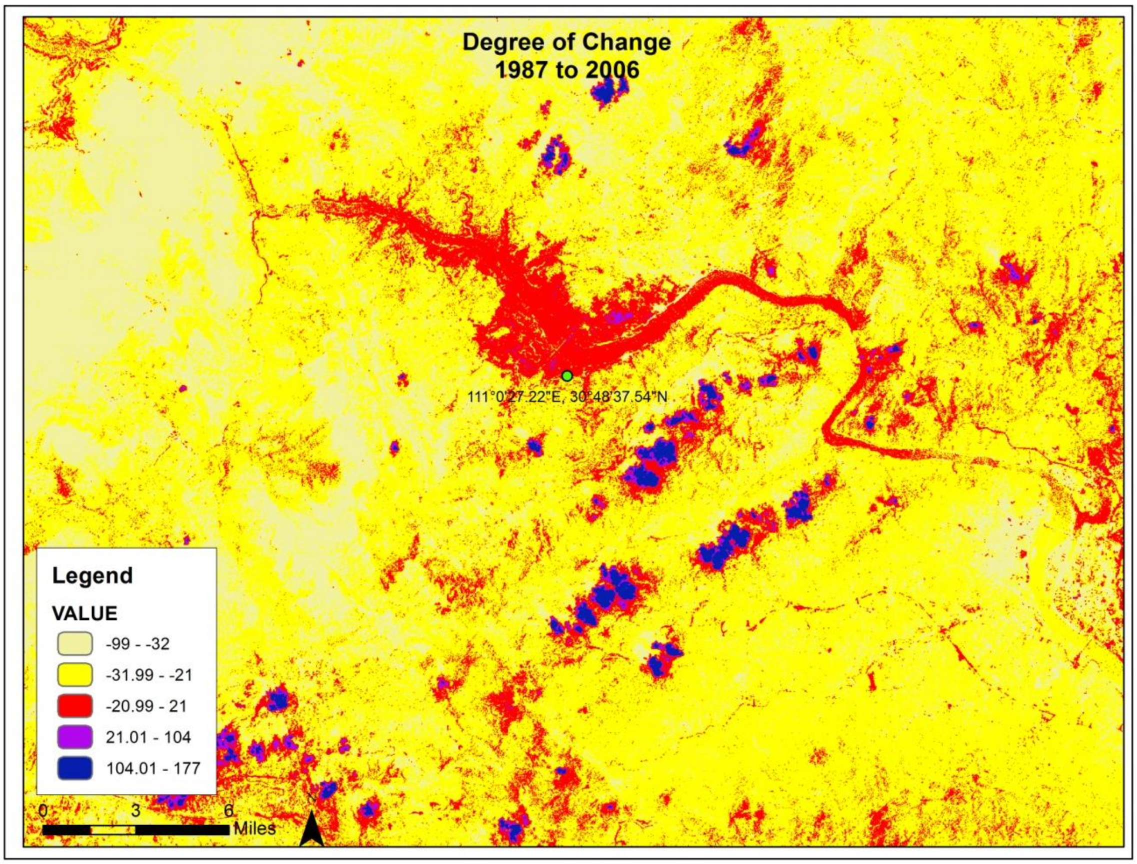

Figure 7: Change Calculation Results using ArcGIS

Image Classification

The analysis shown in Figures 8 and 9 revealed that the Three Gorges Dam construction resulted in land cover changes in the surrounding region. But how much did it change? Further analysis was conducted to understand how the land uses and land cover in this region changed over the 19 year period. MultiSpec, a freeware multispectral image data analysis system, was used to perform a supervised classification on both the 1987 and 2006 images. The following classification categories were used: water, urban/bare ground, agriculture, and forest. The image was displayed using bands 5-4-3 for classification purposes. First, training sites were chosen for each class. A minimum of 4 sites were chosen for each class to maximize accuracy. Two test/validation sites were then chosen for each class. Once all areas were defined, the Classify tool was used to perform the image classification. A maximum likelihood classification was done for both images and text reports containing input parameters, channels used, training/validation sites used, a confusion matrix, and a class distribution by area table were produced.

