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Mapping the Frequency and Distribution of the Rio Grande de Añasco plume using MERIS

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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 (RGA) watershed located in western Puerto Rico, funded by the UPR-Sea Grant, aims to understand the relationship between runoff and sediment yields from the RGA watershed with the dynamics of sediment plumes. The project is aiming to find a better accuracy in Total suspended sediment (TSS) estimation to accomplish this. The current undergraduate study used the ESA's ENVISAT-1 and its MERIS sensor to estimate TSS in the Mayagüez Bay, providing dataset for further comparisons with the results from the SWAT model. 128 images with 300 meters of spatial resolution were chosen based on low cloud cover around the RGA plume area; these were processed on BEAM, an open-source software for viewing, analyzing, and processing of remote sensing raster data, then transferred to ArcGIS v10.1 software for analyses and plume dynamic mapping. It was determined that Rio Grande de Añasco's river plume dynamics were very dependent of different river discharge flows during 2005-2011. The river plume indicated movement and area coverage towards the northwest during high and moderate flow discharges. During low flow discharges suspended sediments maintained their position and area coverage near the mouth area and alongside the coast line of the Añasco bay. High sediment values showed little extension maintaining their position near the river mouth. Medium sediments values showed greater extension and movement towards northwest than high values, while low sediment values showed a much greater extension than the previous 2 traveling northwest and further away from the Añasco bay. The Añasco bay has an area of approximately 57.63 km^2; from 2005 through 2011, suspended sediments in average covered an area of 39.44 km^2. There were one or two high peaks of sediment area coverage occurring each year. These high peaks occurred during the months of the wet season from August to November, demonstrating that from 2005-2011 the Añasco bay had the largest sediment area coverage during the wet season. These sediment areas impacted a coral reef zone on the Añasco bay. The coral reef was greatly impacted by low suspended sediment values on the other hand it was reasonably impacted by medium values. High values barely affected the coral reef, the reason being that high values maintaining their position near the river mouth, while medium and low TSS values display a much greater extension especially low sediment. Variability issues were found when correlating sediment data with discharge data on the Añasco bay, specifically near the river mouth area. Linear correlation coefficient (R^2) results were less than expected, none were bigger than 5.0 due to the fact that high sediment values maintained their position near the river mouth for the 128 images from 2005-2011. Because of this there was a lack of sediment variability. Sediment at 5.5 km away from the river mouth related with discharge data had the best R^2 result an R^2 of 5.0.

Keywords: ArcGIS, GIS, MERIS, River, Suspended Sediment, River Plume, Bay, Discharge, 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 74,000 m from the elevation of 1,204 m to the Caribbean Sea and drains an area of 520000 m^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 (Figure 2) in the latitude 18°15'56.27"N and longitude 67°11'22.53"W(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 weather conditions, 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**.** Overdeveloped or altered catchments, such as logging, deforestation, harvesting, grazing and urban development via heightened erosion on less vegetated landscapes, will bring more sediment to the coast coral reefs (Li et al., 2013). Sediment inputs to coral reefs have amplified over the last 150 years in some parts of the world (Li et al., 2013). Sedimentation has become one of the most significant disturbance factors on the degradation of shallow coral reefs in the world. Increased suspended sediment concentration in the water column would lead to an increase in seawater turbidity, reduce light availability for zooxanthellae (photosynthetic algae that live in coral tissue) and ultimately decrease the food source for coral colonies (Li et al., 2013). Sediment accumulation directly on the coral surface may result in suffocating and bacterial infection of coral tissues and lead eventually its death (Li et al., 2013).

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 dynamics 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 Añasco-Mayagüez Bay (Ramos and Gilbes, 2012). Among several possible ways to study the river plumes in the Mayagüez Bay, the current undergraduate study will use the ESA's ENVISAT-1 and its MERIS sensor to estimate TSS in the Mayagüez Bay and will provide a dataset for further comparisons with the results from the SWAT model.

