UNDERGRADUATE RESEARCH
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University of Puerto Rico
Mayaguez Campus
Faculty of Arts and Sciences
Department of Geology

Characterizing the Añasco River Plume using MERIS

Principal Investigator

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Josué Aceituno Díaz
Undergraduate Student
802-06-0014
Mayagüez Campus
Department of Geology
Josue.Aceituno@upr.edu
J.AceitunoDiaz@yahoo.com
Advisor: Dr. Fernando Gilbes Santaella

Abstract

An investigation called Application of the Soil and Water Assessment Tool (SWAT) to Estimate Discharge and Sediment Yields from the Río Grande de Añasco Watershed, Puerto Rico funded by the UPR-Sea Grant, aims to understand the relationship between runoff and sediment yields from the Rio Grande de Añasco watershed with the dynamics of sediment plumes**.** Research from Delvin et al. (2012), Hu et al. (2004), and others, suggest that river plume extent is associated with high river discharge frequencies. Concentrations of total suspended sediments are higher than normal during these types of events as well as its spatial distribution. It was then hypothesized and proved that from August through November (wet season) the concentration of total suspended sediments on Rio Grande de Añasco's river plume was higher compared to dryer months (December to May), and its spatial distribution was more extensive during those month. Suspended sediments of the RGA plume may not necessarily be associated with river discharge, R^2 (linear) = 0.63656 and R^2 (logarithmic) = 0.55439. The current undergraduate study has used the European Space Agency's Environmental Satellite and its Medium Resolution Imaging Spectrometer (MERIS) sensor for the first time in this region and thus to providing MERIS data collection, data processing and data analysis for the Sea Grant project. A new methodology for characterizing the RGA river plume was constructed, as it was a crucial component of this undergraduate research because it has never been done at the Mayagüez Bay.

Keywords: MERIS, Suspended Sediment, River Plume, Coastal Area, Rio Grande de Añasco, Puerto Rico.

1.0 Introduction

Río Grande de Añasco (RGA)'s watershed is located in western Puerto Rico and it extends over seven of the 78 municipalities of Puerto Rico (Figure 1). The main channel has a length of 74,000m from elevation 1,204m to the Caribbean Sea and drains an area of 520000m^2 (Díaz and Jordan, 1987). The river rises in the mountains near Lares, enter the lower valley at El Espino, and discharges to the sea in the Añasco Bay in the latitude 18°15'56.27"N and longitude 67°11'22.53"W (Figure 2), (Díaz and Jordan, 1987).

Soils in the mountain region are predominantly red, acid soils with silt clay profiles. In the coastal valleys soils have developed from sediments of the upland soils. The coastal valley soils have varying textures, but are generally fine to moderately fine and vary in drainage properties from well to poorly drained (Gierbolini, 1975). Three main types of geologic groups predominate in the Río Grande de Añasco basin. Quarternary-alluvium deposits predominate in the lower flood plains and the river valleys. The northern part of the watershed including Atalaya Mountains consists of Tertiary and Late Cretaceous volcanic and sedimentary rocks. In the eastern, central and southern parts of the watershed, Cretaceous sedimentary and volcanic rocks predominate (Gierbolini, 1975). Warm, wet summers, and warm but dry winters describe the climate, with progressively cooler temperatures occurring in the mountainous regions. The long-term average annual rainfall is approximately 220 cm (Harmsen et al., 2009). A wet season usually occurs from August through November and a drier season from December through May (Gilbes et al., 1996). During the dry season a large amount of sediments are re-suspended due to strong waves. Recurrent cold fronts that travel across the Caribbean region during winter produce such wave action.

Land-based activities (as traditional agriculture) typically induce an increase in the amount of sediment being exported from watersheds and therefore represent a threat to near shore coral reef systems (Ramos and Gilbes, 2012). Such localized increase in anthropogenic activity is perceived to be an important cause of the generalized decline in coral cover observed throughout the Caribbean Region.

An investigation called *Application of the Soil and Water Assessment Tool (SWAT) to Estimate Discharge and Sediment Yields from the Río Grande de Añasco Watershed, Puerto Rico* funded by the UPR-Sea Grant, aims to understand the relationship between runoff and sediment yields from the RGA watershed with the dinamics of sediment plumes. The project is aiming to find a better accuracy in Total suspended sediment (TSS) estimation to accomplish this. The Sea Grant funded project is addressing watershed assessment actions recommended by the US Coral Reef Task Force by quantifying and modeling water discharge and sediment yields from the Río Grande de Añasco in western Puerto Rico. In collaboration with a parallel study, runoff and sediment yield estimates will be used to better understand sediment transport dynamics within Mayagüez Bay (Ramos and Gilbes, 2012). Among several possible ways to study the river plumes in the Mayagüez Bay, the current undergraduate study has used the European Space Agency (ESA)'s Environmental Satellite (ENVISAT-1) and its Medium Resolution Imaging Spectrometer (MERIS) sensor for the first time in this region and thus to providing MERIS data collection, data processing and data analysis for the Sea Grant project. The MERIS sensor has a spatial resolution of 300 meters and aimed to be the first ocean color sensor that is adequate for coastal remote sensing (Kratzer et al., 2007). It also has an improved spectral resolution, with 15 programmable spectral bands. The MERIS Case 2 water algorithm is a neural network, which uses the logarithm of the remote sensing reflectance above the water surface in eight of the fifteen MERIS bands after atmospheric correction. The eight bands used for deriving the level 2 products are centered at 412, 442, 490, 510, 560, 620, 665 and 708 nm (Kratzer et al., 2007). ESA announced on April 2012 that they lost contact with ENVISAT. The spacecraft was still in a stable orbit, but attempts to contact it were unsuccessful. Operations ceased on May 2012, but its timeframe functioned well for the proposed work (Ramos and Gilbes, 2012). This research intended to determine the correlation between RGA's river plume sediment extent from MERIS data and daily discharge data from USGS station. Research from Delvin et al. (2012), Hu et al. (2004), and others, suggest that river plume extent is associated with high river discharge frequencies. Concentrations of TSS are higher than normal during these types of events as well as its spatial distribution. It is then hypothesized that from August through November (wet season) the concentration of TSS on RGA's river plume will be higher compared to dryer months (December to May), and that its spatial distribution will be more extensive during those months. As part of this analysis the distribution of the river plume throughout the Añasco Bay during both seasons were also determined.

2.0 Methods

2.1 Image Search and Download

A total 307 MERIS images with 300 meters of spatial resolution and covering the west part of Puerto Rico, were downloaded from ESA's CoastColour Project archive (http://coastcolour.org/data/archive/puertorico/). ESA launched the CoastColour project to fully exploit the potential of the MERIS instrument for remote sensing of the coastal zone (Brockmann, 2011). The product requirements have been derived from a user consultation process. CoastColour is developing, demonstrating, validating and intercomparing different Case 2 algorithms over a global range of coastal water types, identifying best practices, and promoting discussion of the results in an open, public form (Brockmann, 2011). The images available dataset are from 2005 to 2012, but no images of the year 2012 included Puerto Rico and therefore the downloaded images are from 2005 to 2011.

2.2 Image and Data Selection

After several weeks of downloading the 307 MERIS images, they were processed from level 1 (raw image) to level 2 (final products). Level 2 images contain the concentration retrieval products of chlorophyll (CHL), total suspended matter or sediments (TSM), coloured dissolved and detrital matter (CDOM) and many others. The main interest of this research was to obtain the concentration of TSM.

The First step to obtain the concentration of TSM was to process the images thorough the MERIS Case 2 Regional Processor, which consist of three different algorithms. The regional algorithm of this processor relates the radiances observed by MERIS to first atmospherically corrected reflectance and then to water quality constituents. Each image is then saved as BEAM-DIMAP in order to process the images faster. BEAM is an open-source toolbox and development platform for viewing analyzing and processing of remote sensing raster data that was originally developed to facilitate the utilization of image data from Envisat's optical instruments (http://www.brockmann-consult.de/cms/web/beam/). Some processing parameters are established for every image before the processing. These are an atmospheric correction, regional water algorithm, 1.0 TSM conversion exponent, 1.73 TSM conversion factor, 1.04HL conversion exponent, 21.0 CHL conversion factor and 4.0 Spectrum out of scope threshold. After the processing was finished the band with the TSM product was chosen. TSM is given in g/m^3 units.

After several weeks of processing through the MERIS Case 2 Regional Processor, only 128 images were selected (out of 307 images) based on those that showed the least partial cloud cover around the RGA's river plume area. In order to develop and validate the appropriate methodology for processing and analyzing the MERIS images, and due to the lack of time the amount of images to extract the TSM concentrations was reduced in this first stage of the study. Only 2 images representing the largest and shortest plume length or extension from each year were selected by measuring such length with BEAM's range finder tool, making it a total of 14 images. They where divided into 7 images with maximum plume length (Table 1) and 7 images with minimum plume length (Table 2).

In addition, stream discharge data collected by a USGS gauging station located on the main RGA channel (USGS 50144000) was downloaded from the USGS website (http://pr.water.usgs.gov/), analyzed and categorized for the same dates of the images. Dr. Carlos Ramos Scharron, the main investigators for the Sea Grant funded project did the initial analysis, which involves determining the frequency of different types of flow conditions during the 2005-2011 period. The basin hydrological conditions that were considered are the total amount of flow during four periods: 4 cumulative hours before the image was generated followed by 8 cumulative hours before, 12 cumulative hours before, 18 cumulative hours before, 24 hours cumulative before, 48 cumulative hours before and 72 cumulative hours or 3 days before the image was generated. The discharge is measured in m^3. It is important to note that these values represent water discharge in the middle of the basin and not in the mouth. It is difficult to determine how long it would it take the water to get from the gauging station (USGS 50144000) to the mouth because there are not any gauging stations near the RGA's mouth (figure 3). These data were compared with the TSM extracted from the images to evaluate their relationship between. These analyses along with visual interpretation of the processed images helped with the characterization of the RGA river plume. Constructing a new methodology for characterizing the RGA river plume is a crucial component of this undergraduate research because it has never been done at the Mayagüez Bay.

2.3 Extracting TSM Product

To extract the TSM concentrations of the 14 images, an analysis grid around the RGA had to be defined and established to use in each image. After several trials and errors creating different area grids on BEAM, a final grid was selected. The analysis grid (Figure 4) was created using ArcGIS Desktop v.10. The grid consists of 6 transects with a length of 25 kilometers, starting from the mouth of the RGA and extending through the bay. A distance of 5 km between each transect was established at the end of the 25 km transects. To better understand the RGA's plume behavior the analysis grid was divided into different zones, six zones from north to south and five zones from east to west. The east to west zones were established by measuring every 5 km of the six transects until reaching the 25 km mark, this gave 5 different zones to analyze the behavior of the plume east to west.

The analysis grid defined in ArcGIS was used to determine the sampling stations (i.e. the same coordinates) for extracting the TSM concentration in the MERIS images using BEAM. A random image of the 14 images was used to show the TSM product and define the analysis grid on BEAM. Each 5 km mark and 25 km mark coordinates was added using BEAM's pin manager tool (Figure 5). Using BEAM's line drawing tool, the transects were traced trough each mark and thus creating the same grid that was created on ArcGIS. Each pixel that touched the six transects were then carefully marked with a Ground Control Point (GCP), using BEAM's GCP manager (Figure 6). A GCP stores the geographical coordinates of each pixel on the transects. These GCP points were saved in a text (.txt) file so that the same analysis grid could be used for the different 14 images. Through BEAM's pixel extraction tool each pixel of the TSM product in the analysis grid for each image was extracted. The pixels were divided in north to south zones (Z1, Z2, Z3, Z4, Z5, Z6) and east to west zones (Z1, Z2, Z3, Z4, Z5).

2.4 Analysis

2.4.1 Visual Analysis

Each image was visually analyzed taking into account only the major concentrations of TSM coming out of the mouth and extending through the analysis grid and its dynamics in the north to south and east to west zones. A BEAM tool called color manipulation was used to visually see these high concentrations. Opening an image in BEAM either loads image settings from the product itself (BEAM-DIMAP format only) or uses default color settings, which in this case the default setting was a gray scale color palette. Images of a single, spectral/geophysical band use a color palette to assign a color to a sample value in the source band. By default, the editor is in a mode where sliders are used to modify the color palette and with this change the assignment of sample values to colors (Figure 7). The Colour Manipulation tool has a couple of predefined color palettes. All of them were tested to see which worked best showcasing the river plume and its TSM concentrations. The one selected was CHL_SeaWiFIS color palette, which automatically distributes points of the color palette between maximum and minimum values. This palette showcased clearly the movement of the TSM along the analysis grid. Certain colors of this palette were change to highlight the TSM (e.g., dark blues were changed to black).

2.4.2 Statistical Analyses

The statistical analyses were performed using Microsoft's Excel Formulas tool and considering the study zones: north to south analysis and east to west. The extracted pixels containing the TSM values from the analysis grid were used to calculate the maximum, minimum, average and median TSM values for the six north to south zones of the 14 images. These values were then plotted (four charts) by zone in a stacked column chart to see the dynamics of the plume in each zone. The pixels that were shared by each transect (the mouth pixel) were excluded from these calculations. The same methods were used for the 5 zones east to west analysis of the 14 images. The east to west analysis is divided in 5 zones.

To have a better understanding of the dynamics of the RGA's plume, the images with maximum TSM values were gathered on a single table for both north to south and east to west analyses. The same approach was done for images with minimum TSM values. These values where plotted (stacked columns) and compared among years, months, and zones (3 charts on maximum, 3 charts on minimum).

The pixel value of TSM in the mouth river was selected from each year and compared with the basin hydrological conditions (i.e. the stream discharge from the USGS) considering a period of 4 cumulative hours before the image was generated, 8 cumulative hours before, 12 cumulative hours before, 18 cumulative hours before, 24 hours cumulative before, 48 cumulative hours before and 72 cumulative hours or 3 days before the image was generated. A regression analysis with a linear trend and logarithmic trend line of the data were created with a marked scattered chart in Excel for each of the cumulative hours.