Table 1: Classification Comparison, 1987-2006

	2006 - Area Classification			1987 - Area Classification			Change (1987-2006)	
Class	**Samples**	**Percent**	**Area (Acres)**	**Samples**	**Percent**	**Area (Acres)**	**Percent Change**	**Area Change(Acres)**
Water	90,224	2	20,065.32	78,396	1.8	17,657.01	14%	2,408.31
Forest	1,837,402	41.6	408,628.10	1,672,959	38.1	374,663.34	9%	33,964.76
Agriculture	2,257,909	51.1	502,146.54	2,324,481	58.1	570,843.31	-12%	(68,696.77)
Urban/Bare Ground	232,753	5.3	51,762.99	342,452	2	19,439.28	166%	32,323.71
Total	**4,418,288**	**100**	**982,602.95**	**4,418,288**	**100**	**982,602.95**		
Maximum likelihood classifier used. 6 channels. Overall class performance: 99%.								

Table 1 shows the results of the two classifications and the change over a 19 year time period. The area classified totaled 982,000 acres. In 1987, approximately 58 percent of the region was agricultural and two percent was urban/bare ground. Dam construction began in 1994 and was fully completed in 2011. By 2006, the area inundated by water had increased by 14 percent with a large portion of this increase occurring just north of the dam, as shown when comparing Figure 10 and Figure 11. Approximately 5.3 percent of the region became urban and agricultural land was reduced by over 68,600 acres, or 12 percent. The classification results for 2006 also reinforce that the areas shown as undergoing a high rate of change (blue regions in Figure 8) are in fact newly developed towns.