The MERIS sensor had 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 had an improved spectral resolution, with 15 programmable spectral bands from 412 nm to 900nm (Table 1). 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). Previous studies (e.g. Alvarez-Romero et al. 2013: Delvin et al. 2012: Hu et al. 2004), suggests 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.

Based on a previous undergraduate study (Aceituno, 2013), it was hypothesized in this study that the RGA plume moves northward in general with a large extent to the west during high discharge events on wet season (August-November). It was also expected that peak of sediments discharge will affect benthic and the coral reef communities on that area. On the other hand, it was expected that during the dry season the RGA plume will not make a significant impact on Añasco Bay.

2.0 Methods

2.1 Image Search and Download

MERIS images with 300 meters of spatial resolution covering the western region 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 for Puerto Rico were from 2005 to 2011.

2.2 Image and Data Selection

307 MERIS images were downloaded and processed from level 1 (raw image) to level 2 (final products) as described in Aceituno (2013). Level 2 images contain the concentration of chlorophyll (CHL), total suspended matter or sediments (TSM), coloured dissolved and detrital matter (CDOM) among many others. The main interest of this research was to obtain the concentration of TSM and therefore the other products were not used. The concentration of TSM was obtained using the MERIS Case 2 Regional Processor, which consist of three different algorithms. The regional algorithm relates the radiances measured by MERIS to the first atmospherically corrected reflectance and then to water quality constituents. Each image was then saved as BEAM-DIMAP in order to process the images faster. BEAM is an open-source software 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 were established

for every image before the processing. These were an atmospheric correction, regional water algorithm, 1.0 TSM conversion exponent, and 1.73 TSM conversion factor. After this initial processing the band with the TSM product (calculated from the 620 nm band) was chosen (Aceituno, 2013). TSM is given in g/m3. All images used in this project were processed to TSM in the previous undergraduate research.

Out of the 307 images collected from 2005 and 2011, 128 were chosen based on low cloud cover around the RGA plume area. These 128 images of TSM were processed in this study using a different tool on BEAM so they could be transferred in a format recognized and used by the ArcGIS v10.1 software. This is a GIS software used for different tasks, including mapping, data compilation, spatial analysis, geodata and image management, and geographic information sharing (http://tinyurl.com/ArcGIS-Help10-1). Each image was georeferenced (establish its map projection and coordinate system) using the "Reprojection" tool on BEAM. The tool creates a new file with a chosen projected Coordinate Reference System (CRS). In this investigation the geodetic datum used was World Geodetic System (WGS) 1984 with a geographic latitude and longitude projection. After each image was georeferenced an offset and scaling factor was calculated and applied automatically to each image using the BEAM tool "*Create Band by Band Math*" so that TSM values would not change when transferred to ArcGIS (http://tinyurl.com/BEAM-Help-Forum). The tool creates a new image file with the TSM product. Finally, the new image was exported to ArcGIS as a GeoTIFF file, which allows georeferencing information and TSM values to be embedded within the file.

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 investigator of the Sea Grant funded project did the initial processing and analysis of these data, which involves determining the frequency of different types of flow conditions during the 2000-2012 period.

2.3 ArcGIS Processing and Analyses

All TSM raster images without clouds over the RGA bay were exported to ArcGIS as GeoTiff files in order to create maps of spatial frequency and distribution, and generate statistical analyses of the RGA river plume. Most of the images showed other areas of the Caribbean, not only Puerto Rico, therefore the tool called "Clip" was used to generate a new image of the area of interest showing only Puerto Rico. These clipped images were used for the rest of the ArcGIS processing.

2.3.1 Visual Analysis

The discharge analyses were made by Dr. Carlos Ramos Scharron based on the available data from the USGS station (50144000) between 2000 and 2012. He determined the frequency in which different types of flow conditions occurred during this period. The basin hydrological conditions that were considered are the total amount of flow that proceeds the time the image was collected; starting with the cumulative flow 4 hours before the image was created until 3 days (72 hours) before the image was created. Dr. Ramos' analysis was used to determine the conditions of the basin associated with each river plume image. Therefore, based on this analysis the images were divided into four categories:

- *Low Flow* **-** Means that means that 75% of the time the streamflow regime was higher than the values shown (extremely dry conditions with very little runoff/sediment input into the Bay)

- *Moderate Flow* **-** Means that 50% of the time the streamflow regime was higher than those values (moderately-low, close to average runoff/sediment delivery into the bay)

- *High Flow -* Means that 25% of the time the streamflow regime was higher than those values (wet periods of high runoff/sediment delivery into the bay).