3.0 Results

3.1 Visual Analysis Results

A lot differences between the images with maximum plumes and minimum plumes were found. The majority of the images with maximum plumes (Figure 8) showed the plume moving north. There were high concentrations of TSM favoring the Z1 and Z2 regions of the north to south zones; the plume moved north and along the coastline. It also moved approximately 15 km west as most of the maximum values reached the Z3 region of the east to west zones (2005/Nov/08, 2007/Nov/07, 2008/Nov/10 and 2009/Sep/18 dates of figure 8). Only one image surpassed the Z3 region reaching the 25 km with high concentrations of TSM (2011/Nov/12 date). High concentrations of TSM would be colors from dark maroon up to the color green-yellow, as the legend on Figure 10 shows.

The majority of the images with minimum plumes (Figure 9) did not move significantly outside the mouth area, however they show some movement due north of small TSM concentrations moving along the coastline (2005/Dec/23, 2006/Jun/19, 2010/Mar/15 and 2011/Jan/27 dates of figure 9). Generally the TSM values of these images are lower than the images showing the maximum plumes. The color green-yellow is more abundant than darker colors like dark maroon and red.

3.2 Statistical Analyses Results

3.2.1 North to South Plume Dynamics

Most of the maximum values from north to south, distributed themselves almost uniformly throughout Z2, Z3, Z4 and Z5 (Graph 1). Z1 shows higher TSM values and does not behave uniformly with relation to the other zones most of the time, however there are significant occasions were Z1 and Z6 behaved almost uniformly in relation to the other, both showed high TSM values (Graph 2). Most of the minimum values are uniformly distributed throughout the zones (Graph 3).

If the average values are equal to the median values, the distribution of data does not contain extreme values. The average TSM values were similar to the median values on the dates were minimum plumes occurred, 4 out of 7 dates with minimum plumes had similar average and median values (Graph 4 & 5). Unlike dates showing maximum plumes; average and median values differed (Graph 6 & 7).

A pattern of TSM distribution is seen when comparing maximum TSM values among zones (graph 8), months (graph9) and years (graph 10). Throughout the 7 years (2005-2011) the maximum TSM values mainly occurred on Z1 (zone 1), in September and

November from 2007 to 2009. Minimum TSM values over 7 years mainly occurred on from Z3 to Z5, in June, September and November, in 2006, 2008 and 2009 (Graph 11, 12 &13).

3.2.2 East to West Plume Dynamics

Most of the maximum values from east to west are on Z1 and Z2; Z1 having the highest values out of the 5 zones (Graph 14). The minimum values appear on Z5 (Graph 15). The average TSM values were similar to the median values on the dates were maximum plumes occurred. Unlike dates showing minimum plumes; average and median values differed.

When comparing maximum TSM values among zones (Graph 16), months (Graph18) and years (Graph 19), throughout the 7 years (2005-2011) it can clearly be seen that the maximum concentrations of TSM occurred on Z1in every month of the 7 years. Minimum TSM values over 7 years mainly occurred on Z5 in June and September, in 2006 and 2009 (Graph 20, 21 and 22).

3.2.3 TSM vs. Discharge Results (Graphs 22-35)

TSM vs. Discharge regression analysis with a linear trend and logarithmic trend line of the data for the 4-cumulative hours showed a linear regression of 0.55396 and a logarithmic regression of 0.51841. For the 8-cumulative hours linear regression was 0.58866, the logarithmic regression was 0.53746. For the 12-cummulative hours linear regression was 0.61381, logarithmic regression was 0.55125. For the 18-cummulative hours linear regression was 0.63656, logarithmic regression was 0.55439. For the 24-

cummulative hours linear regression was 0.53182, logarithmic regression was 0.51128. For the 42-cummulative hours linear regression was 0.54945, logarithmic regression was 0.50419. For the 72-cummulative hours linear regression was 0.52704, logarithmic regression was 0.46154.

4.0 Discussion

Visual results show that the RGA’s plume main movement during the wet season (August through November) is due north with a 15 km extension due west. During the wet season concentrations of TSM are high, although in some cases there were high concentrations of TSM in drier seasons (December to May), which are probably detected as high values of TSM by MERIS, due to the phenomenon of re-suspended sediments generated by strong waves. Generally during drier seasons the RGA’s plume extension shows a slight movement along the coast due north but not significantly, as it does not surpass 5 km and most of the plume stays near de river mouth where the highest values of TSM are located during these drier seasons. These values are significantly lower than TSM values of the wet season.

The visual results are backed up by the statistical analysis. Statistical Analysis showed that on wet seasons the TSM would move uniformly along the analysis grid for a few kilometers until a certain point where high concentrations will start to move north (Zone 1, North to South). Occasionally, not often the RGA’s plume will do this in both north and south thus moving in the two directions. (Moved to zone 1 & 6, north to south). Based on the statistical analysis on dry seasons the RGA’s river plume also moves north but with much lower values of TSM concentrations. High TSM values appeared mostly on the wet season months of September and November. Half of the lowest values appear in the wet seasons, half appear on the drier seasons. When it comes to low values there is not much of a connection with dry or wet seasons as low values could mean values of pixels that are far away from the mouth. It does not necessarily mean that were on a dry season, unlike the appearance of very high values of TSM which could indicate a wet season.

The 18-cummulative hours linear regression of 0.63656 and logarithmic regression of 0.55439 showed the biggest relationship between TSM and Discharge. This raises questions as it was expected that the relationship between the two would be at least near 0.8 in any of the cumulative hours. A possible explanation is that the discharge values represent water discharge in the middle of the basin and not in the mouth; a portion of the drainage basin reading is missing, as there are no gauging stations near the mouth area. So it is possible that the TSM values in RGA's plume come from a discharge that took place 18 hours before MERIS reached the area and generated the image.

5.0 Conclusion

The MERIS sensor is reliable to detect suspended sediment in the water surface of the RGA. Based on my analysis grid, during wet seasons the RGA's plume will move north and extend approximately between 20 to 15 kilometers to the west during high discharge events. During the wet seasons especially on the month of November the RGA plume will have the highest peak of sediment values. The lowest values will occur during dry season mostly but they may also occur during the summer. During these dry seasons the RGA plume will not make a significant or big move due north, but it will still move at least 5 km to the north along the coastline.

Suspended sediments of the RGA plume may not necessarily be associated with river discharge there could be other factors contributing to the suspension of sediments in the area. This subject needs further investigation as it is still on debate.

Further analysis could better the understanding of the RGA's plume. A different analysis Grid could be made around the plume using other methods and a different set of images could be included on the analysis. Not all the images covered 100% the RGA plume, some of those images could be use and compared with the ones used on this research.

6.0 Acknowledgements

I would like to give a big thank you to my advisor Dr. Fernando Gilbes Santaella for his guidance and for always being available when I needed his help with my research. I would also like to thank graduate student Belitza Brocoo for explaining how use the BEAM toolbox and finally thanks to Dr. Carlos Ramos Scharron for providing the discharge data for 2005-2011.

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8.0 Tables

Table 1. Dates with maximum (long) plume length.

Year	Month	Date	Downloaded	Processed	Cloud Coverage Percentage	Plume length (km)
2005	November	8	Yes	Yes	0%	15.942
2006	March	9	Yes	Yes	0%	17.946
2007	November	7	Yes	Yes	0%	15.120
2008	November	10	Yes	Yes	0%	13.988
2009	September	18	Yes	Yes	0%	11.866
2010	January	1	Yes	Yes	0%	4.370
2011	November	12	Yes	Yes	0%	27.819

Table 2. Dates with minimum (short) plume length.

Year	Month	Date	Downloaded	Processed	Cloud Coverage Percentage	Plume length (km)
2005	December	23	Yes	Yes	0%	3.408
2006	June	19	Yes	Yes	0%	1.817
2007	July	28	Yes	Yes	0%	2.824
2008	March	26	Yes	Yes	0%	3.485
2009	April	18	Yes	Yes	0%	3.596
2010	March	15	Yes	Yes	0%	3.622
2011	January	27	Yes	Yes	0%	4.804

Figures

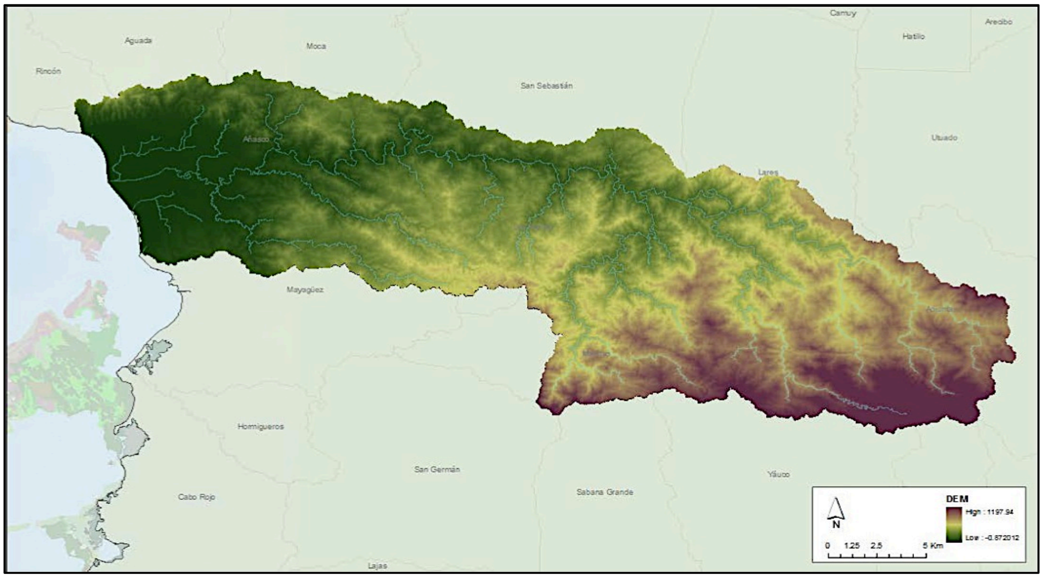


Figure 1. Río Grande de Añasco (RGA)'s watershed is located in western Puerto Rico. From Ramos and Gilbes (2012).

Figure 2. Añasco Bay showing RGA's river plume. Image from Google Earth, 2013.

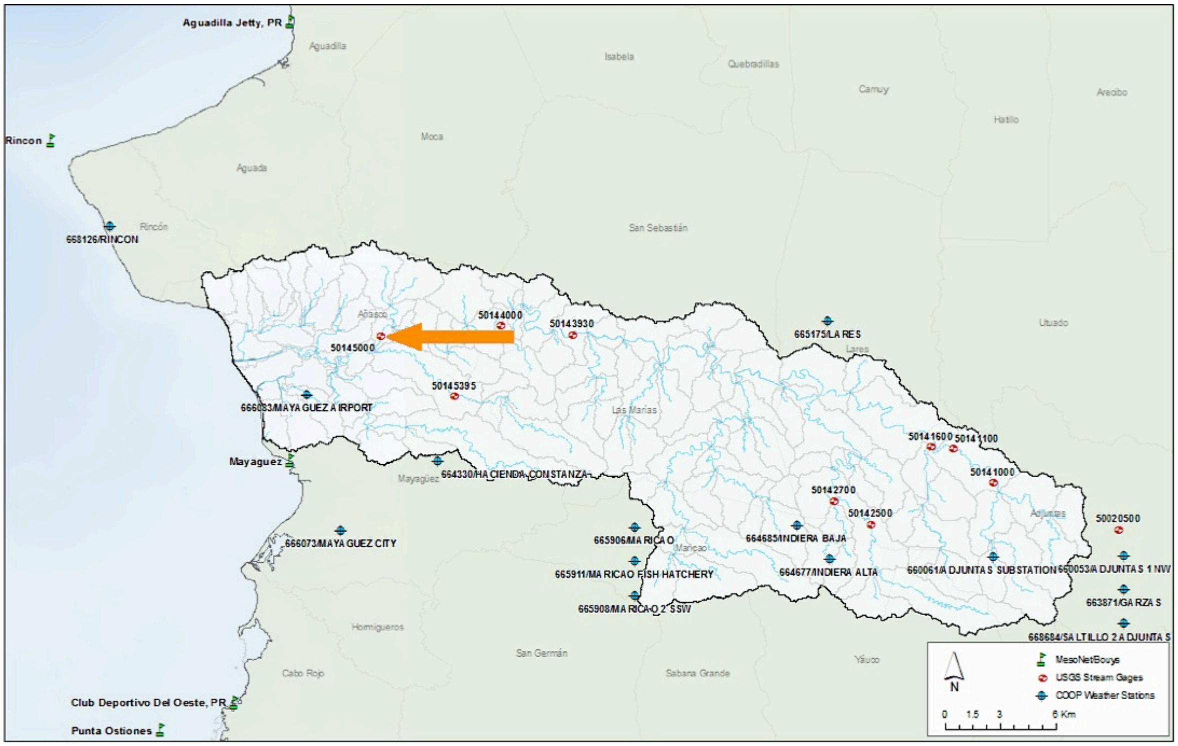


Figure 3. Discharge values represent water discharge in the middle of the basin and not in the mouth. It is difficult to determine how long it would it take the water to get from the gauging station (USGS 50144000, see arrow) to the mouth because there are not any gauging stations near the RGA’s mouth.