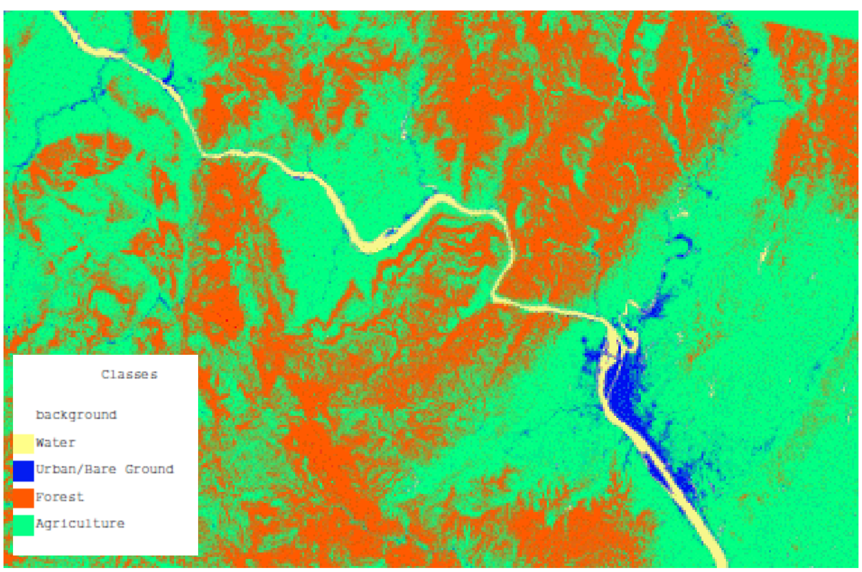

Figure 8: 1987 Classification Results using MultiSpec

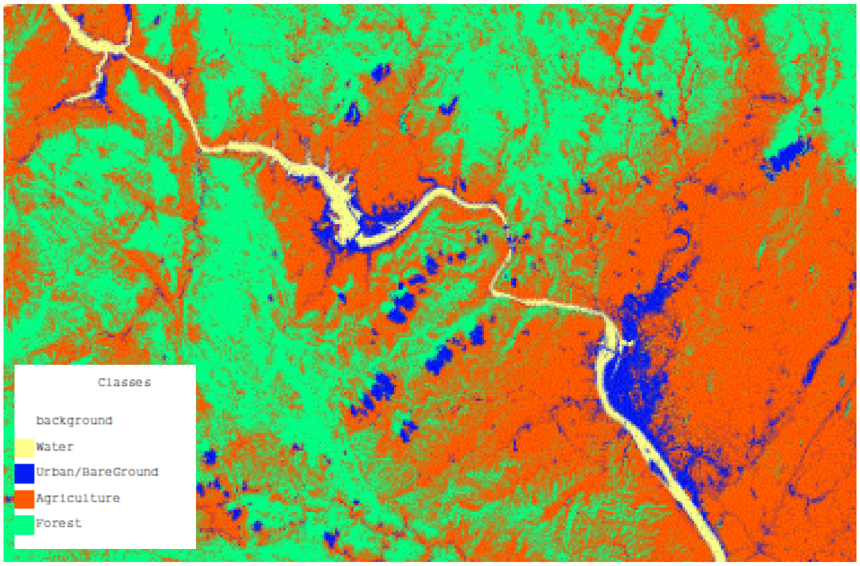

Figure 9: 2006 Classification Results using MultiSpec

NDVI Classification

A final analysis was performed using MultiSpec to indicate the presence and condition of green vegetation. The normalized difference vegetation index (NDVI) was calculated for the region by applying the following formula to each pixel within the raster containing the 12 bands from both years:

$$128 + (c10\text{-}c9/c10+c9) * 128$$

This calculation was used to create a map from the 2006 data; c10 corresponds to the NIR band and C9 corresponds to the red band. This calculation will result in NDVI values that range from 0 to 255, instead of –1.0 to 1.0 because MultiSpec can only deal with 8-bit integer data (0-255 values). Figure 12 shows the results of this calculation. Vegetated areas will generally yield high values due to their relatively high near-IR reflectance and low visible reflectance, as is the case in Figure 2006. Areas that have been submerged by the reservoir show a low value, whereas the mountains still covered in vegetation show the highest values in red.

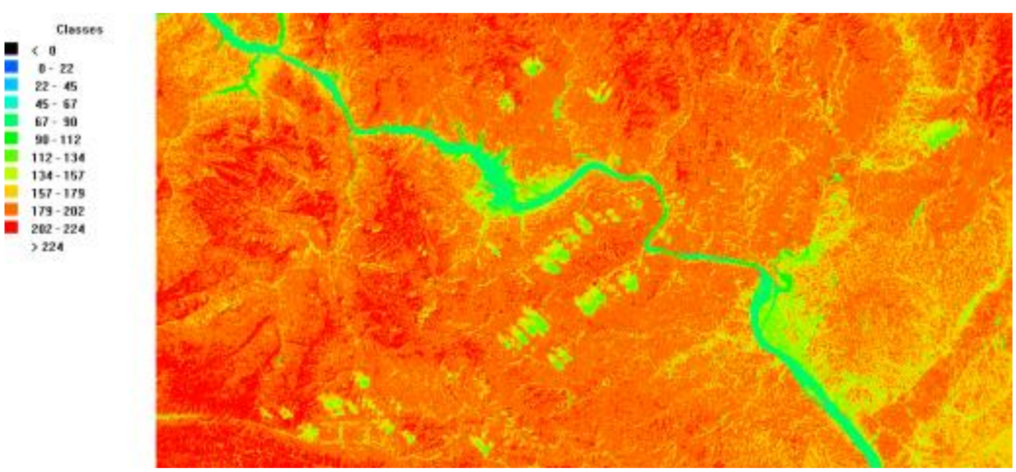

Figure 10: NDVI Results, 2006

The same calculation was applied to the 1987 data using c4 and c3 in place of c10 and c9. The results are shown in Figure 13. In 1987, the lowest values appear in the urban area in the south eastern stretch of the Yangtze River. No bare ground or buildings are apparent where the dam now stands. This analysis used the NDVI because it helps to compensate for extraneous factors such as changing illumination conditions and surface slope.

