Undergraduate Research Project

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Improved monitoring of suspended sediments in the Añasco River plume by using ETM+

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Abstract

Monitoring *in situ* concentrations of suspended sediments on coastal environments has proven to be hard work. Even though there have been several efforts to use remotely sensed imagery to provide valuable information on suspended sediment monitoring, there are many limitations that include low spatial resolution and high costs of remotely sensed data (Miller and McKee, 2004). Therefore, this research aims to enhance the multispectral and high resolution data available free from the Landsat ETM+ sensor. A pan-sharpening software named Pancroma is applied to improve the ETM+ images collected after 2003. Linear relationships are established between discharge, reflectance data, and total suspended sediments. Total suspended sediments are estimated using an algorithm developed by Rodriguez and Gilbes (2009). Four images where selected for processing. Discharge and Total Suspended sediments show an R^2=0.895, which demonstrates a significant relationship. Further comparisons are done in the research. The capabilities of the enhanced ETM+ images prove to be precise.

Keywords: ETM+, Suspended Sediment, Discharge, Pancroma

1. Introduction

Concentration and distribution of suspended sediments (SS) in Puerto Rico's water bodies has been increasing due to the high rates of erosion produced by heavy rain, river discharges, and anthropogenic activities (construction and agriculture activities) (Rodriguez and Gilbes, 2009).The size of the sediment particles transported on water will vary depending on the amount of discharge or turbulence present at the moment (Ondrusek et al., 2012). Most suspended sediment particles are in the range of clay (<0.002mm) or silt (>0.002 − 0.06mm). These sediment particles can be suspended in water for hours or even days depending on

concentrations and water turbulence (discharge, tides, etc.) present (Ondrusek et al., 2012). Rodriguez and Gilbes (2009) explain that high concentrations of SS will affect the ability of light to penetrate into the water column affecting the production of an ecosystem. This is why monitoring suspended sediments, especially for lakes and bays, is considered one of the most important water quality parameters (Min et al., 2012). For purposes of this research the Mayagüez Bay has been selected.

The Mayagüez Bay is located to the west of Puerto Rico between latitudes 18° 09'N to 18° 18'N, and longitudes 67° 09'W to 67° 15'W (Rodriguez and Gilbes, 2009). This area is highly affected by large sediment input from the Añasco River, which has a drainage area of ~200 square miles according to United States Geological Survey (USGS) National Water Information System. In addition to large sediment inputs, the Bay is affected by geomorphological processes such as longshore drifts and tides, which affect the distribution of SS in the river's mouth. All these processes make the Mayaguez Bay a great location for monitoring and understanding the dynamics of SS under different conditions, and their impact to the bay. There are a variety of sensors available to perform remote sensing research (Hu et al., 2004), but some of them can have limitations or be too expensive for continuous studies. Some examples of these sensors are the MODIS and the IKONOS sensors. MODIS sensor images are free to the general public, but they have a limited spatial resolution of 250m in selected bands. Even though this resolution is considered low in our ever evolving technology, it has proven to produce good quality results, but with some limitations (Hu et al., 2004). Another sensor is IKONOS. This is a commercial satellite that can take very high spatial resolution images of 1 m. The only problem with this sensor is that the images can cost thousands of dollars, making them

too expensive for continuous monitoring. Still, there is a free and high spatial resolution sensor available for use by general public, which is the Landsat 7 ETM+.

The Landsat 7 satellite was launched April 15, 1999 (Schott et al., 2001). This satellite carries the Enhanced Thematic Mapper+ (ETM+) sensor (Schott et al., 2001). This sensor is a high resolution imagine spectrometer that operates in the visible to near-infrared (VNIR), short wave infrared (SWIR), and thermal infrared regions of the spectrum providing images at 30m (15m for panchromatic band 8) resolution (Schott et al., 2001). The ETM+ is said to be "the most stable, best characterized Earth observation instrument ever placed on orbit" by the National Aeronautics and Space Administration (NASA) (Schott et al., 2001). The images provided by this satellite have proven to be of excellent quality in previous researches (Schott et al., 2001).The problem with the ETM+ is that in May 2003 the Scan Line Corrector (SLC) stopped working. According to NASA the SLC is used to "remove the zigzag motion of the imaging field of view produced by the along- and across-track motion" (NASA webpage), see figure 1 for an example. Without this component operating, the images produced by the ETM+ only acquire 78% of all the data, leaving the other 22% in gaps; an example is shown in figure 2. Even though the ETM+ images have these gaps, it still has the same level of accuracy and precision in geolocation and calibration. This research will benefit from the capabilities of the ETM+ sensor by enhancing its images after the SLC stopped working. This will be done by using a pan-sharpening software named Pancroma.