- <u>*Very High Flow -*</u> Means that only 0% (none) of the time the streamflow regime was higher than those values (very wet periods with extremely high runoff/sediment delivery into the bay).

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 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). Figure 4 shows the number of images obtained by the different flow categories based on cumulative discharge for 24 hours prior to the time when the image was obtained. This period was selected because it showed the best correlation between cumulative discharge and TSM. Table 2 shows the 128 images and their category for the 24 hour cumulative discharge. Maps were constructed to visually show the dynamics of the river plumes in each category from 2005-2011, except for very high flow, because no image fell in that category.

An initial visual analysis was made to construct frequency maps demonstrating how the river plume as a whole behaves under the influence of each category; a spatial analyst tool called "Cell Statistics" was used. Cell Statistics calculates statistics (Majority, Maximum, Mean, Median, Minimum, Minority, Range, Standard Deviation, Summary, and Variety) per-pixel from multiple raster images and creates a whole new raster image representing the statistical analysis. For this research only the median statistic was used, as it represents best the average of the values of TSM on each pixel, it describes best the dynamics of the plume for each category from 2005-2011 (Figure 5).

2.3.2 TSM Area Coverage

An analysis of TSM area coverage over the Añasco bay was made using various ArcGIS tools. The purpose was to calculate TSM area (km^2) coverage of the 128 images and use the data for mapping the plume sediment concentration and distribution on the Añasco bay and to analyze how it impacts nearby coral reefs. A model was created to simplify the processing of the 128 images as each image required the use of various ArcGIS tools to generate the results. Models are workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input. ModelBuilder can also be thought of as a visual programming language for building workflows. Figure 6 presents the Area Coverage Model (ACM) used for this process, the model was created by Ms. Vilmaliz Rodriguez. For this process an analysis grid over the Añasco bay had to be created (Figure 7). Some nearby coral reefs were not considered for this analysis grid because they are in shallow waters and their spectral signal is confused with TSM signal on the MERIS sensor making it difficult to differentiate them. Only one coral reef zone is not expected to display this issue and it was included in the analysis (seen figure 7). The ACM first uses the "Clip" tool and cut the original images reducing the size and restricting the image to the Añasco bay. The ACM then uses the "Project Raster" tool to generate a geographic transformation from WGS 1984 to North America Datum (NAD) 1983 State Plane Coordinate System. The TSM values on these newly georeferenced images are then divided in categories similar to the Discharge and flow categories done by Dr. Ramos using the "Reclassify" tool. This tool changes the values in a raster images into three classes: High (1), Medium (2) and Low (3) TSM values:

Old Values g/m^3	New Values g/m^3
0 - 0.82	No Data
0.83 - 3.33	3
3.34 - 18.57	2
18.58 - 60	1

The model then turns these new values on the Añasco bay into polygon shape files using the “Raster to Polygon” tool (a polygon object is a closed shape defined by a connected sequence of x,y coordinate pairs). With the input of the analysis grid the model then uses the “Clip” tool again to cut the polygons restricting them to just the analysis grid. Then the “Dissolve” tool merges the polygons based on their respective TSM category, creating a categorized polygon shape file based on the three classes (1, 2, and 3). The “Dissolve” tool was used again to merge the three categories or classes into a single polygon shape file. Finally the model uses the “*Calculate Area Field”* Tool to calculate the area in square Kilometers (km^2) for each class and the area of the combination of these classes. The final output products of the model were, 128 categorized polygon shape files showing the TSM area coverage of each class and 128 general uncategorized polygon shape files showing the overall TSM area coverage of each image (Figure 8).