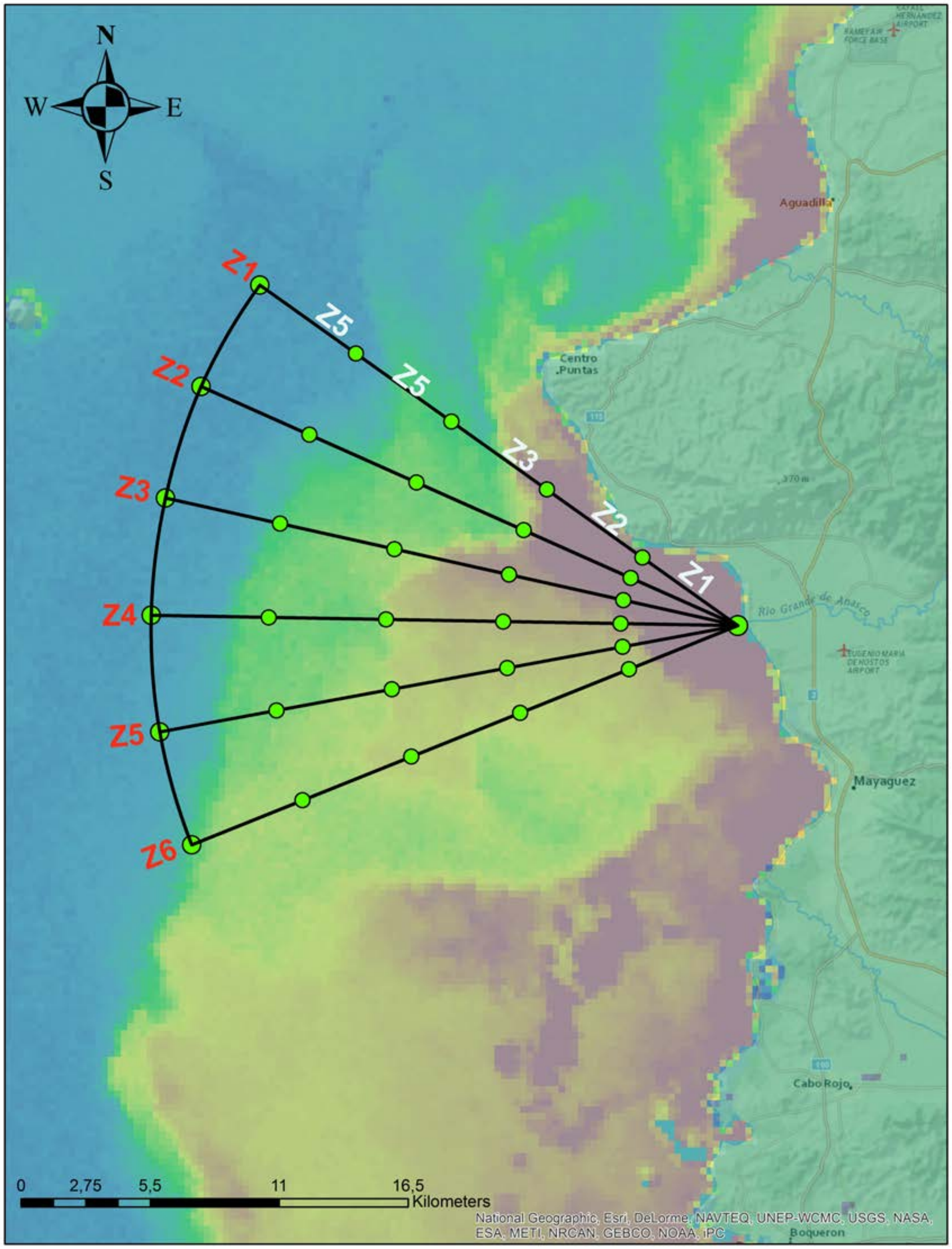


Figure 4. Analysis Grid created on ArcGIS Desktop v.10. The north to south zones are in color red (Z1, Z2, Z3, Z4, Z5 and Z6). The east to west zones are in color white (Z1, Z2, Z3, Z4 and Z5)

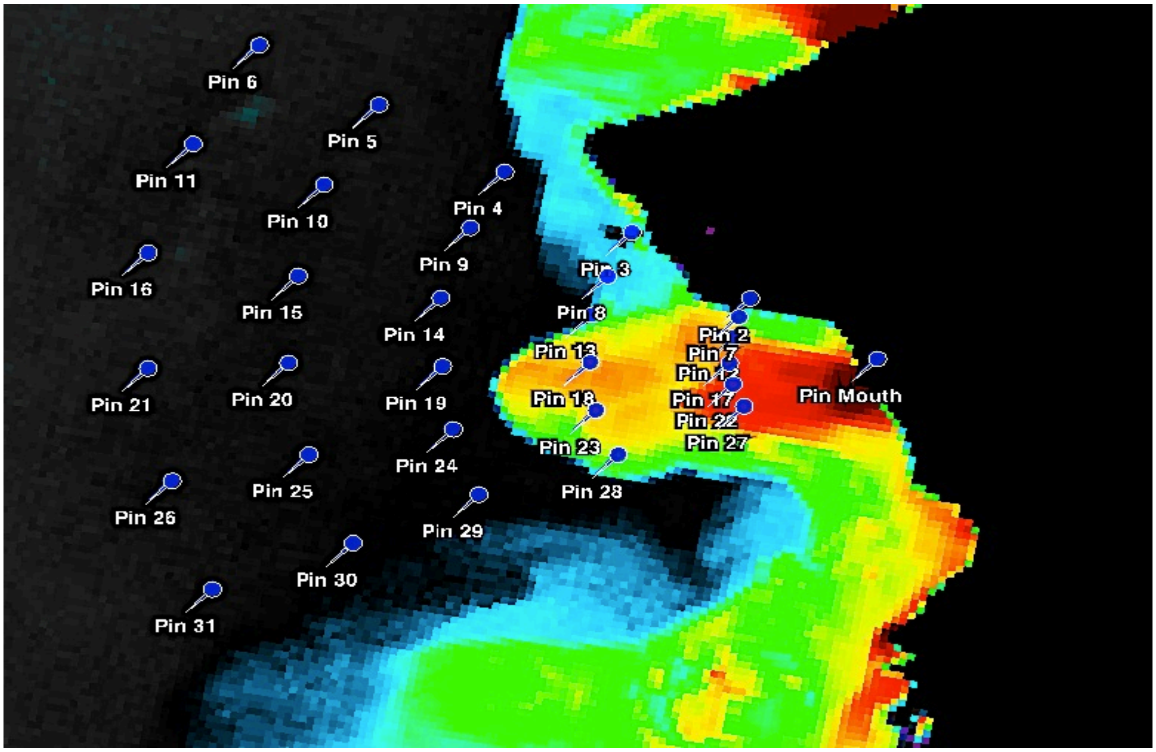


Figure 5. Coordinates from the analysis grid created on ArcGIS being transferred to BEAM using the pin manager tool.

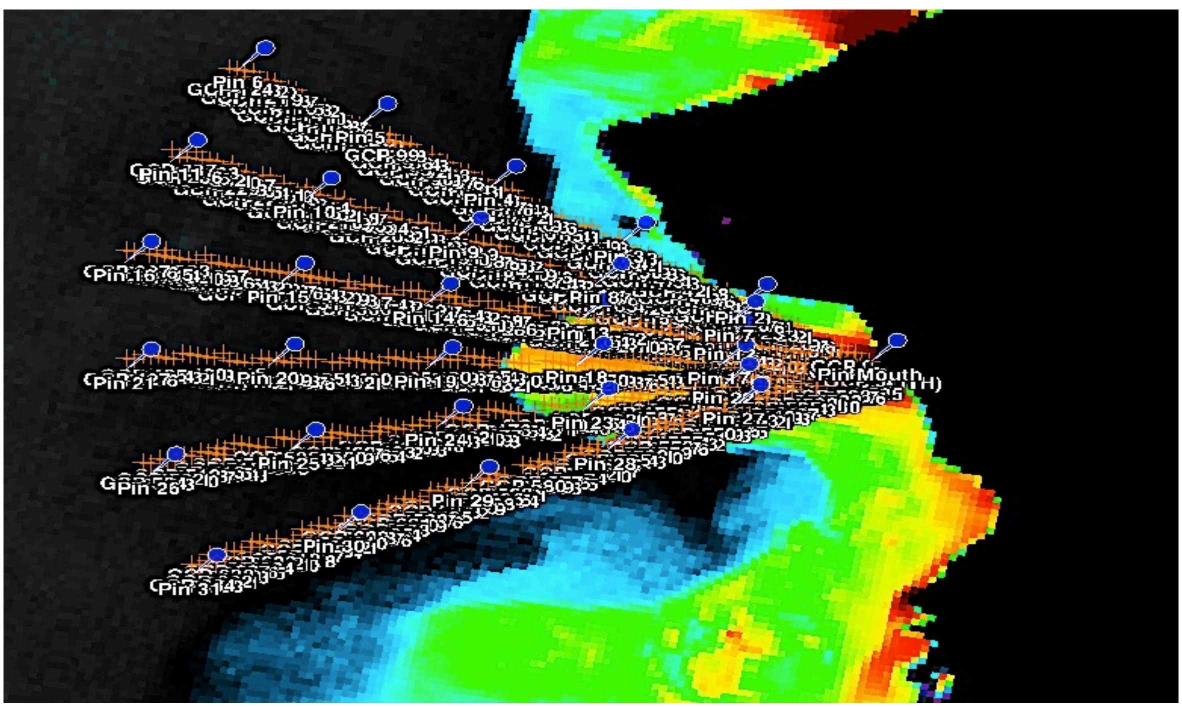


Figure 6. Transects pixels marked with Ground Control Points (GCPs) using GCP manager.

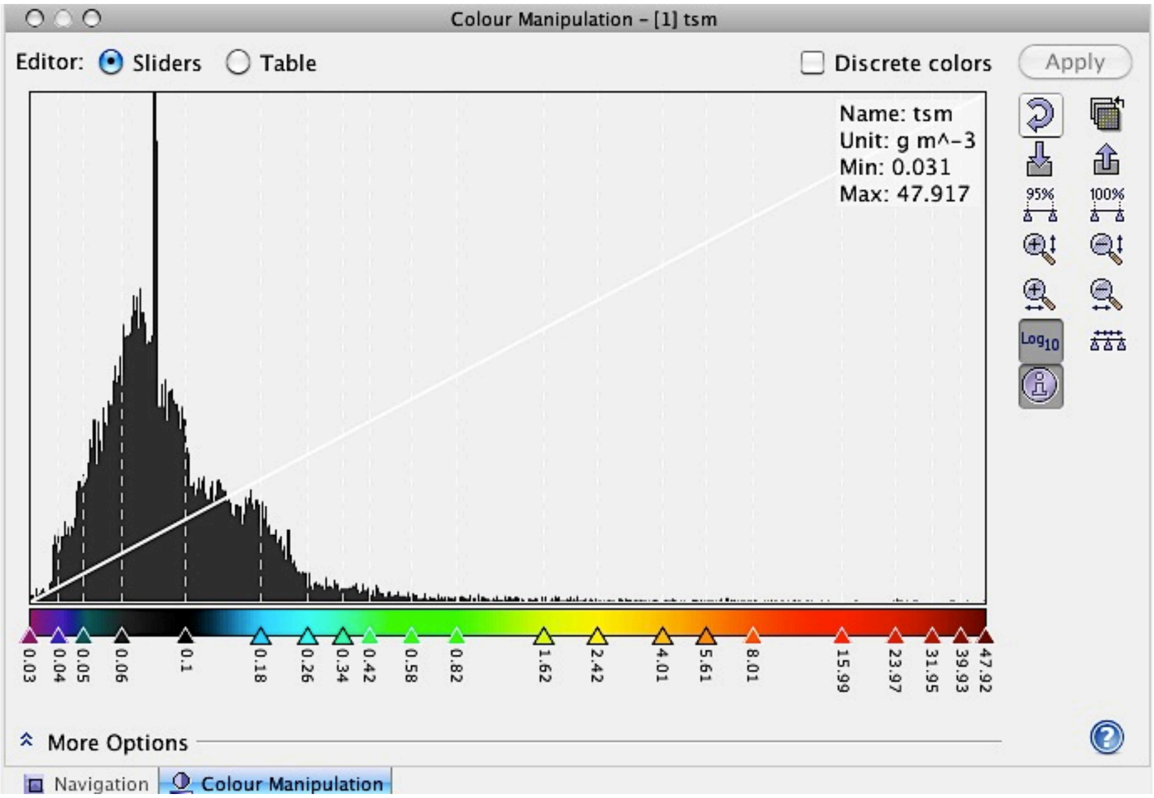


Figure 7. Editor in sliders mode, they are used to modify the color palette and with this change the assignment of sample values to colors.