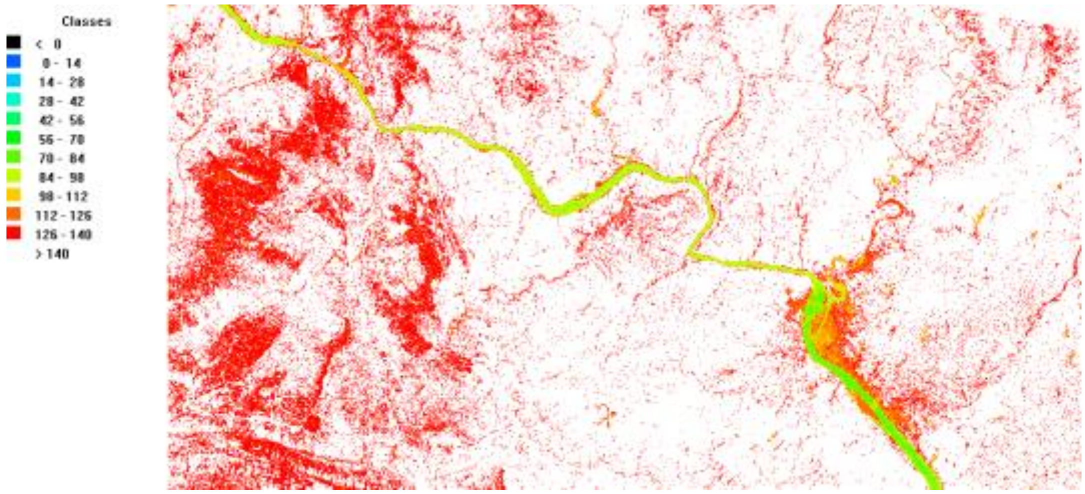

Figure 11: NDVI Results, 1987

Literature Review

A review of literature was performed on the use of remote sensing to detect change in the Yangtze River in China to provide background on the dam and to understand previous uses of remote sensing for change detection. The ideas presented by studies have been considered in developing a hypothesis for this analysis. Three of these papers are reviewed below.

A. Yongming Xu, Ming Wei, Yonghong Liu and Jingjing Lv, "Research on regional land cover mapping of the Yangtze River Delta using MODIS 250m data", Proc. SPIE 6790, 67901Q (2007); http://dx.doi.org/10.1117/12.749294

The authors of this study were interested in analyzing the influence of landscape change in the Yangtze River Delta region. This has become one of the most economically developed areas of China during the last two decades, and masses of cropland have been converted to housing, roads, and industrial estates. Their purpose was to develop a comprehensive land cover map with finer resolution than those land cover datasets made available from moderate resolution remote sensing data (such as IGBP Discover and University of Maryland 1km land cover products). In this paper, the land cover map of the Yangtze River Delta was generated using the 16-day composite EVI data and 8-day composite reflectance data derived from MODIS. Some special pre-processing and post-classification were also carried out to improve classification accuracy.

The authors constructed a total set of 24,041 pixels, which were divided into a training subset (70%) and a testing subset (30%) by random sampling, for the purpose of independent training and accuracy assessment. They then defined a classification scheme made up of 9 land cover types: water, coastal wetlands, built-up, annually double-crops, annually double-crops in wet-dry land, double cropping rice, needleleaf forest, broadleaf forest and shrublands. After the final map was developed, the authors compared their results with the selected test dataset derived from Landsat images and the 1km MODIS-IGBP land cover product. They found that the greatest discrepancies occurred in built-up forests and cropland areas. The authors were most interested in the development of cropland, and it proved to be the most important land cover in the area. The MODIS land cover map had only one cropland type while the authors were able to divide cropland into three classes, resulting in the ability to provide a more detailed analysis. The analysis is an example of the importance of accurate and up-to-date land cover maps for regional analysis. It showed that large scale land cover datasets provide an unprecedented view of the global system, but their coarse spatial resolution is not a perfect fit for a smaller scale study.