The TSM area coverage data was extracted as tables and analyzed in various forms. The average TSM area coverage (uncategorized) from 2005-2011 was calculated, along with the average TSM area coverage for each of the 3 classes or categories from 2005-2011. Using Microsoft’s Excel monthly trend charts were also created based on the calculated median and mean TSM area values each of the 12 months from the years 2005-2011. Sediment movement maps were created on ArcGIS using the area outlines of the resulting polygons shape files the ACM created. One map is based on the TSM dynamics under the influence of High, Moderate and Low Flow for 24-hr cumulative discharge. The other map is based on the dynamics of each class (High (1), Medium (2) and Low (3) TSM values) on the Añasco bay. Lastly a Coral Reef impact analysis was made visually using these polygon shape files. The analysis consists on calculating the percent at which the river plume impacted the coral reef and the impact percent of each class (Table 5).

2.3.3 TSM and Discharge Correlations

To study the relationship between total suspended matter and river discharge, various analyses were made. First a pixel with decimal degrees coordinates (-67.193083, 18.266528) was chosen to represent the mouth of the RGA River. The analysis tool called "Buffer" (Figure 9) was used to create a buffer of 2.5 km around that location, thus creating a new zone (Figure 10). This zone was used to run statistical analyses (maximum, minimum, sum, mean, standard deviation and range) using the Zonal Statistics Model (ZSM) (Figure 11). The model uses the "*Zonal Statistics as Table (Spatial Analyst)*" tool with the 128 images as raster input along with the 2.5 km buffer zone area it creates the statistical analyses for each image in that buffer zone; it also generates a table with the data output. Only the mean, maximum (Max) and Summary (Sum) were correlated with 24-hour cumulative discharge data. The Sum, summarizes the values of a raster within the zones of another dataset and reports the results to a table. For reasons later discussed on results, various analyses of suspended sediment and discharge correlation were made using different methods. For each of these different correlation analyses, the 24 hour cumulative discharge correlation with sediment data was the one that would show the best results out of the other cumulative discharges (4-hr cumulative, 8-hr cumulative, 12-hr cumulative, up to 72-hr cumulative).

A series of transect points (labeled 0, 1, 2, 3, 4, 5, 6 and 7) with specific coordinates (Figure 12) were created and placed along the extension on the RGA river plume to determine how the sediment data in these different locations relates with discharge. The first point (0) correspond to the same coordinates chosen to represent the mouth of the river. The second point was created at 0.5 km away from the mouth and the rest of the points were located every 1.0 km away from each other giving a transect of 6.5 km. The spatial analyst tool called "Extract Multi Values to Points" was used to extract the values of each selected location from the 128 images and record them in a table. The TSM values for each point were correlated with the discharge data. Then, a second analysis using the point that showed the best sediment and discharge correlation was made utilizing the ZSM. When the analysis grid was applied to the transect point with the best sediment and discharge correlation a small square of approximately 4km^2 area covered the point, this zone was used with the ZSM to run TSM statistical analysis. Only the mean, Max and Sum were correlated with 24-hour cumulative discharge data. Finally, the area calculated from the ACM was correlated with the river discharge.

3.0 Results & Discussion

3.1 Visual Analyses

The resulting maps from the cell statistics analysis for each discharge category (High, Moderate, and Low) are presented in figure 13. These maps represent median TSM values of the 128 images from 2005-2011. During High Flow discharges (Map A), suspended sediments show a great extension and movement towards northwest, while Moderate flow discharges (Map B) triggers a smaller sediment extension and movement towards northwest. During Low flow discharges (Map C) suspended sediments seem to maintain their position near the mouth area and along the coast line of the Añasco bay**.**

3.2 TSM Area Coverage Analyses

Table 3 shows the uncategorized TSM area coverage in square kilometers calculated by the ACM for all the images. The Añasco bay has an area of approximately 57.63 km^2, this area is based on the analysis grid and does not include area outside of the analysis grid. The average TSM area coverage from 2005-2011 was calculated and the result was an average of **39.44 km^2**. This means that for the period of 2005 through 2011, TSM in average covered an area of 39.44 km^2 on the Añasco bay based on the analysis grid constructed.