Pancroma software enables the creation of high resolution color images using the satellites band files. The program can be used to pan sharpen images from satellites such as Landsat, SPOT, Digital Globe, GeoEye, and ASTER. For purposes of this study Pancroma was used to fill up the gaps present in the ETM+ images. The program allows post 2003 SLC-Off

band files with missing data to be recovered by filling the gaps using pre 2003 SLC-On band data. This is important because ETM+ is an unrestricted license and free imagery available to the general public. Pancroma can restore the value of the data available, providing multispectral data for land use, mineral exploration, or like in this case, SS monitoring.

2. Methodology

This study emphasizes in providing corrections to the ETM+ images using specialized software. The enhancement was done using Pancroma software provided by the Geological and Environmental Remote Sensing Laboratory (GERS Lab) at the Geological Sciences Department in the University of Puerto Rico at Mayaguez. This research intended to use *in situ* data to compare to the ETM+ measurements, but no images could be found that coincide with the dates of sampling. Instead a comparison was done using discharge values for the dates that the images where taken. The algorithm developed by Rodriguez and Gilbes (2009) was implemented to determine if the gap filling corrections made to the ETM+ imagery do not affect the values of total suspended sediments. The algorithm applied was:

$$TSS = 602.63*(0.5157*(ETM+ \text{ band } 1) - 0.0089) + 3.1481 \text{ (Rodriguez and Gilbes, 2009)}$$

This approach will define the potential of corrected ETM+ images to monitor SS in Mayaguez Bay.

A. Landsat ETM+ SLC-OFF Data

The Landsat ETM+ images were ordered from USGS Earth Explorer webpage. Each order takes 1 to 3 days depending on the amount of orders being processed at the moment. The images are processed at a Level 1B, this means they are precision and terrain corrected. Once the

ordered images were ready, they were downloaded through Earth Explorer webpage. Each of the downloaded images included 8 bands and the Metadata. The bands were blue (450-515nm), green (525-605nm), red (630-690nm), near infrared (750-900nm), mid-infrared (1550-1750nm), thermal infrared (10.4-12.5µm), mid-infrared (2090-2350nm), and panchromatic (520-900nm) respectively. The Metadata file provided all the information concerning the image. Images from 2003-2010 where examined to ensure there was not cloud cover that affect the values over the study area. After rigorous examination 4 images were selected for processing:

- April 14, 2004
- February 28, 2005
- April 4, 2006
- March 8, 2008

These images can be seen in figure 3. Once the images where obtained the initial processing began.

B. Pancroma Processing

Since Pancroma was installed for the first time at the GERS Lab, initial processing took nearly 18 hours to understand how the software works. To start image processing the first thing to do is create a subset of the area you wish to work with. The gap images (Reference image) included the whole Island of Puerto Rico, but we were only interested in the West coast where the Mayaguez Bay is located. To create a subset, the reference images were loaded into Pancroma in the order of Band 1 (blue), Band 2 (green), and Band 3 (red). For purposes of this study these bands were the only ones needed. Using the "Band Combination" tool in Pancroma, initial subsetting was performed. The desired area was selected using the "Rubber Band Box Select" tool which provides a box like feature that enables the selection of the specific area to be cropped. This tool provides the corner coordinates of the subset. The same process was done to

an image without gaps (Adjust image). Before the images were further used they had to be pre-processed. In order to use the images, they were settled at the same scale. Sometimes Landsat images acquire two different resolutions (28.5 and 30m).To make sure the images were at same scale we loaded the image into Pancroma and use the "Pre Process" tool – "Resize Image" – "Scale Landast 28.5 to 30m", this multiplies the rows and columns by a factor of 28.5/30, and then multiply the x and y scale by the inverse ratio. This process ensured that each image has the same resolution.