B. Jiazhu Huang and Guochun Ma, "Application of remote sensing and GIS to the assessment of bank stability in the Lower Yangtze River", Proc. SPIE 3504, 445 (1998); http://dx.doi.org/10.1117/12.319538

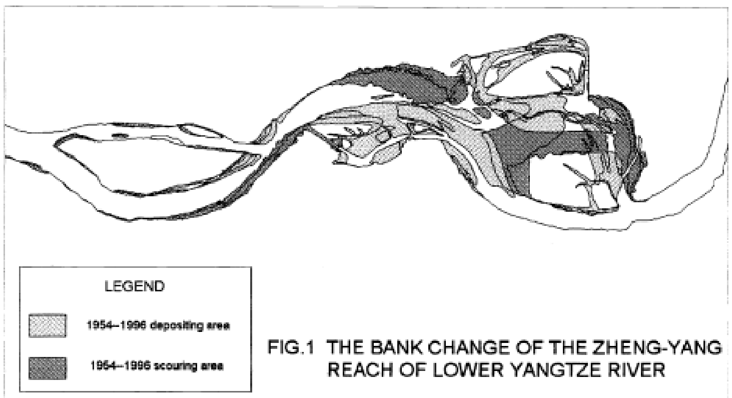

Figure 12: Bank change of the Zheng-Yang Reach of the Lower Yangtze

The authors of this study, completed in 1998, were interested in assessing the stability of the banks of the Yangtze River and researching riverbed evolution, geology, geomorphology, water depths, and bank revetment projects using remote sensing and Geographic Information Systems (GIS). The purpose was to detect the channel deformation for the needs of the development and utilization of the bank lines resources, the channel improvement, and hazard prevention in the Yangtze River using a GIS based remote sensing survey. The authors conducted a dynamic, multi-temporal remote sensing analysis of river bank migration over a period of 40 years using aerial photographs from 1954, 1964, and 1981 and Landsat TM images from 1984, 1989, 1993, and 1995. From these data, the authors developed a graphic database of the bank migration of the Lower Yangtze covering a period from 1954 to 1995 (Figure 4).

The authors found that the banks in some reaches of the Yangtze River have migrated by 1 to 2 km since the 1950s. Some banks have been stabilized in recent years by man-made bank revetments, but there are still many segments that are prone to collapse and will need to be protected. They found a remote sensing, multi-temporal analysis to be an effective method for surveying and monitoring the fluvial processes and variations of large rivers. The use of GIS allowed the authors to develop a database that can be used to predict future trends, evaluate bank stability, and serve as a scientific basis for future decision making in hazard prevention.

C. Deying Li, Kunlong Yin, Huaxi Gao and Changchun Liu, "Design and application analysis of prediction system of geo-hazards based on GIS in the Three Gorges Reservoir", Proc. SPIE 7492, 749239 (2009); http://dx.doi.org/10.1117/12.837229

The Three Gorges Dam causes the water in the Yangtze River to fluctuate and rise, resulting in environmental problems and hazards, including landslide, collapse, and debris flow, that result in the enormous loss of property and human life. The authors of this paper discuss the function and data processing of a hazard prediction system that is intended to prevent and control geo-hazards. In 2009, ArcGIS was used to display and explore spatial geographic data, evaluate the relationship between landslide distribution and different environmental parameters, perform hazard assessment of regional and urban landslide based on spatial data processing, evaluate the risk of landslide surge, and present that data graphically. Satellite Digital Elevation Model (DEM) data were used to develop a hydrological distribution model, which the authors used to analyze the influence of effective rainfall and water levels on landslide occurrence. The authors found that this model will prove to be a useful tool in risk evaluation and engineering decision making in the region that they studied. The prediction system they developed could be used as an early warning and emergency management tool that has the potential to save lives in the future. Figure 5 shows a landslide hazard assessment map that resulted from the study. It shows the areas of Badong that have the highest risk of a landslide.