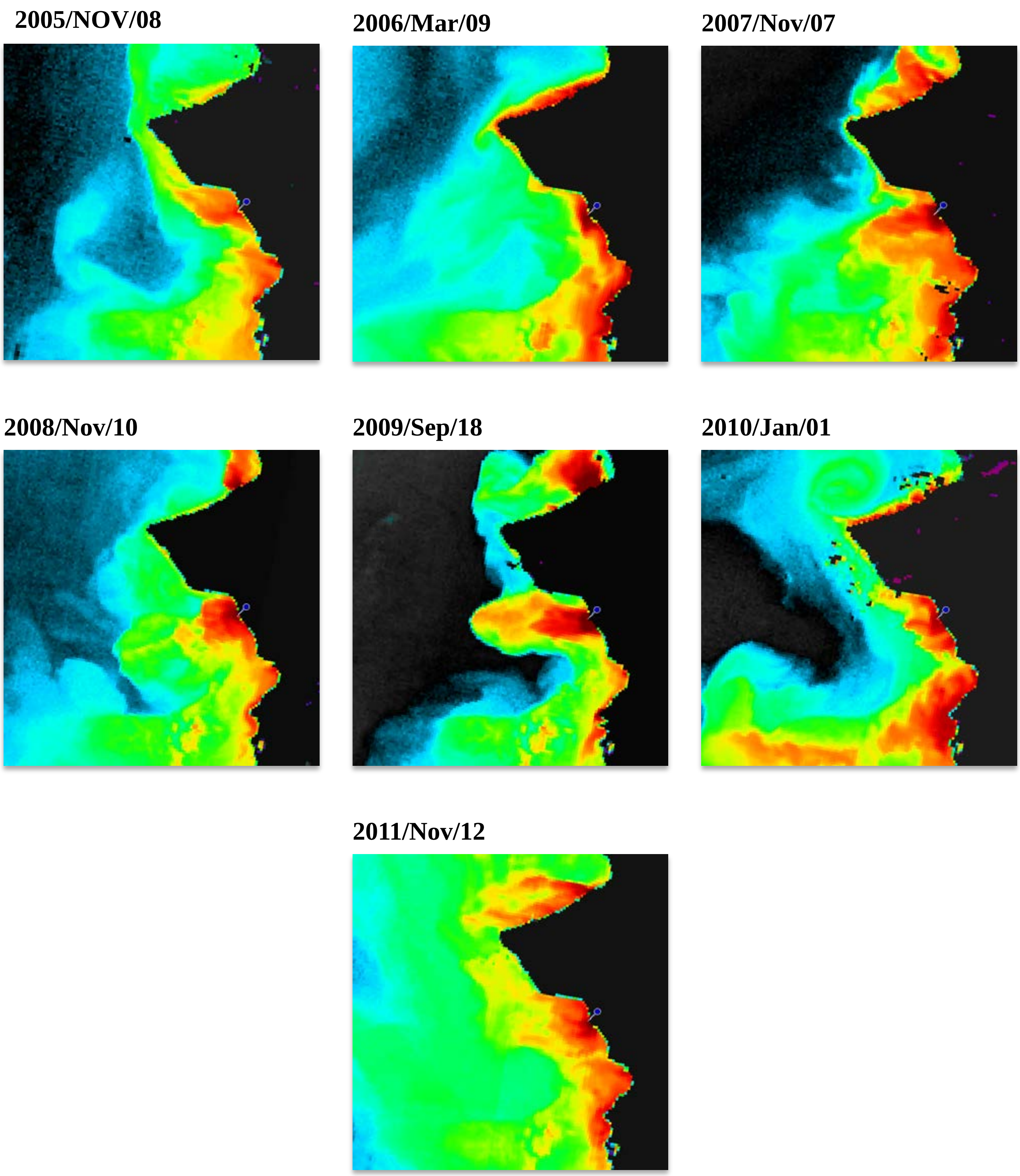


Figure 8. Images from 2005 to 2011 showing when the maximum plumes occurred

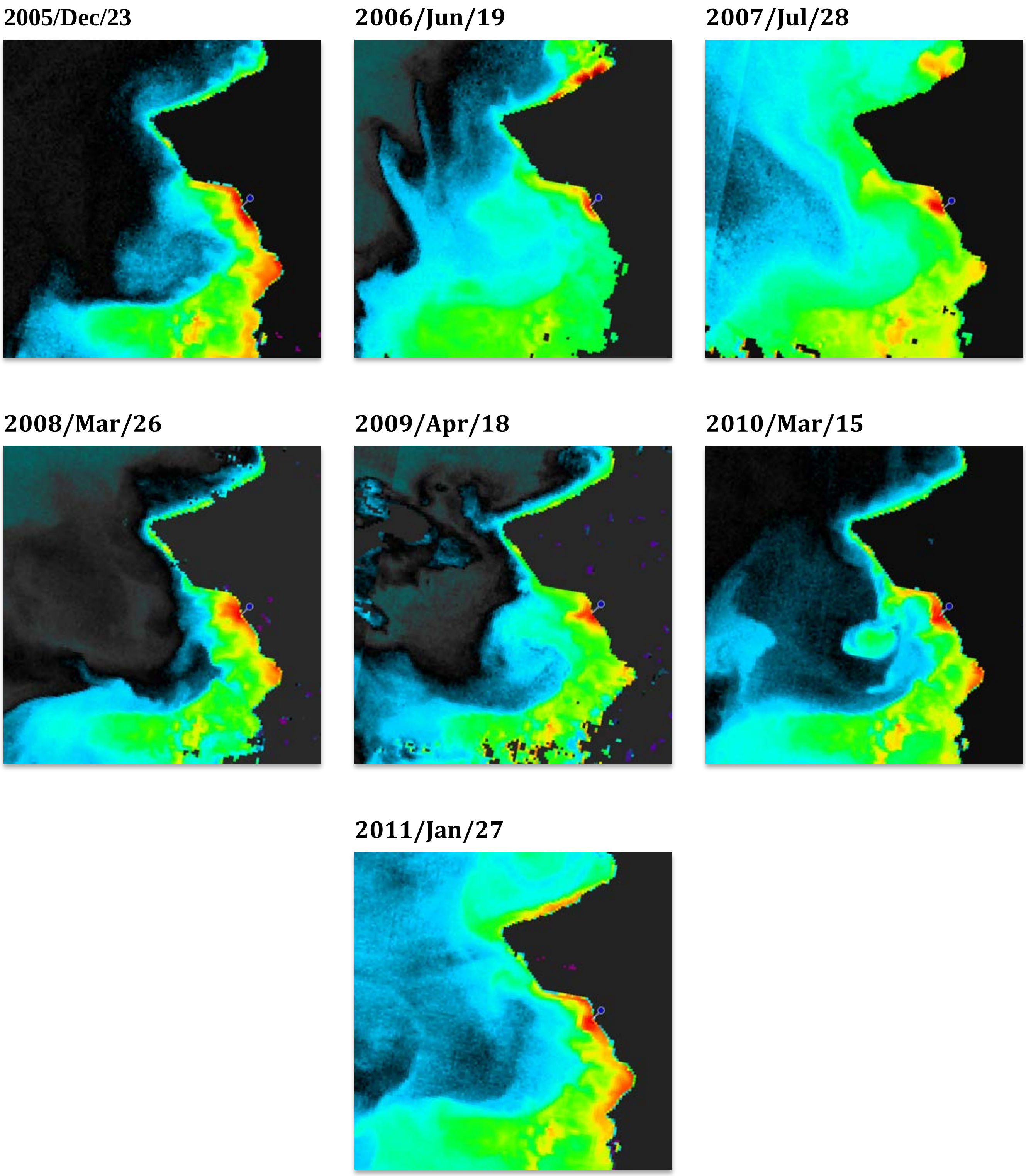


Figure 9. Images from 2005 to 2011 showing when the minimum plumes occurred.

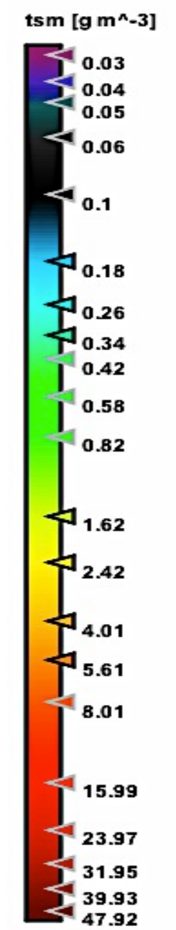
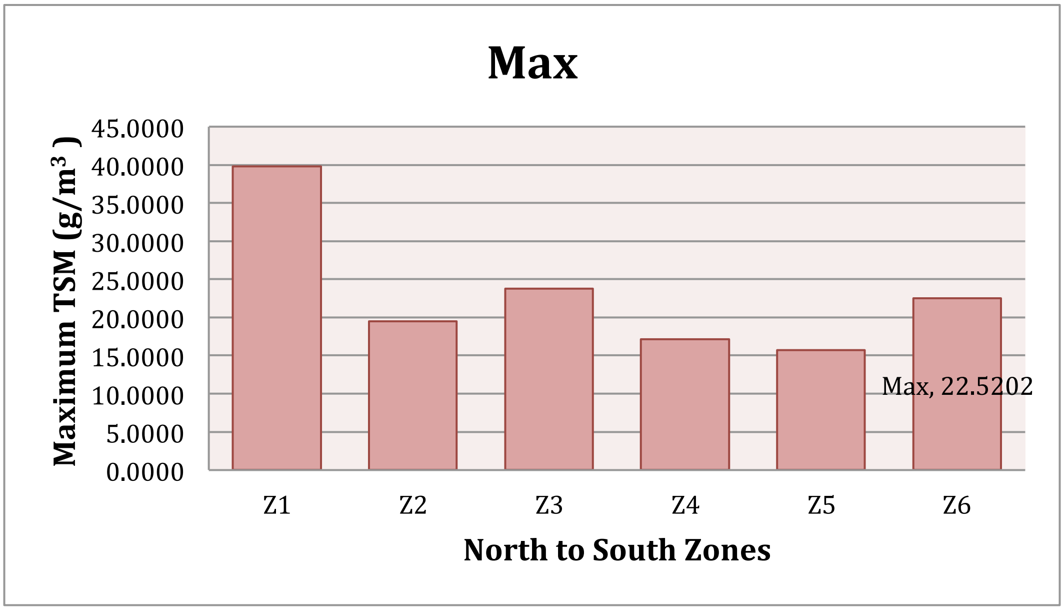


Figure 10. TSM color legend.

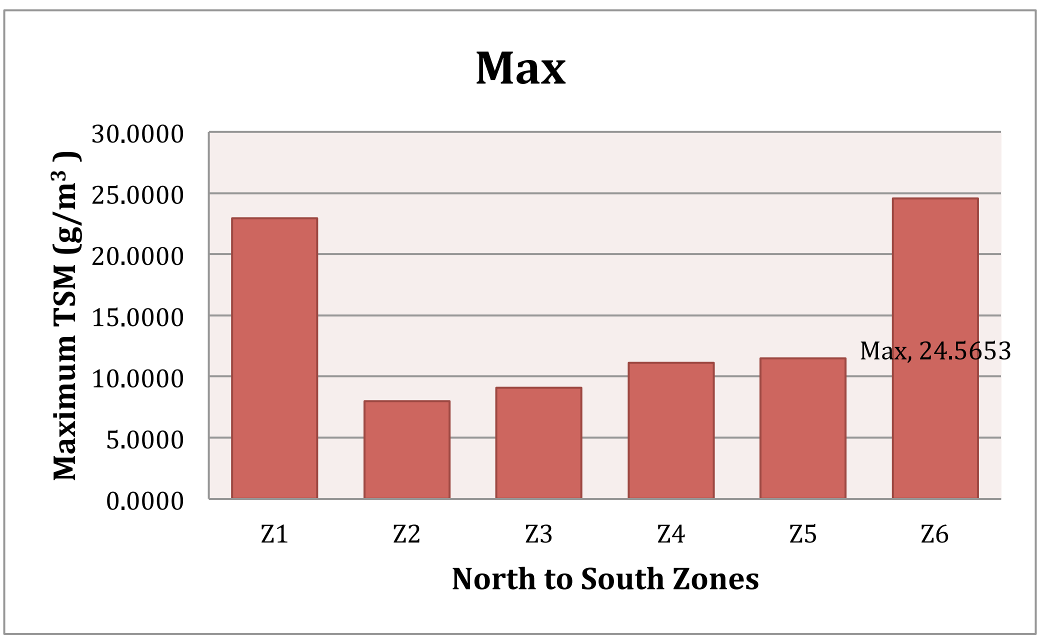
9.0 Graphs

9.1 North to South Plume Dynamics Graphs

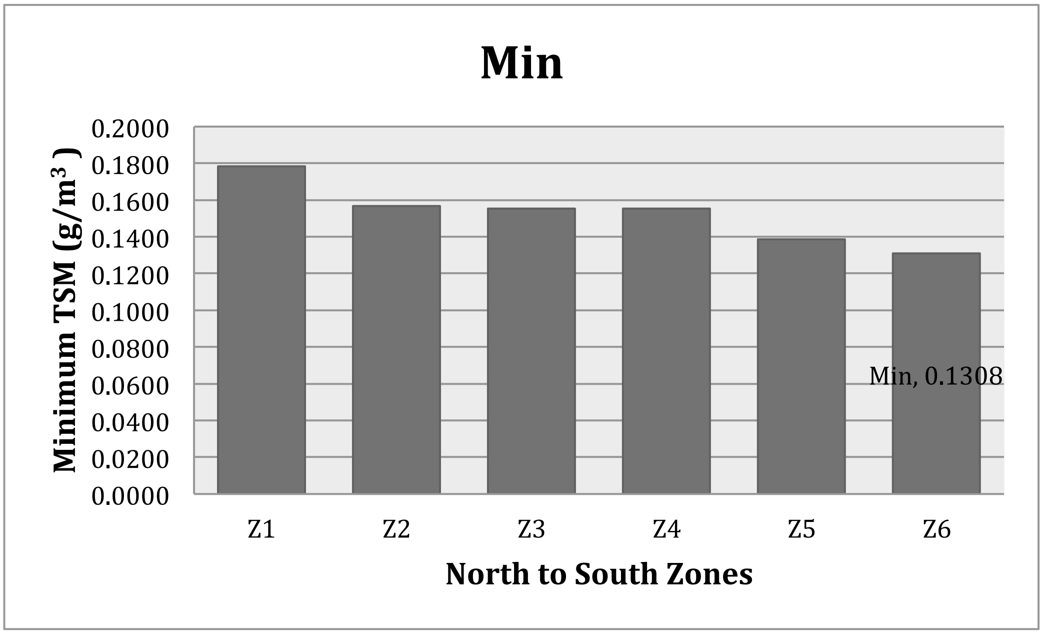
Graph 1 (2008/Nov/10). Maximum values of TSM from north to south



Graph 2 (2011/Nov/12). The Z1 and Z6 behaving almost uniformly in relation to the other.



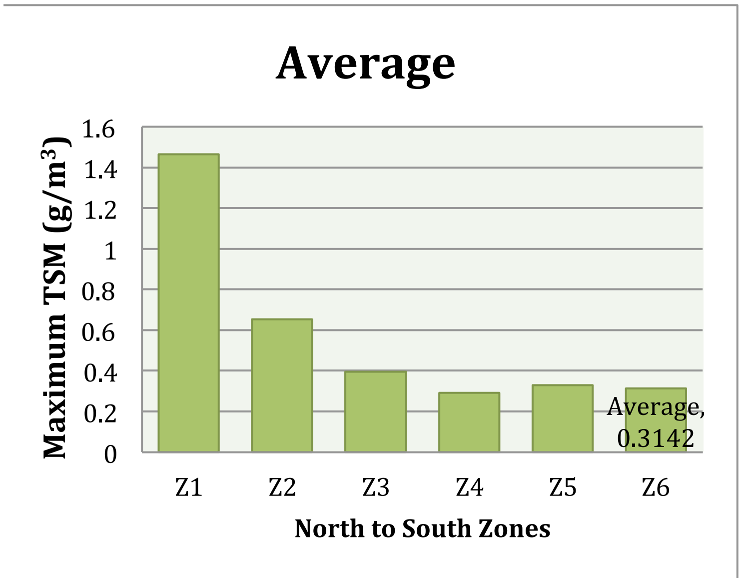
Graph 3 (2011/Jan/27). Minimum values uniformly distributed throughout the zones.