To fix the gaps in the images the Adjust image must have the exact same area of the Reference image. To do this the subset reference bands have to be uploaded to compute the maximum common extents, the same has to be done to the Adjust images. Once the images had the same area, the histogram tool was used to compare the images colors. This tool matched the histogram of the Adjust image to the histogram of the Reference image, which provides better results when filling the gaps; go to figure 4 for an example. After the image was pre-processed the gap filling process began.

Three different methods are provided by Pancroma to fill the gaps on the images. The Transfer method, the Hayes Interpolation method, and the TERAS method. The Transfer method works by transferring the information from the adjust image directly into the reference image. The Hayes Interpolation method, instead of directly substituting the gaps, it computes the brightness level of each missing pixel in the Reference image by using information of the exact same pixel in the Adjust image. The TERAS method is an optimization method. It works by establishing a square frame with twice the search radius of the other two methods. This frame is positioned over targeted digital numbers (DN) and produces localized mapping matching only with DN's that are directly in contact to the targeted DN. The matching is repeated continuously

until the whole gap is filled. Each of these methods is applied through Pancroma's interface and processing time will vary depending on the capabilities of the computer in which the software is running. This study focused in the use of the TERAS method, because this method produced better images when filling the gaps. The method was applied by loading the image into Pancroma, select the "Gap Fill" tool – "TERAS Method" – then adjust the values wanted manually. The manually adjusted values varied for every image. In order to get best results the values were manipulated, and many combinations were done to ensure image quality. This process was done to each band individually, taking 2 to 3 hours in processing a full color image; see example in figure 5. Once the full color image was created, it was loaded into ENVI 4.8 for data analysis.

C. ENVI 4.8 Data Processing

The initial processing, using Pancroma, was a preliminary phase providing improvements to the images quality. Image processing using the Environment for Visualizing Images software (ENVI) uses different steps to generate functional products. ETM+ images have DN instead of calibrated pixels, so they were converted to reflectance. This conversion was done automatically on ENVI using the Metadata file provided when downloading the images. With the DN converted to radiance values, atmospheric correction was made. ENVI provides a tool for atmospheric correction. This tool selects the darkest value in the image and subtracts it providing reasonably reflectance. After all that processing was done the implementation of the local algorithm from Rodriguez and Gilbes (2009) was performed. This algorithm was implemented to the image using the "Band Math" tool on ENVI. After the algorithm was applied the pixel values were converted to TSS. Seven points from the Añasco River plume where selected for analysis.

The values of those points were compared to radiance (Rrs) and discharge values to see if there is a relationship.

D. Discharge Values

Discharge values for the Añasco River where obtained from the USGS National Water Information System on the web. The USGS station used for Añasco River was station 50144000, located near San Sebastián. Discharge values for the dates of the images can be seen in figure 6.

3. Results and Discussion

The products generated using Pancroma are of very good quality. Images still show fading in areas where the gaps used to be. Pixel values over these areas do not show any significant difference when compared to the next neighbor. These results were obtained using the TERAS method to fill the gaps. This method proved to be the most accurate method of all three. Pancroma has proved to be an effective and accurate tool for enhancing ETM+ images. These images are not only corrected for the gaps, they are now almost 100% fit with information to be used for processing and obtaining data.

The River discharge data for each of the images were compared to the discharge extents of the Añasco River plume. For February 28, 2005 discharge was 2.72 m^3/s and the plume extended 3.31km; April 14, 2004 had a discharge of 2.09 m^3/s and the plume extended 2.30km; April 4, 2006 had a discharge of 11.75 m^3/s and the plume extended 5.45km; March 8, 2008 had a discharge of 2.78 m^3/s and the plume extended 4.04km; see figure 7. Plume extents vs. discharge showed an R^2=0.765. The value for plume extents vs. discharge shows direct relationship as they are thought to have, the slight percent of difference can be because of the other geomorphological processes (tides, longshore drifts, etc.) acting upon the plume. The

Comparison between discharge and total suspended sediments showed an R^2=0.895, this means that there is a significant relationship between discharge and TSS; see graph on figure 7. The same was done using radiance values at 650nm resolution. The calculations for radiance vs. discharge did not show a good relationship. Calculations showed an R^2=0.111. This value is thought to be low because of the variation in reflectance of different sized sediment particles (clays, silts, sand, etc.).