Table 4 shows area coverage in square kilometers calculated by the ACM for suspended sediment classes (High (1), Medium (2) and Low (3) TSM values) present on each image throughout the 7 years. High sediment values are in red color, medium sediment values are in yellow color and low sediment values are green colors. The average area for each class was calculated and the results for High TSM values from 2005-2011 is an average area of **1.72 km^2.** The result for Medium TSM values is an average area of **11.10 km^2** and the result for Low TSM values is an average area of **26.70 km^2.** This means that for the period of 2005 through 2011, high TSM values in average covered an area of 1.72 km^2, medium TSM values in average covered an area of 11.10 km^2 and low TSM values in average covered an area of 26.70km^2 on the Añasco bay based on the analysis grid.

Figure 14 shows the area outlines of the resulting polygons created by the ACM and based on the TSM dynamics under the influence of High, Moderate and Low Flow for 24-hr cumulative discharge for the 2005-2011 period. Map A represents TSM movement during High Flow discharges; Map B represents TSM movement during Moderate Flow discharges; Map C represents TSM movement during Low flow Discharges and Map D represent the combination of the three. Suspended Sediments seem to cover greater areas northwest during high and moderate flow discharges. During low flow discharges suspended sediments maintained area coverage near the river mouth area and alongside the coast. Figure 15 shows the area outlines of the resulting polygons created by the ACM and based on TSM classes (High (1), Medium (2) and Low (3) TSM values) on the Añasco bay from 2005-2011. Class 1 (Map A) sediment values show little extension maintaining their position near the river mouth. Class 2 (Map B) sediments values show much greater extension than class 1and movement towards northwest. Class 3 (Map C) sediment values show a much greater extension than the previous classes traveling northwest and further away from the Añasco bay.

Using Microsoft's Excel yearly and monthly trend charts were created based on the median and mean TSM area values of the 12 months from the years 2005-2011, which helped understand how sediment behaved during each month. Figure 16 shows yearly TSM area trend graph, the graph indicates one or two high peaks of sediment area coverage occurring each year. To comprehend at what time of these years these peaks occurred a monthly trend chart was created. Table 6 shows the calculated mean, median and standard deviation for each month. Figure 17 shows the median TSM area trend graph for each month from 2005-2011 and Figure 18 shows the mean TSM area trend graph for each month from 2005-2011 with their respective vertical error bars. Both graphs indicate that these high peaks occurred during the months of August, September, October and November which are the months of the wet season in Puerto Rico.

Reef impact analysis resulted in a **91.40%** of TSM impact from 2005-2011 because out of 128 images a total of 117 showed river plumes impacting the coral reef. Out of those 117 images, the coral reef was impacted by all 3 sediment classes (High (1), Medium (2) and Low (3) TSM values) **0.85%** of the time. **27.35%** of time the coral reef was impacted by sediment classes 2 and 3 only. **71.80%** of the time it was impacted by class 3 only. During the 2005-2011 period, the coral reef was greatly impacted by low TSM values on the other hand it was reasonably impacted by medium TSM values. High TSM values barely affected the coral reef, the reason is (as indicated in the previous map results) that high TSM values have little extension, maintaining their position near the river mouth, while medium and low TSM values display a much greater extension especially low TSM values which traveled further away from the Añasco bay.