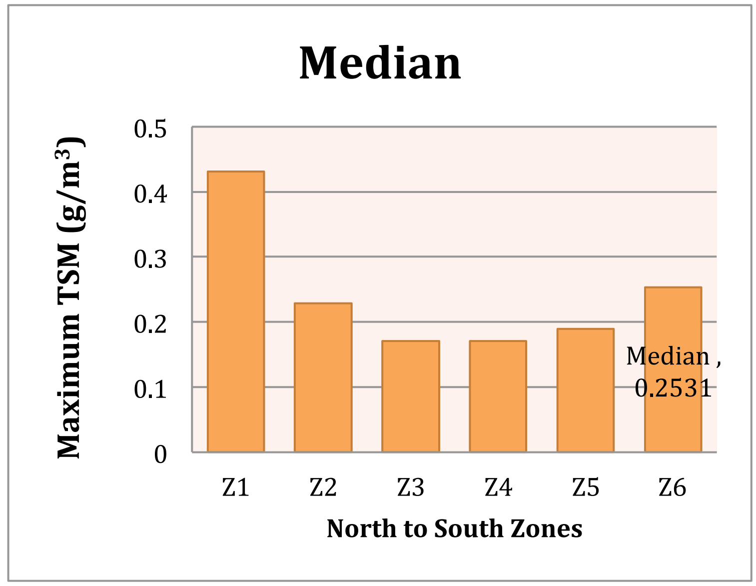


Graph 4 (2007/Jul/28). Average

Graph 5 (20070728). Median

Dates with minimum plumes, showing similarity of average and median, for maximum TSM values.

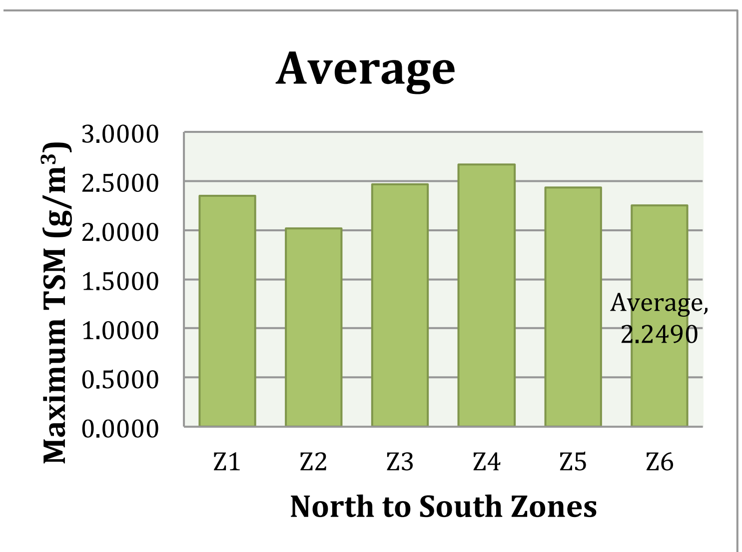


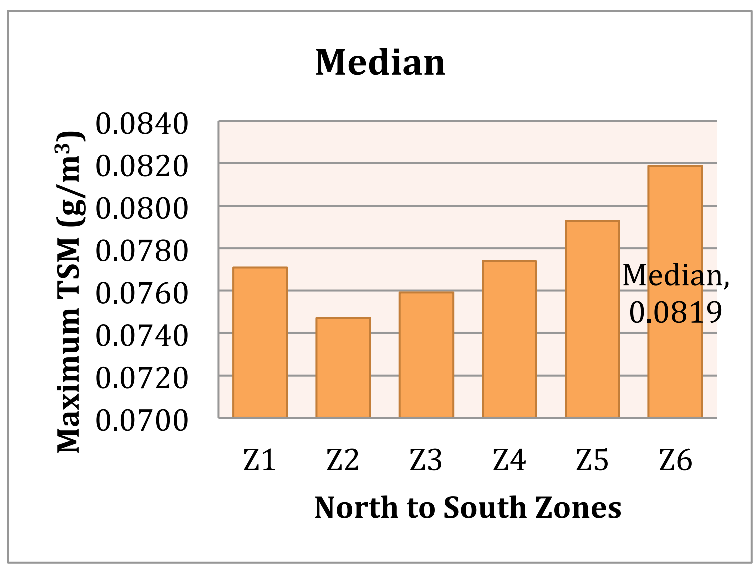


Graph 6 (2009/Sep/18). Average

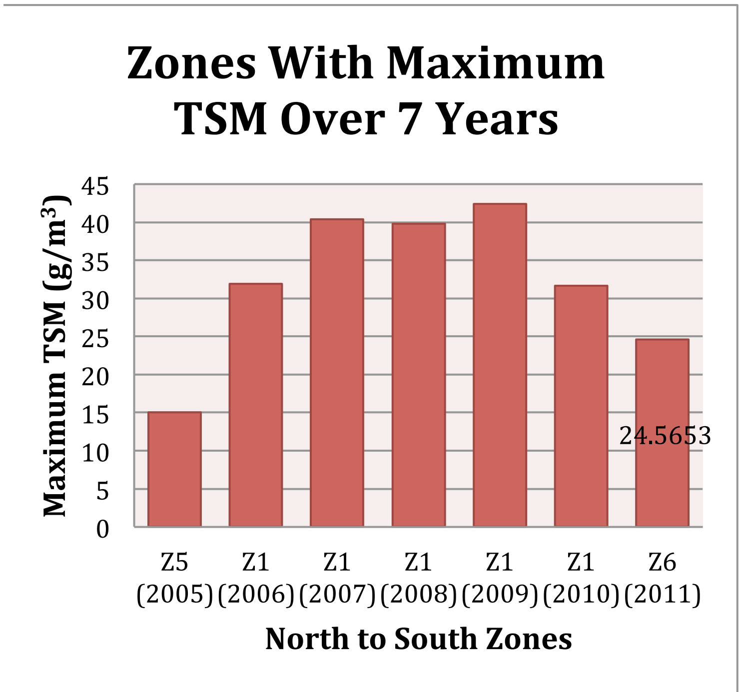
Graph 7 (2009/Sep/28). Median

Dates with maximum plumes, showing a difference in average and median, for maximum TSM values.

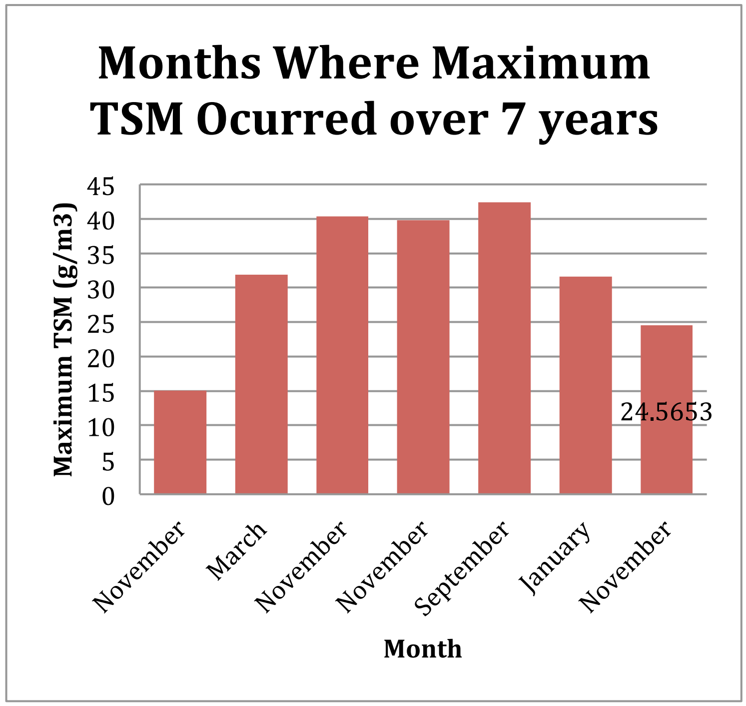




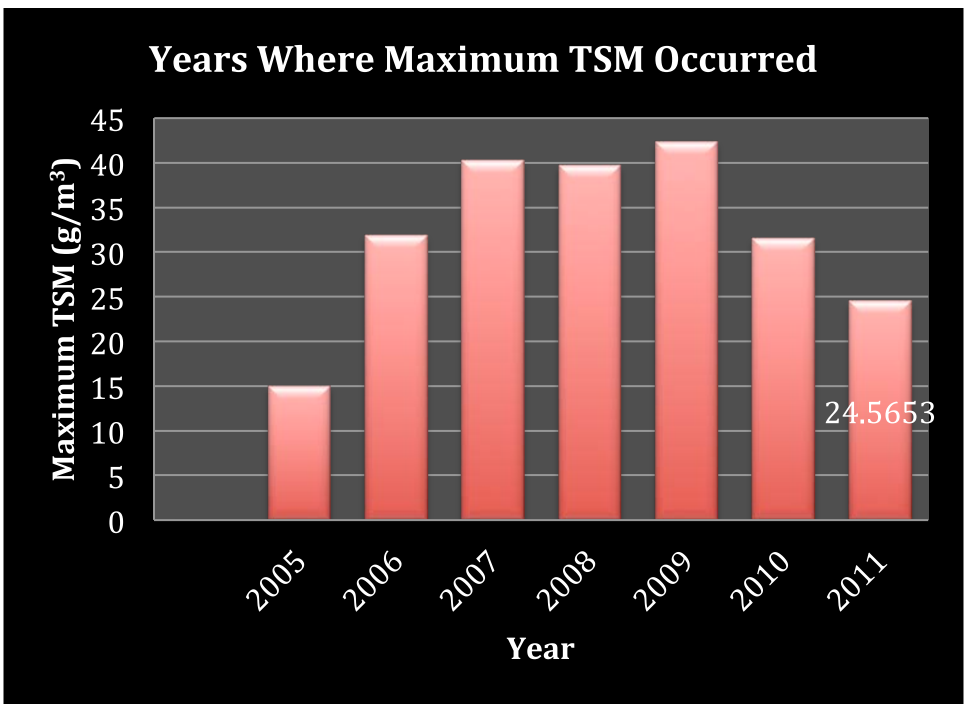
Graph 8. Comparison of maximum TSM values among zones, over 7 Years.



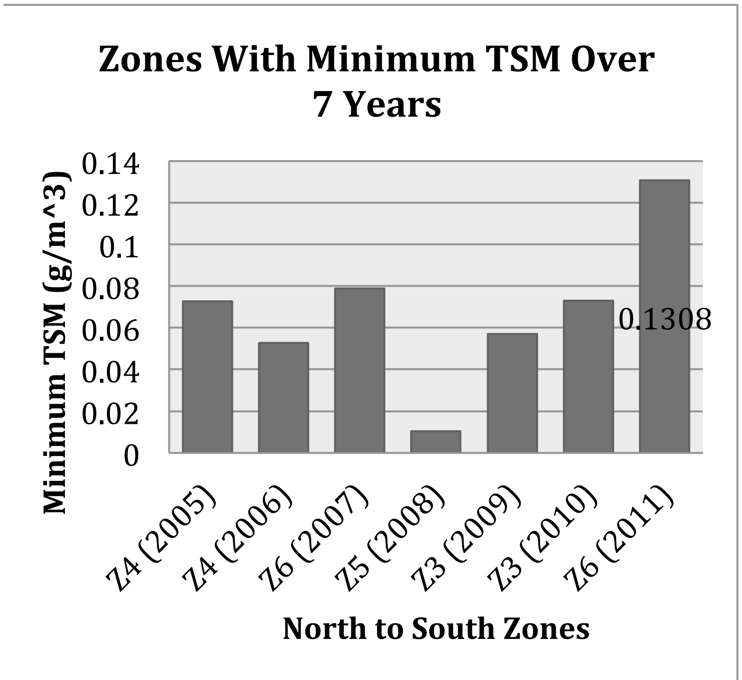
Graph 9. Comparison of maximum TSM values among months, over 7 years.



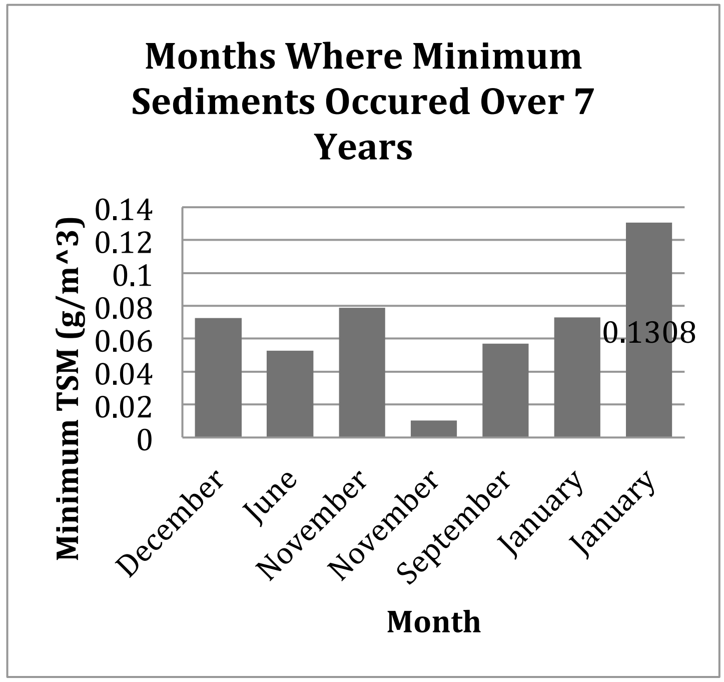
Graph 10. Comparison of maximum TSM values with Years



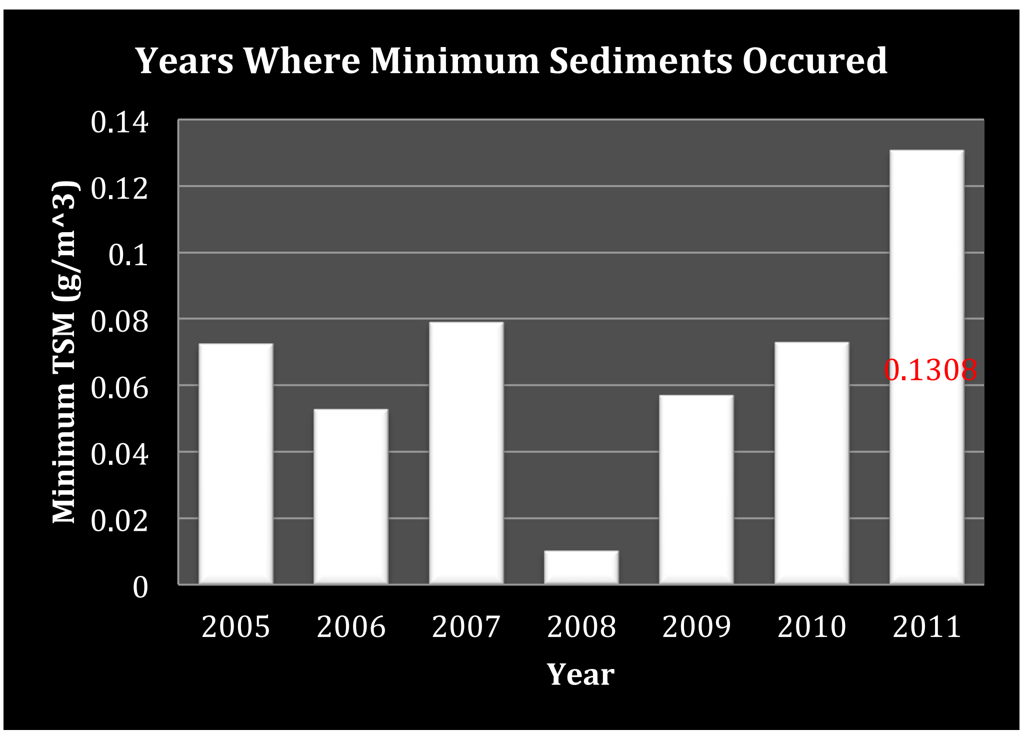
Graph 11. Comparison of Minimum TSM values, among zones.