4. Conclusion

The results obtained in this research suggest that enhanced ETM+ images provide good quality results. This is possible thanks to the high resolution and calibration of ETM+ sensor. Estimation of TSS applying Rodriguez and Gilbes (2009) local algorithm has proved to produce significant results when monitoring suspended sediments. The comparison between TSS and discharge shows a good correlation. This is because most TSS in this area is related to Añasco River discharge on the Bay. The low relationship between radiance and discharge can be due to difference in reflectance of different sized particles and the spectral sensitivity of the sensor. According to Rodriguez and Gilbes (2009) low concentrations of TSS can affect the reflectance values during satellite monitoring because of the low water leaving radiance. In order to verify this it is recommended to collect *in situ* measurements and compare to ETM+ images. Pancroma software has proved to be an efficient tool for enhancing the capabilities of ETM+ imagery.

This study can be used to compare to field data, providing a tool for continuous monitoring. It can also contribute to researches that monitor vegetation indexes and vegetation distribution. It is important to watch out of cloud coverage when working with the images, because it can produce unwanted results.

5. Acknowledgements

6. References

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*A)*Internet References and Other

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Pancroma Website: *www.pancroma.com*

USGS Waterwatch Website:

http://waterwatch.usgs.gov/new/?id=wwchart_ftc&site_no=50144000

7. Figures
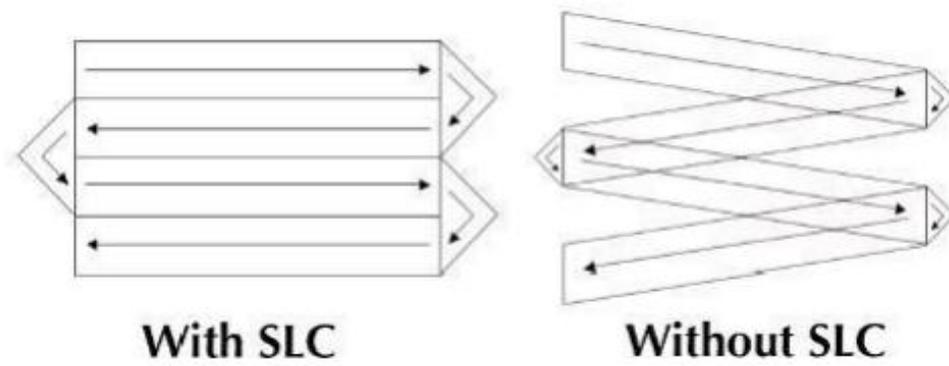
Figure 1: This figure shows an example of how the scan line corrector works in the ETM+ sensor. Without the SLC working 22 percent of the data cannot be seen. Courtesy of TERRAINMAP Earth Imaging LLC 2010,2011,2012
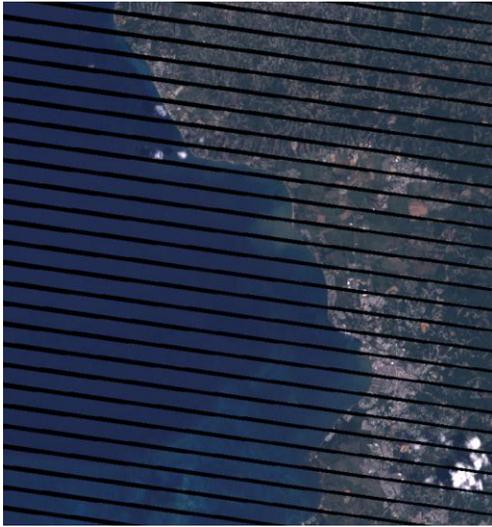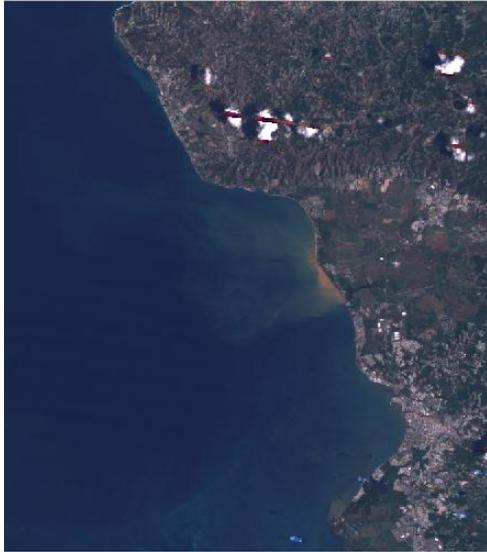
a) Image of April 14, 2004
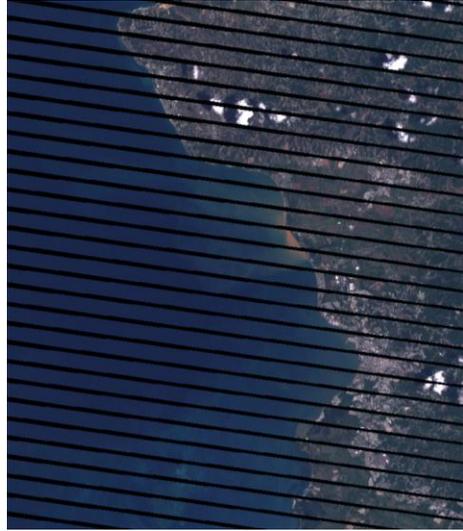
b) Image of February 28, 2005