3.3 TSM and Discharge Correlations

A correlation analysis between TSM and river discharge for the 2.5 km buffer zone near the RGA mouth was done. Figure 19 shows the TSM Sum results from the zonal statistics model (ZSM) analysis (from 2005-2011) correlated with the 24 hour cumulative discharge (Sum results showed the best results compared with mean and Max results). The resulting linear correlation coefficient (R^2) was **0.41**. These were not the expected results; it was expected that sediment values on the buffer area (near the river mouth) associate very well with discharge flows, a higher R^2 value was expected. Because these were not the expected results other correlation analyses were made using different methods. A series of transect points (labeled 0, 1, 2, 3, 4, 5, 6 and 7) with specific coordinates were created and placed along the extension on the RGA river plume to determine how the sediment data of these different points relates with discharge. Out of those points, point 6 showed the best correlation (Figure 20), it has the same linear correlation coefficient as the 2.5km buffer correlation analysis (**R^2 = 0.41**), the difference is that this point is about 5.5 km away from the river mouth and has less sediment data. To add more data the ZSM was used with the zone area of 4 km^2 that covered the point when integrating the analysis grid (see figure 12) adding more TSM data. the TSM Sum results from the zonal statistics model correlated with 24 hour cumulative discharge showed the best correlation with an R^2 of **0.48**, which can be rounded up to an R^2 of **5.0** (Figure 21). The last correlation analysis was created using the area data gathered from the area coverage model, figure 22 shows the resulting correlation analysis with an R^2 of **0.45.**

There were variability issues when correlating sediment data with discharge data on the Añasco bay, specifically near the river mouth area. Linear correlation coefficient results were less than expected, none were bigger than 5.0. This was due to the fact that high sediment values maintained their position near the river mouth for the 128 images from 2005-2011 (as indicated in the TSM area coverage analyses result). Because of this there was a lack of sediment variability throughout the first 4.5 km away from the river mouth. At approximately 5 km away from the river mouth sediment started to show variability, this is the reason why point 6 (5.5 km) correlation with discharge had the best linear correlation coefficient result. Another possible factor as to why linear correlation coefficient results were less than expected is the fact that discharge values represent water discharge in the middle of the basin and not in the mouth. The USGS gauging station located on the main RGA channel (USGS 50144000) is about 28.20 km away from the mouth (See figure 3). There is 28.20 km of unknown discharge data.

4.0 Conclusion

Rio Grande de Añasco's river plume dynamics are very dependent of different river discharge flows. The river plume indicated movement and area coverage towards the northwest during high and moderate flow discharges. During low flow discharges suspended sediments maintained their position and area coverage near the mouth area and alongside the coast line of the Añasco bay. Class 1 (high) sediment values showed little extension maintaining their position near the river mouth. Class 2 (medium) sediments values showed greater extension and movement towards northwest than class 1. Class 3 (low) sediment values showed a much greater extension than the previous 2 classes traveling northwest and further away from the Añasco bay.

The Añasco bay has an area of approximately 57.63 km^2. From 2005 through 2011, suspended sediments in average covered an area of 39.44 km^2. In average class 1 sediment values covered an area of 1.72 km^2, class 2 sediment values covered an area of 11.10 km^2 and class 3 sediment values covered an area of 26.70km^2 on the Añasco bay. From 2005 through 2011 there were one or two high peaks of sediment area coverage occurring each year. These high peaks occurred during the months of the wet season from August to November, demonstrating that from 2005-2011 the Añasco bay had the largest sediment area coverage during the wet season.

Coral reef sediment impact analysis from 2005-2011 resulted in an impact of 91.40% of the time. During the 2005-2011 period, the coral reef was greatly impacted by low suspended sediment values on the other hand it was reasonably impacted by medium values. High values barely affected the coral reef, the reason being that high values maintaining their position near the river mouth, while medium and low TSM values display a much greater extension especially low sediment.

Variability issues were found when correlating sediment data with discharge data on the Añasco bay, specifically near the river mouth area. Linear correlation coefficient results were less than expected due to the fact that high sediment values maintained their position near the river mouth for the 128 images from 2005-2011. Because of this there was a lack of sediment variability throughout the first 4.5 km away from the river mouth. At approximately 5 km away from the river mouth sediment started to show variability. Another possible factor as to why linear correlation coefficient results were less than expected is the fact that discharge values represent water discharge in the middle of the basin and not in the mouth. The USGS gauging station located on the main RGA channel (USGS 50144000) is about 28.20 km away from the mouth; there is 28.20 km of unknown discharge data.