Graph 12. Comparison of Minimum TSM values, among zones.

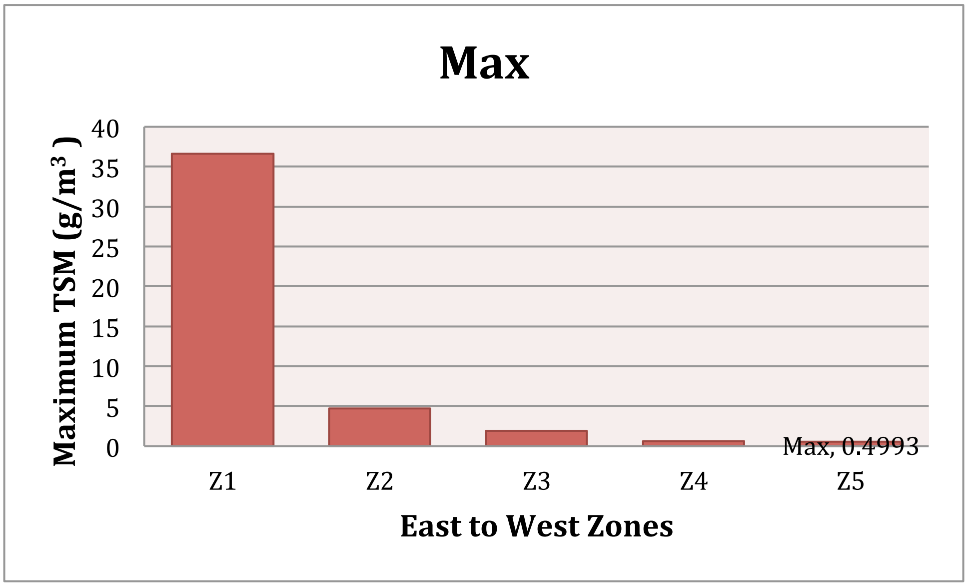


Graph 13. Comparison of minimum TSM values with Years.

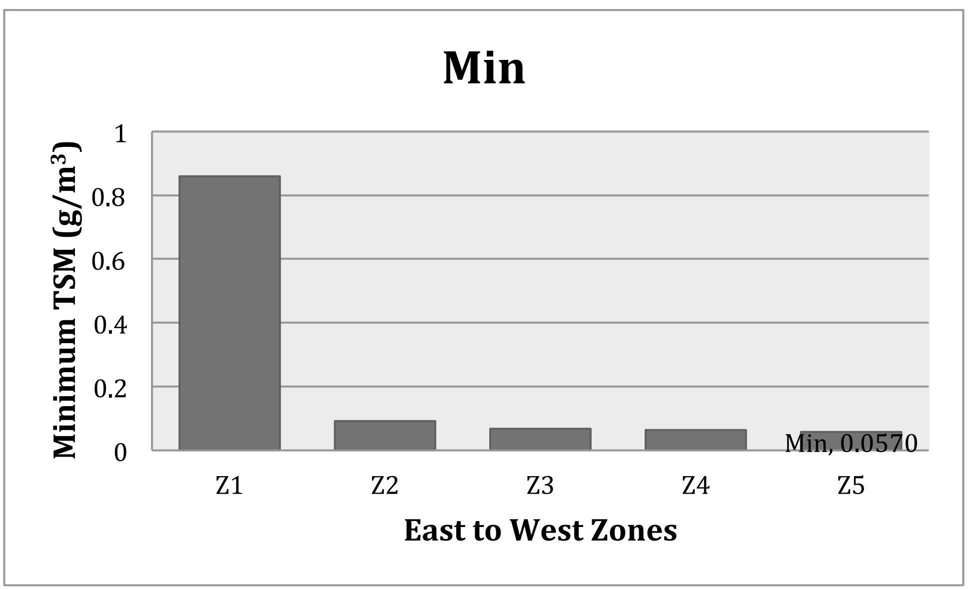


9.2 East to West Plume Dynamics Graphs

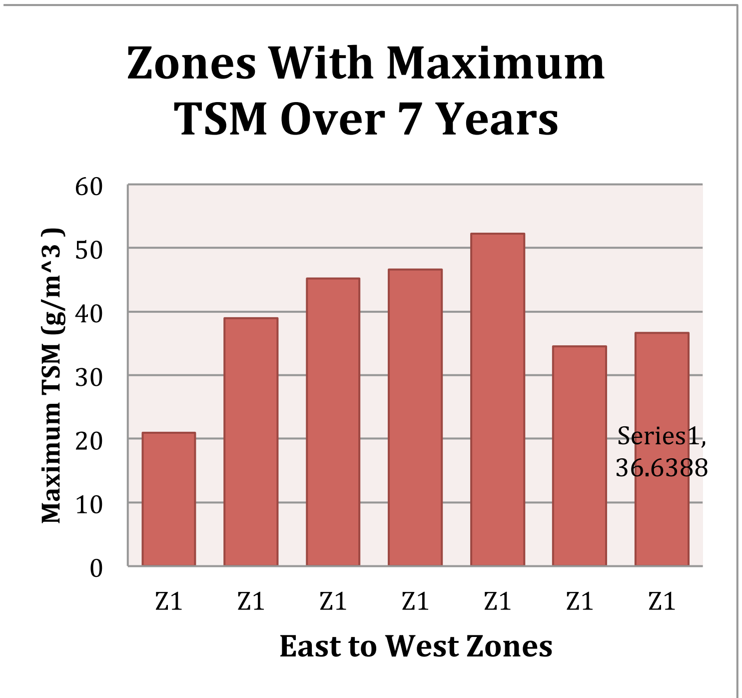
Graph 14 (2011/Nov/12). Maximum values of TSM from north to south.



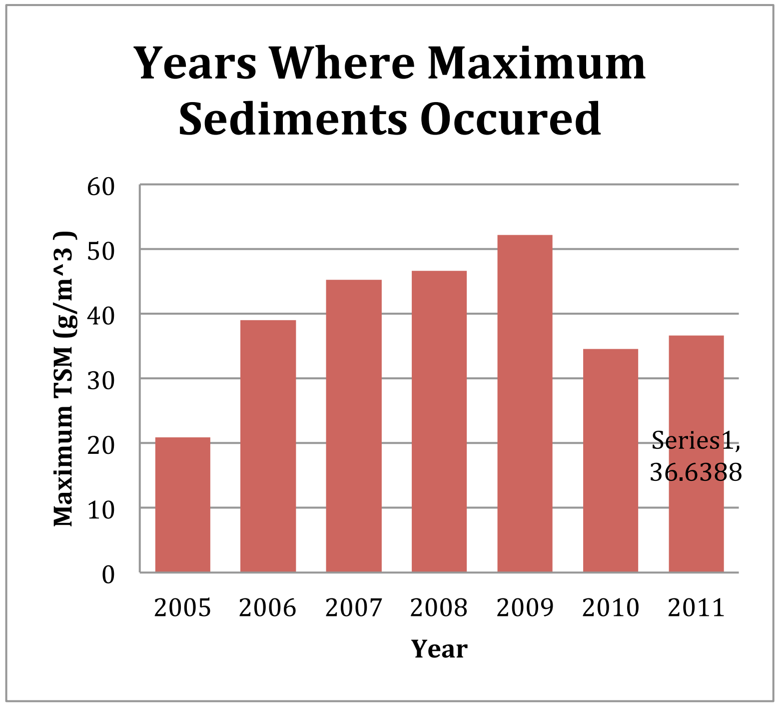
Graph 15 (2009/Sep/18). Minimum values of TSM appearing mainly on Z5.



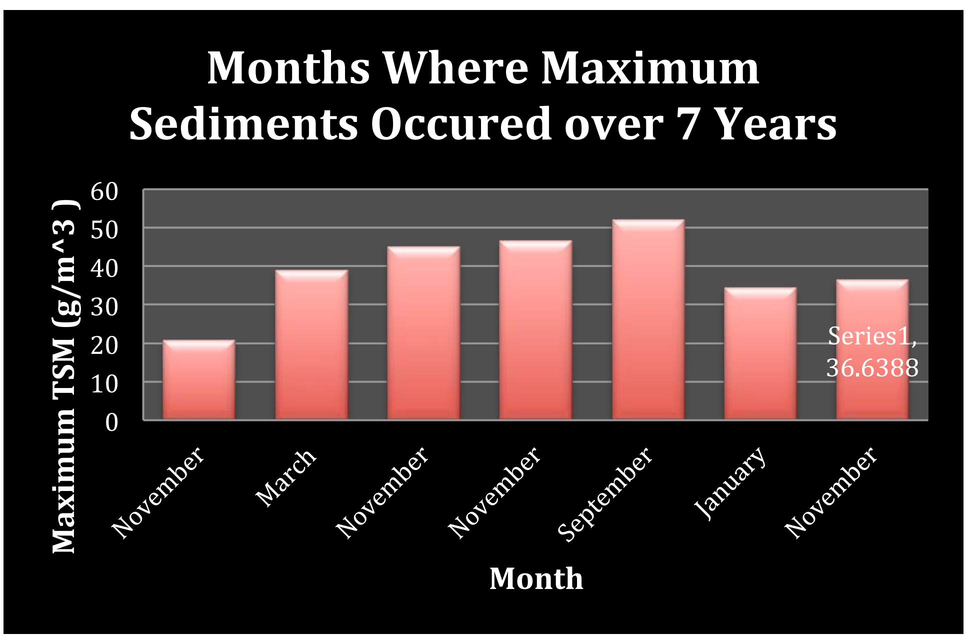
Graph 16. Comparison of maximum TSM values among zones, over 7 Years.



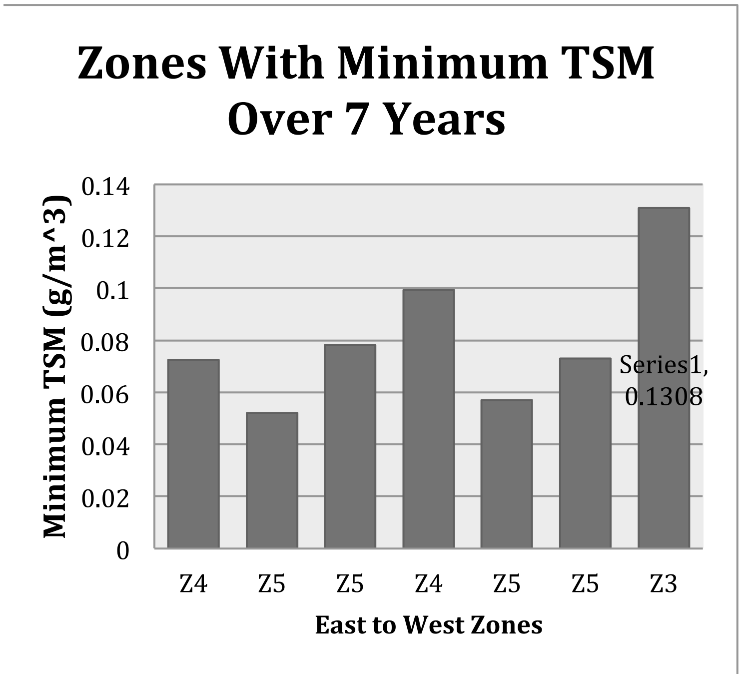
Graph 17. Comparison of maximum TSM values among months, over 7 years.