c) Image of April 4, 2006
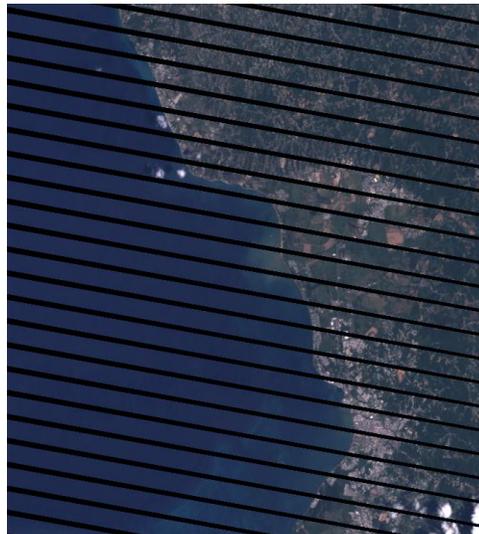
d) Image of March 8, 2008

Figure 2: In images *a-cd* the gaps formed by the SLC-Off can be seen. These gaps do not affect the geolocation or calibration of the image. Image ordered from USGS Earth Explorer webpage, www.earthexplorer.com.
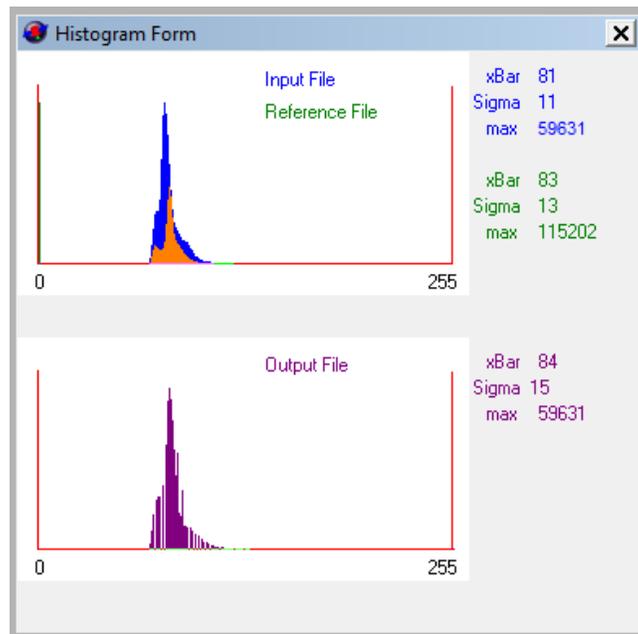
Figure 3: An example of the Histogram matching on image of February 28, 2005 produced by Pancroma to ensure better color quality on the end results.