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Figures

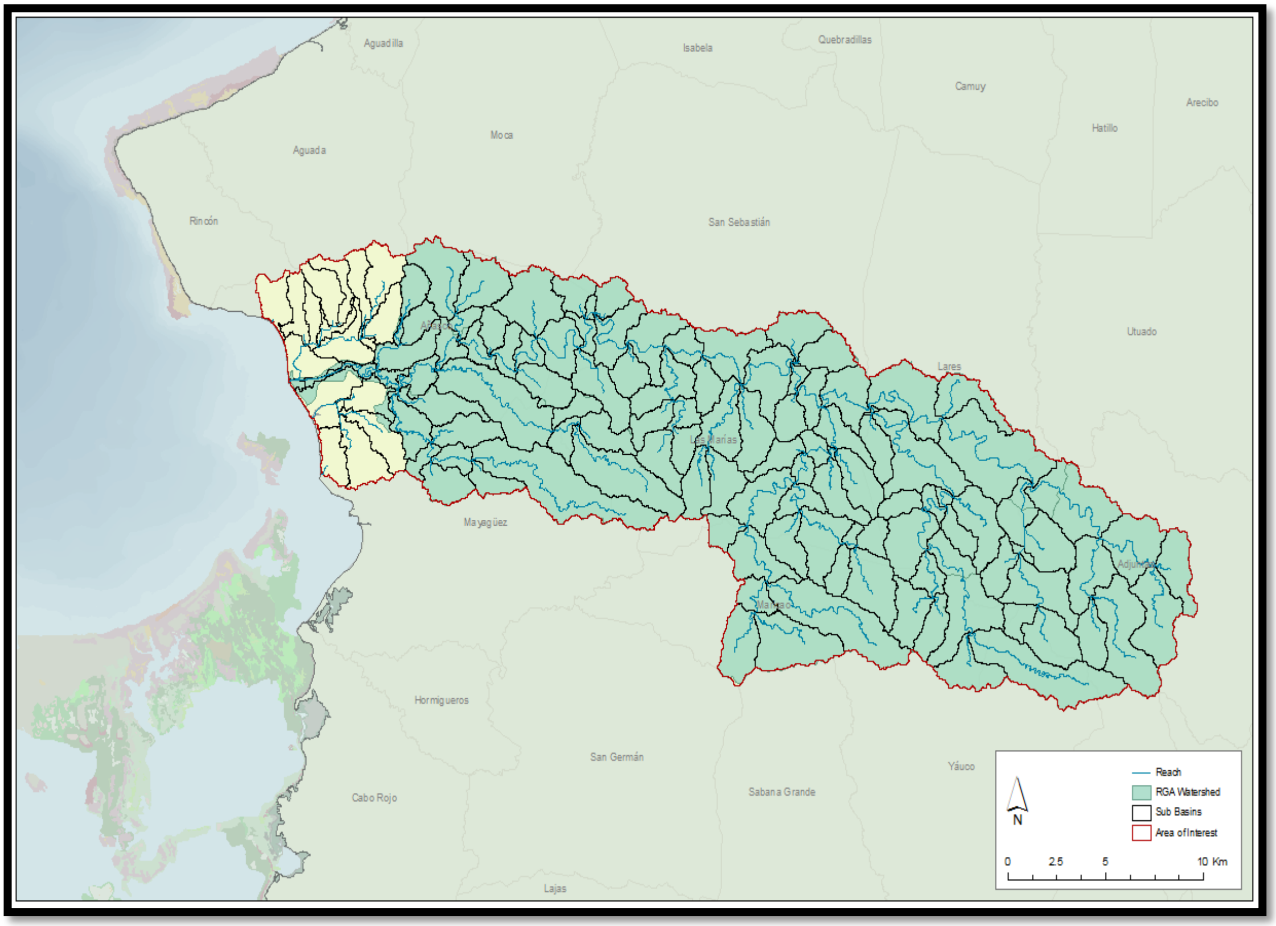


Figure 1. Río Grande de Añasco (RGA)'s watershed is located in western Puerto Rico. From Ramos and Gilbes (2013).