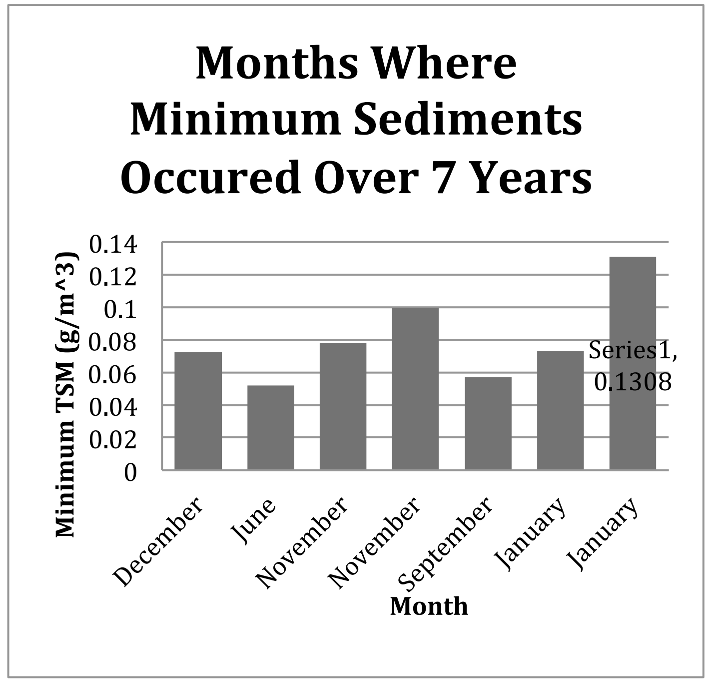
Graph 18. Comparison of maximum TSM values with Years



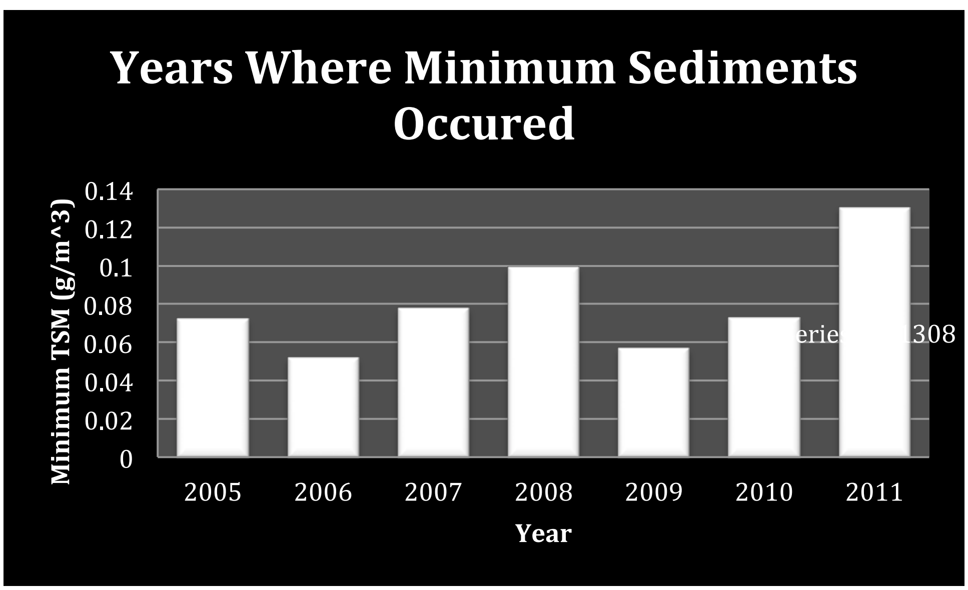
Graph 19. Comparison of Minimum TSM values, among zones.



Graph 20. Comparison of Minimum TSM values, among zones.

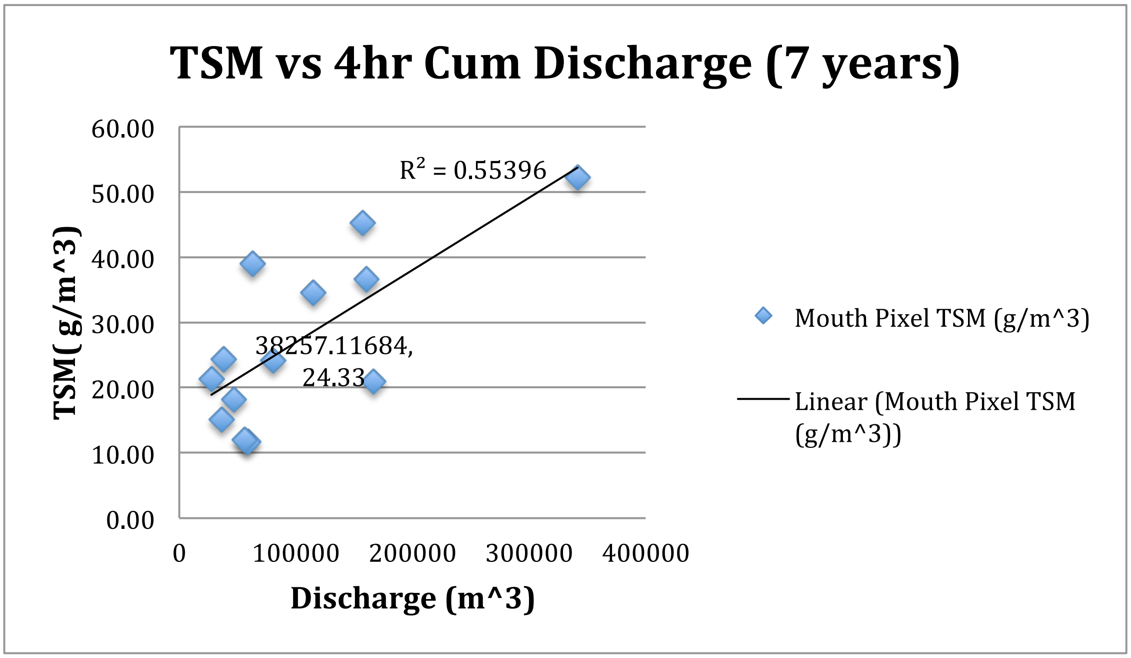


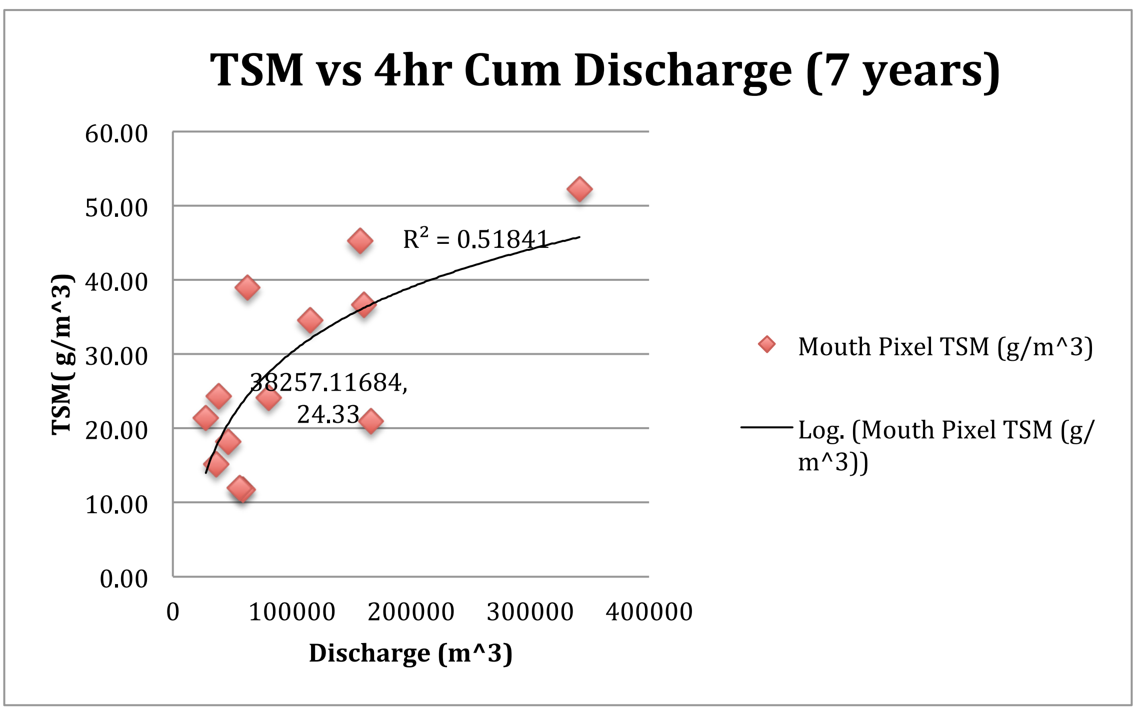
Graph 21. Comparison of minimum TSM values with Years.



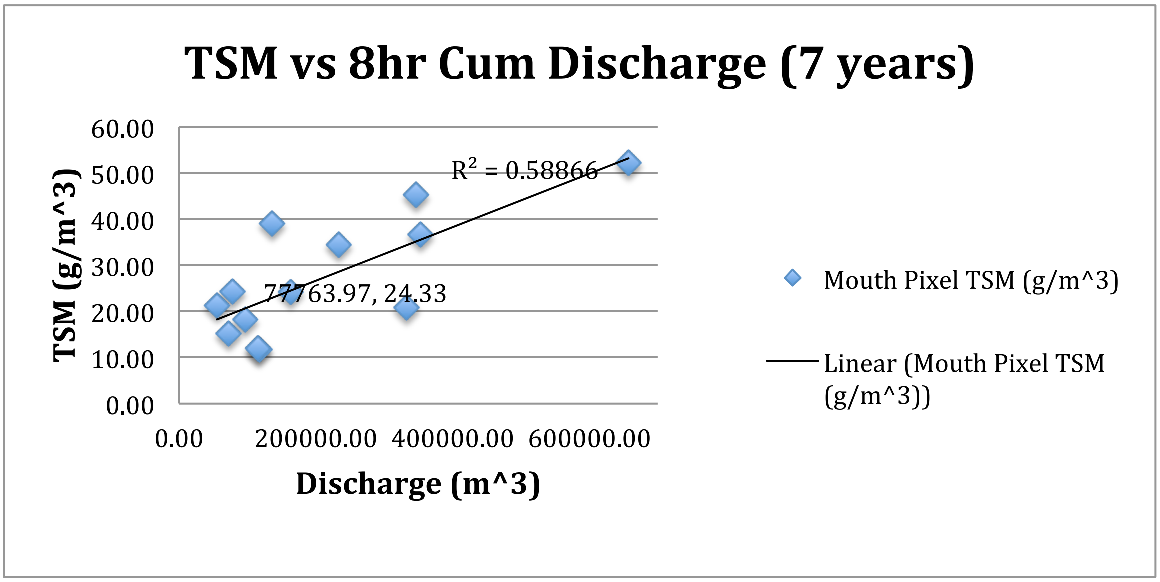
9.3 TSM vs. Discharge Graphs

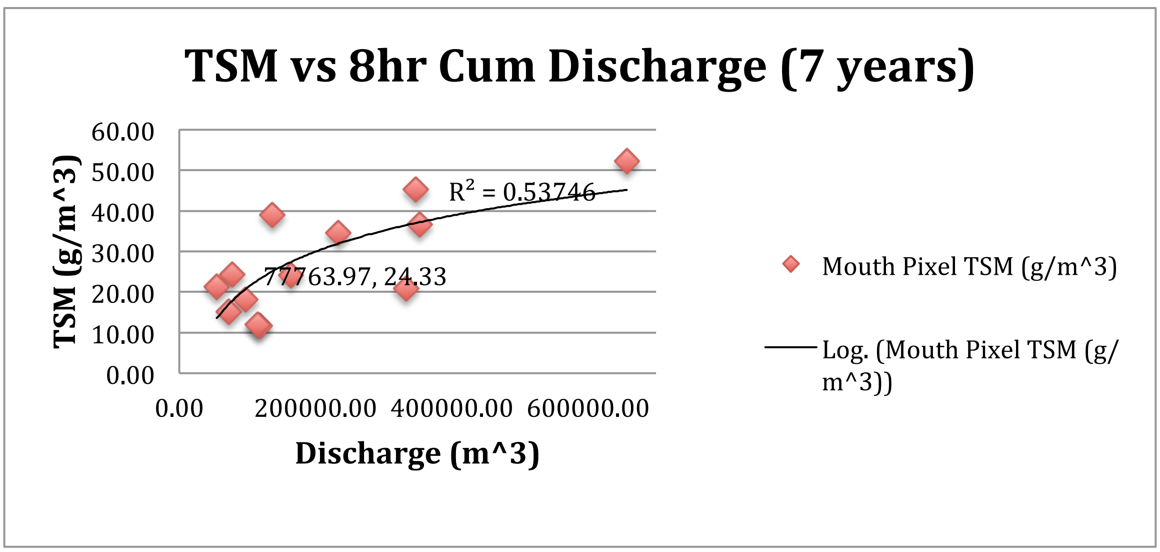
Graph 22 & 23. 4hrs Cumulative Linear and Logarithmic trend



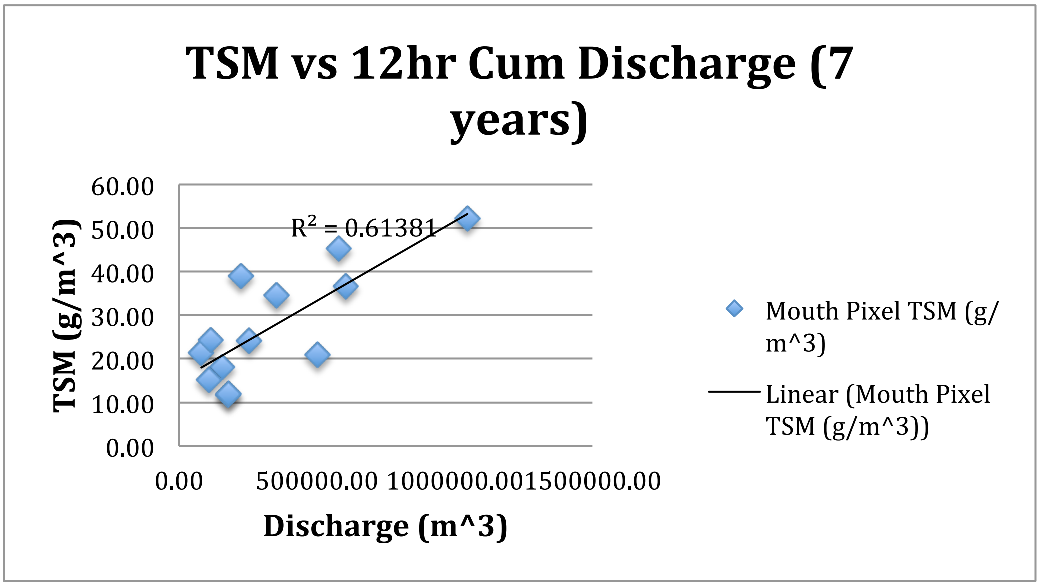


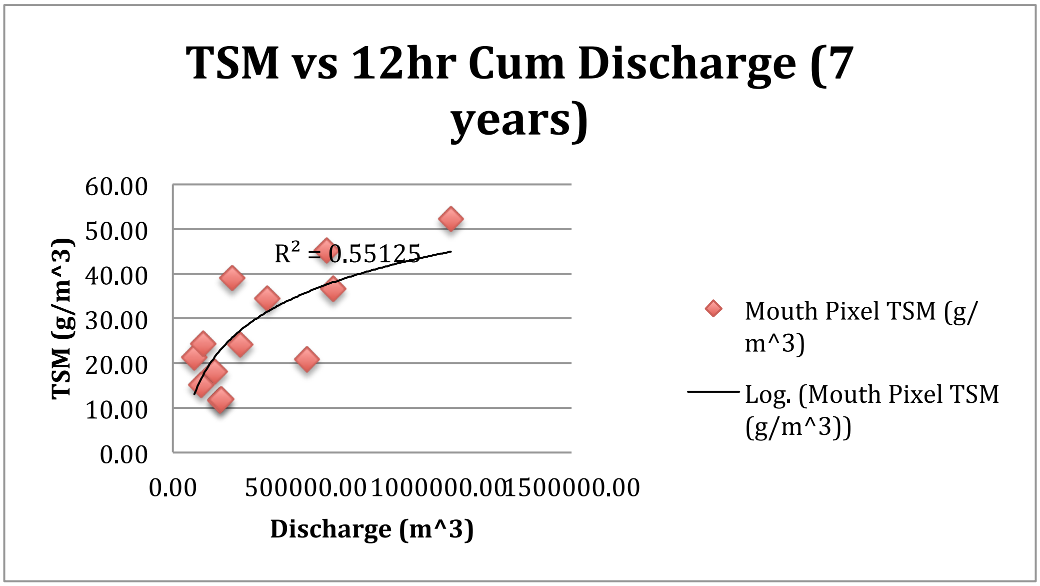
Graph 24 & 25. 8hrs Cumulative Linear and Logarithmic trend