Figure 4
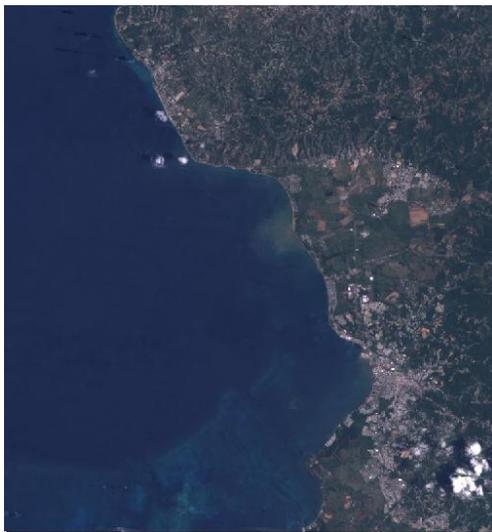
a) Image of April 14, 2004
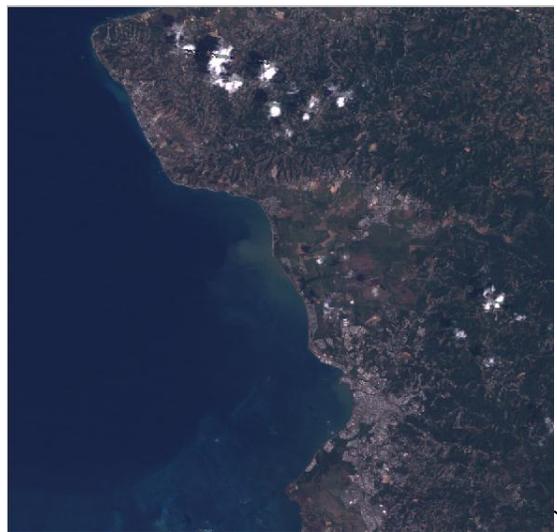
b) Image of February 28, 2005
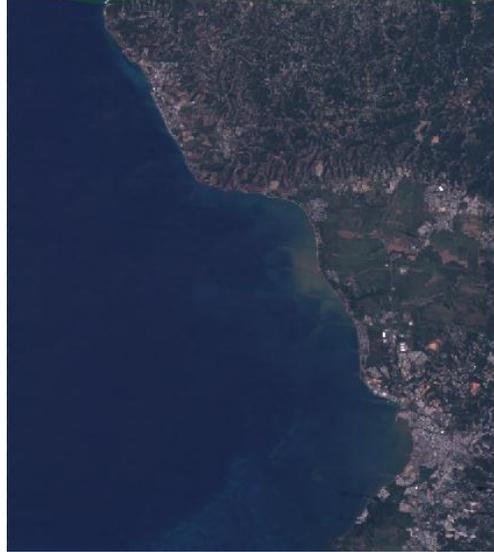
| c) Image of April 4, 2006 | d) Image of March 8, 2008 |