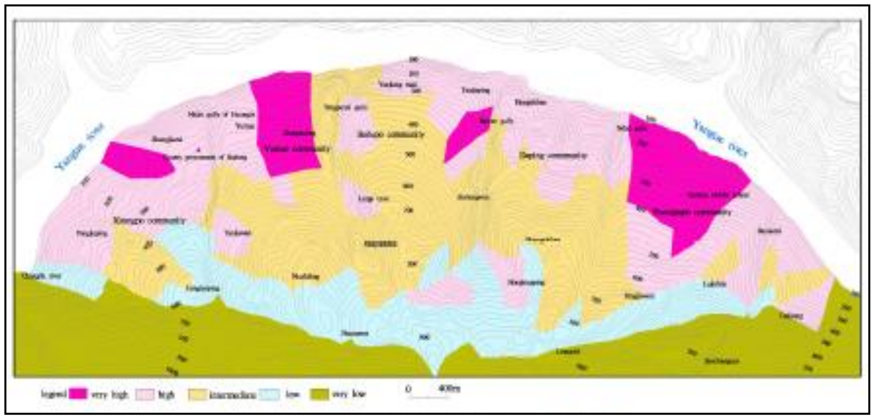

Figure 13: Landslide hazard map of Badong

Concluding Remarks

The articles reviewed illustrate the effective use of remote sensing for analysis in 1998, 2007 and 2009. The authors of the 1998 study used aerial photographs and Landsat TM imagery to perform multi-temporal remote sensing analyses of Yangtze River bank migration over a period of 40 years. This study resulted in a GIS database that could be used to evaluate bank stability. A similar study done by Zhu, Wang, Qiao, Chen and Zhou in 2004 mapped the landslide susceptibility in the Three Gorges area. The study showed that the Three Gorges reservoir will increase the frequency and the magnitude of landslides in the area due to the Three Gorges reservoir and the displaced population moving to the upper slopes, away from the rising water[6]. In 2009, another study of landslide susceptibility was completed by Li, Yin, Gao and Liu. Their analysis underwent a similar process to understand the risks of landslide in the region as a result of the dam; however their process used a satellite Digital Elevation Model (DEM) to develop a hydrological distribution model and then a risk map. The purpose of the third study, done in 2007, was to develop a comprehensive land cover map of the region using MODIS imagery.

As shown through this and past analysis, satellite remote sensing and aerial photography can play an important role in generating information about river systems and their temporal changes through time. The purpose of this analysis was to provide a high level view of how the region has changed over a nineteen year period. One thing to consider is that some change could have occurred between the 1987

6 Axing Zhue, Rongxun Wang, Jianping Qiao, Yongbo Chen, Qianggue Cal, Chenghu Zhou. "Mappling landslide susceptibility in the Three Gorges area, China using GIS, expert knowledge, and fuzzy logic." *GIS and Remote Sensing in Hydrology, Water Resources and Environment.* 2004.

imagery and 1994, when construction on the dam began. The aerial comparison set the stage for the change detection analysis, which provided more detail of the regions that underwent the most change. The classification exercise delved even deeper to reveal the way the environment changed over the 19 year time period. The NDVI analysis provided even more information, but could be further refined to understand what types of vegetation the region has and the changes based on dam construction. A future study could utilize datasets from 1994 and 2012 for change detection and calculations to understand impacts resulting mainly from the dam. Unfortunately these data were not available for this study.

Field surveys of the region would also improve the accuracy of classification and result in a more detailed land use map for both time periods. This would aid in a more reliable change detection and calculation of the impacts the Three Gorges Dam has had on the region. Future research could be conducted to better understand how these changes have impacted the agricultural communities, the Yangtze River delta, and life on both sides of the dam. The Yangtze River used to flood annually, and this is no longer the case. According to one account, the Hubei Province has recently been seeing a drought and water levels in Poyang Lake, China's largest freshwater lake, have dropped to a record low[7]. Remote sensing techniques could be used to investigate these problems and figure out what might be the cause. These technologies are constantly evolving and scientists are better equipped every day to understand and explain the environmental problems facing today's world.

[7] http://www.theepochtimes.com/n2/china-news/shrinking-yangtze-river-challenges-three-gorges-dam-56841.html