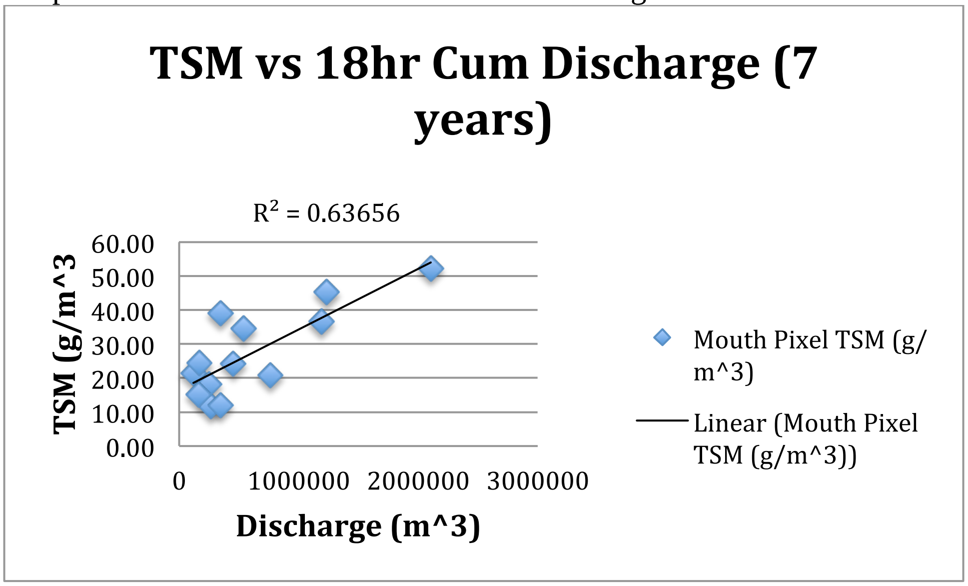


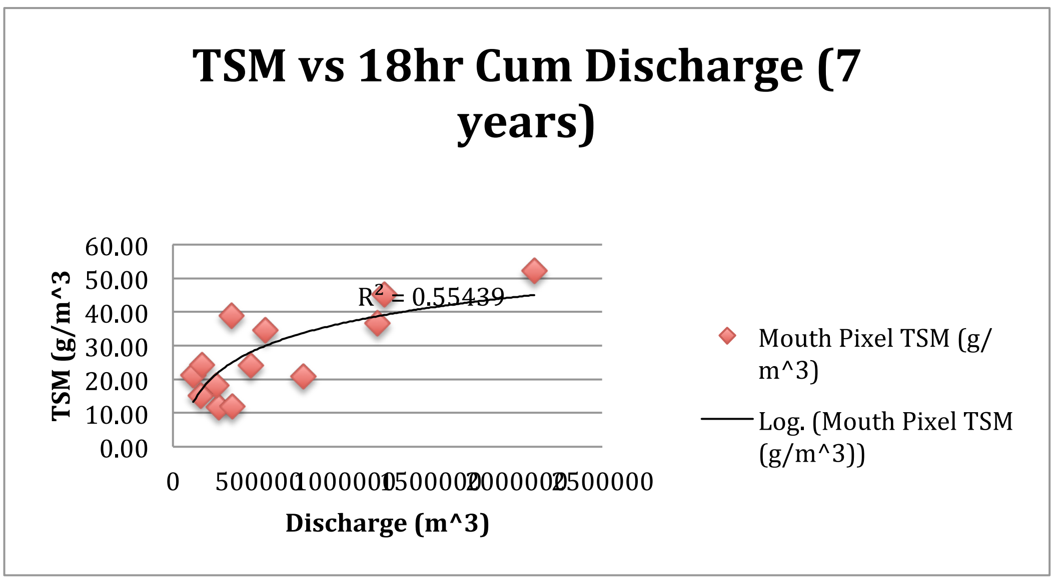
Graph 26 & 27. 12hrs Cumulative Linear and Logarithmic trend



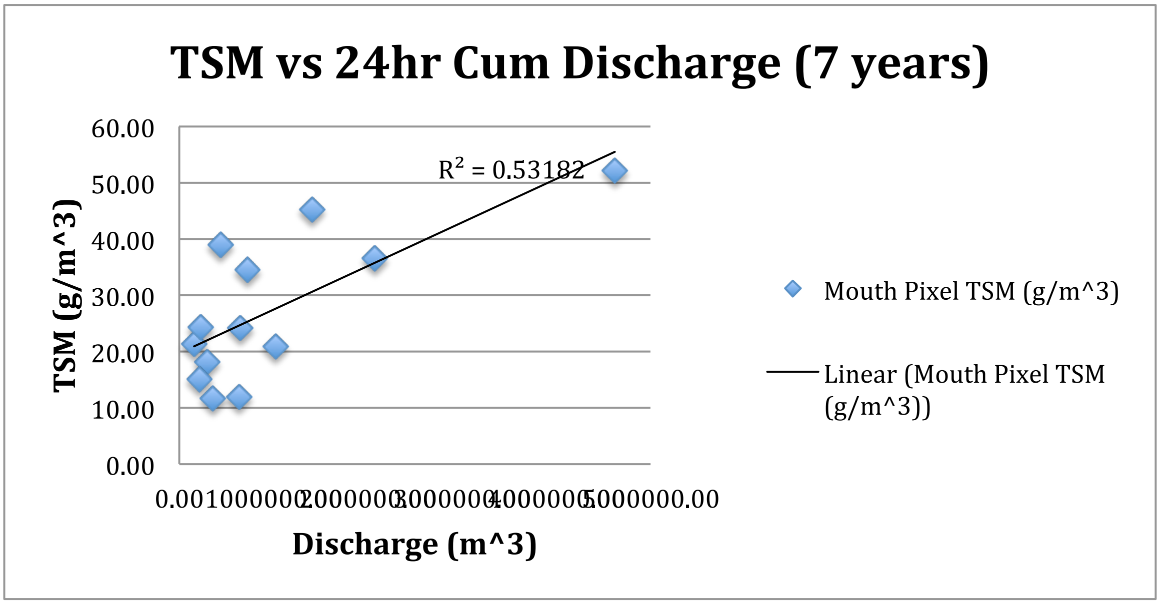


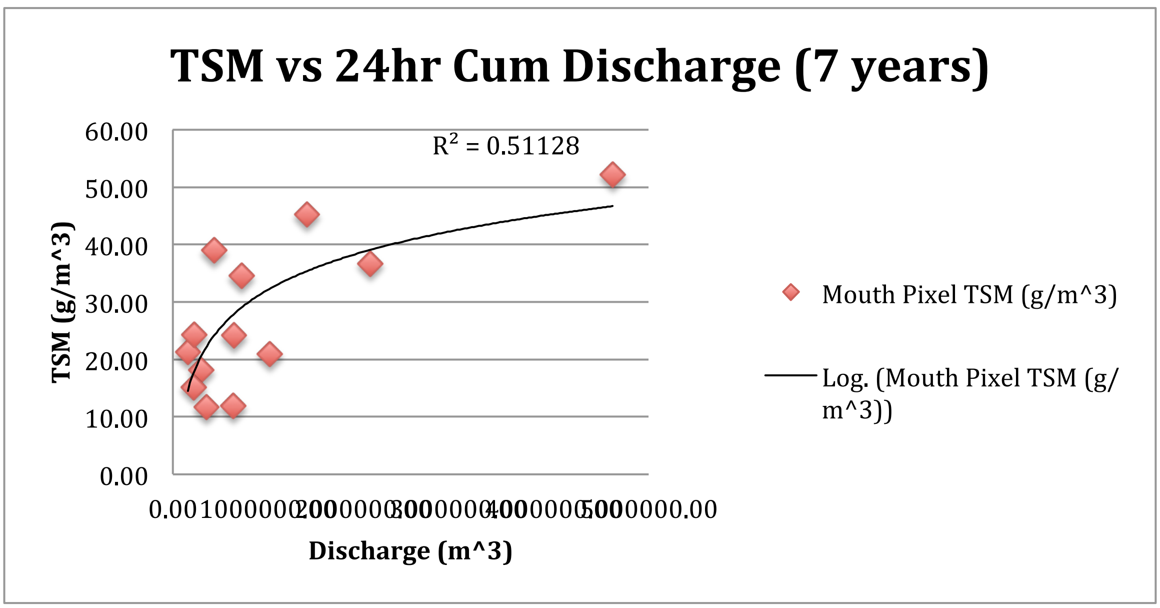
Graph 28 & 29. 18hrs Cumulative Linear and Logarithmic trend



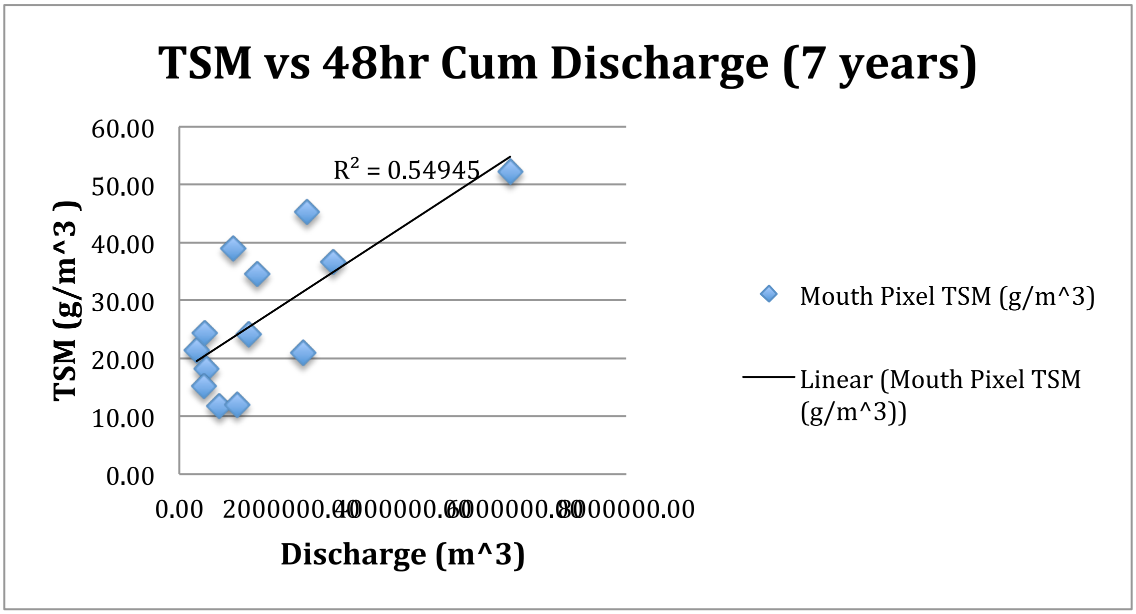


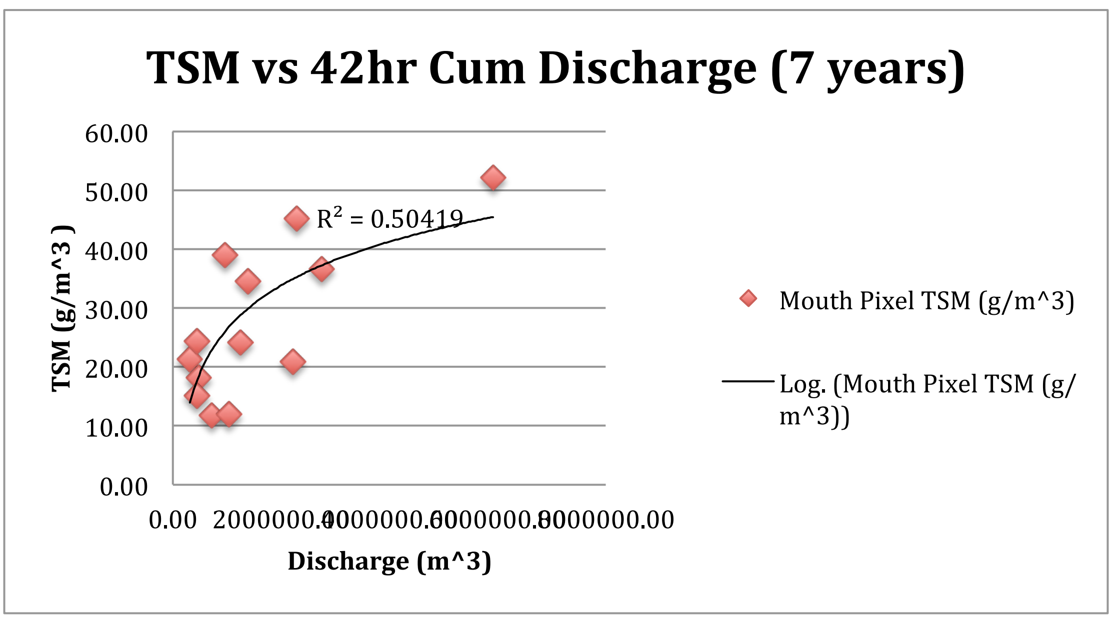
Graph 30 & 31. 24hrs Cumulative Linear and Logarithmic trend





Graph 32& 33. 48 hrs Cumulative Linear and Logarithmic trend





Graph 34& 35. 72 hrs Cumulative Linear and Logarithmic trend