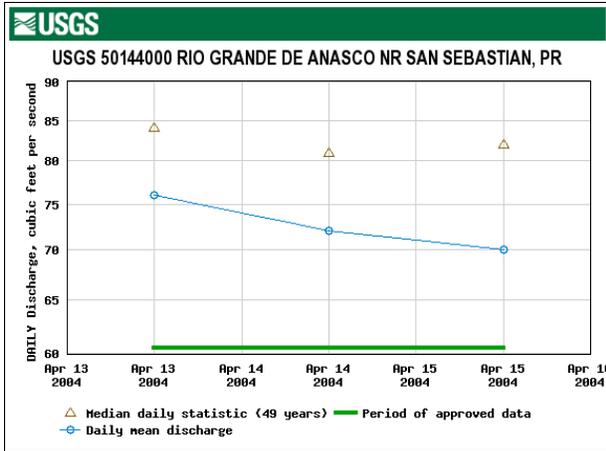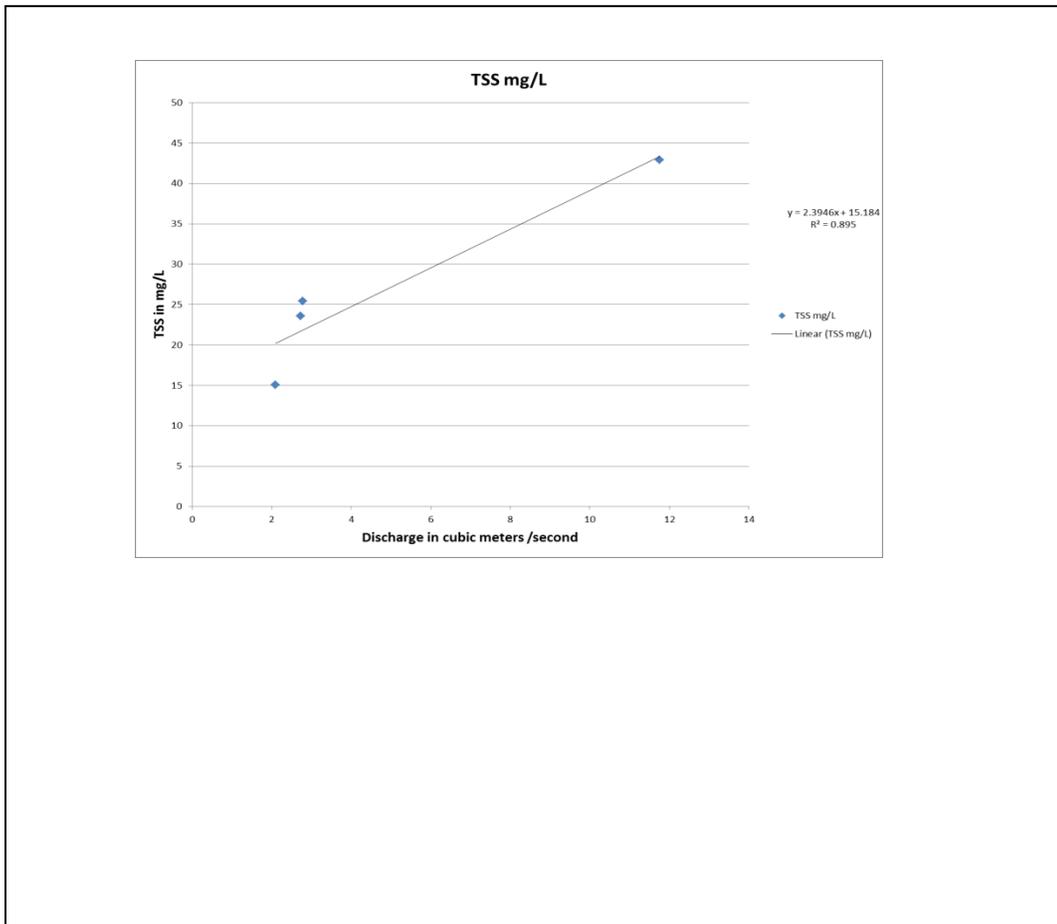Figure 5: Images *a-c* are the results after processing with Pancroma software.
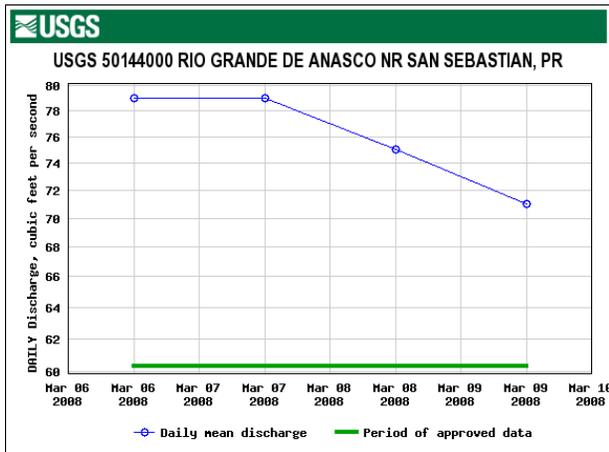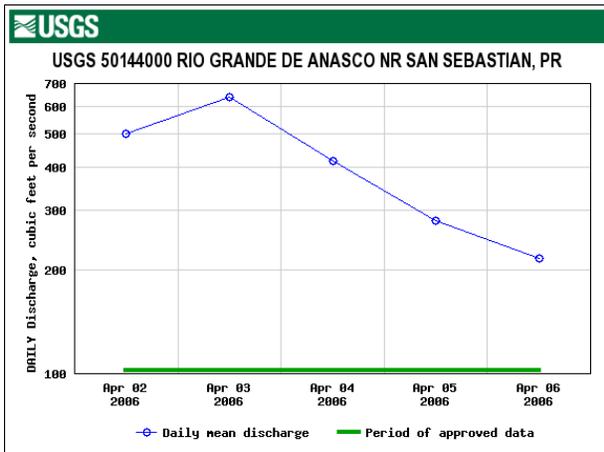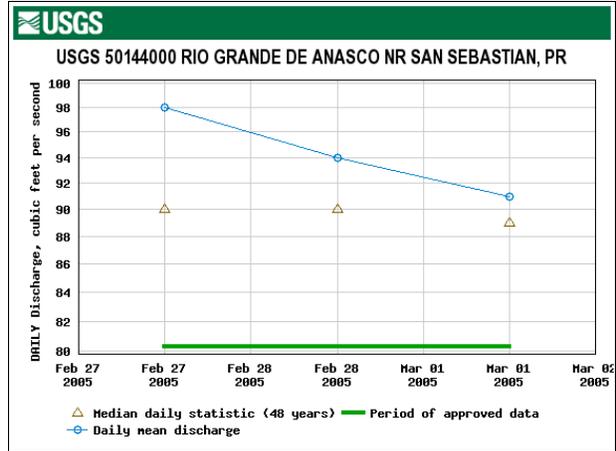
Figure 6: These graphs show discharge for the same dates that the images where taken. This data will be used to compare to plume extents. Graph courtesy of USGS National Water Information System on the web (waterwatch.usgs.gov).
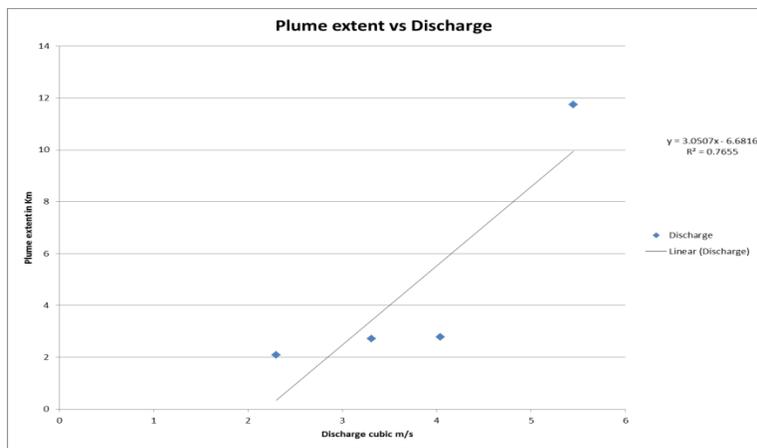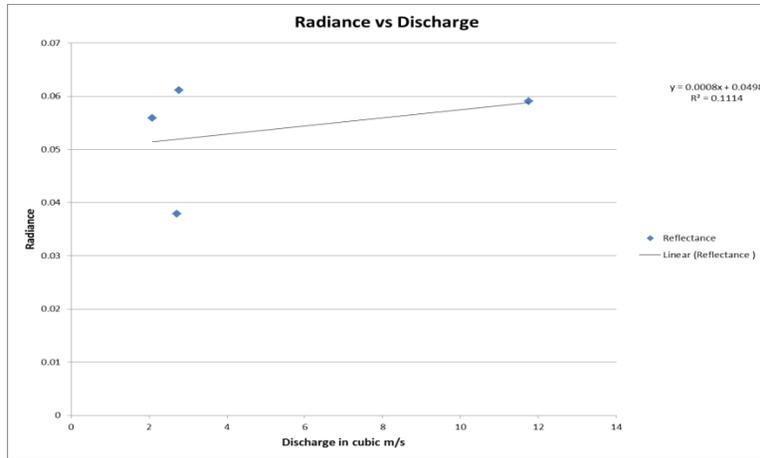
Figure 7: This figure shows the graphs for Discharge, TSS, and Reflectance comparisons.