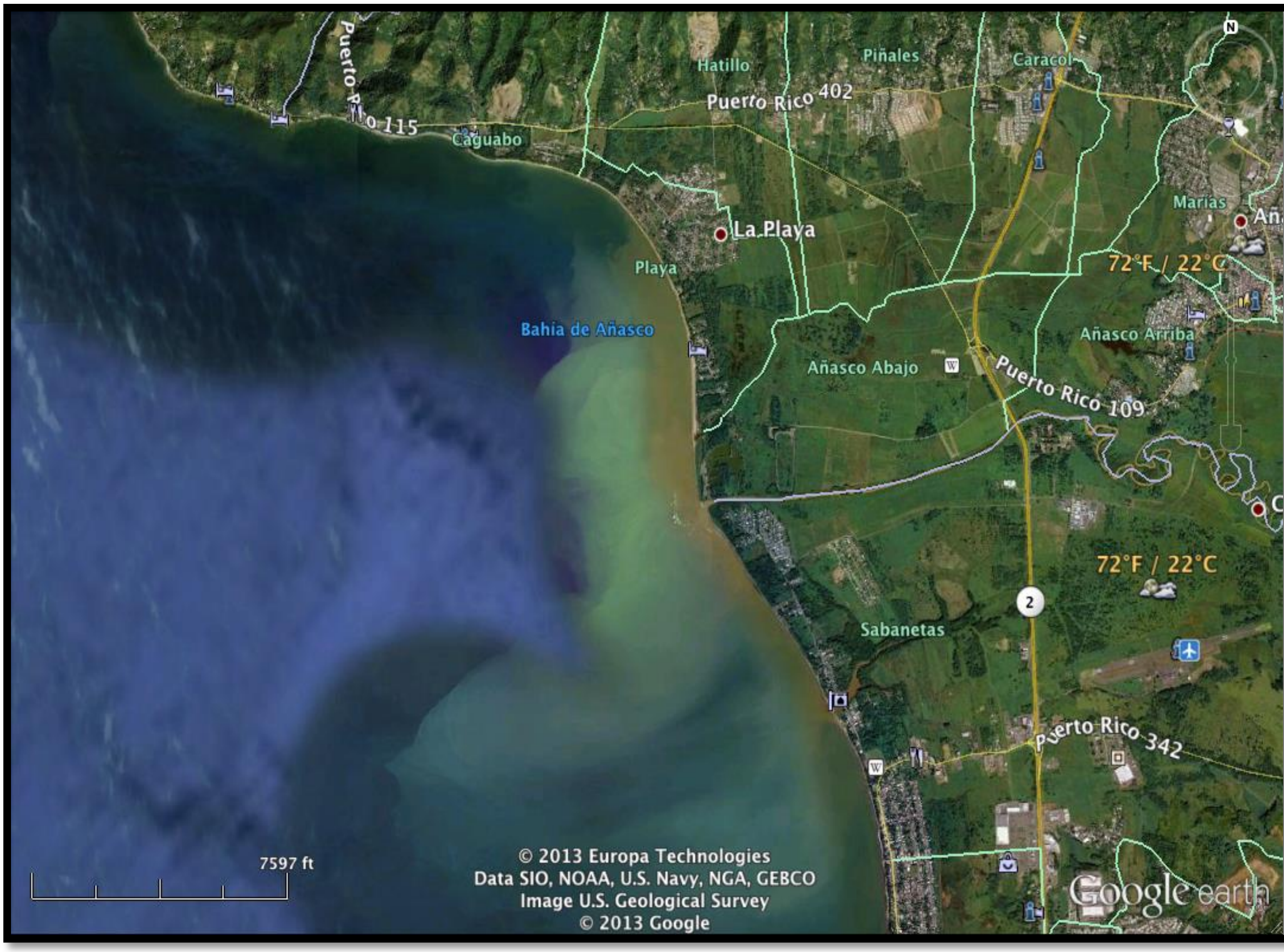


Figure 2. Añasco Bay showing RGA's river plume. Image from Google Earth, 2013

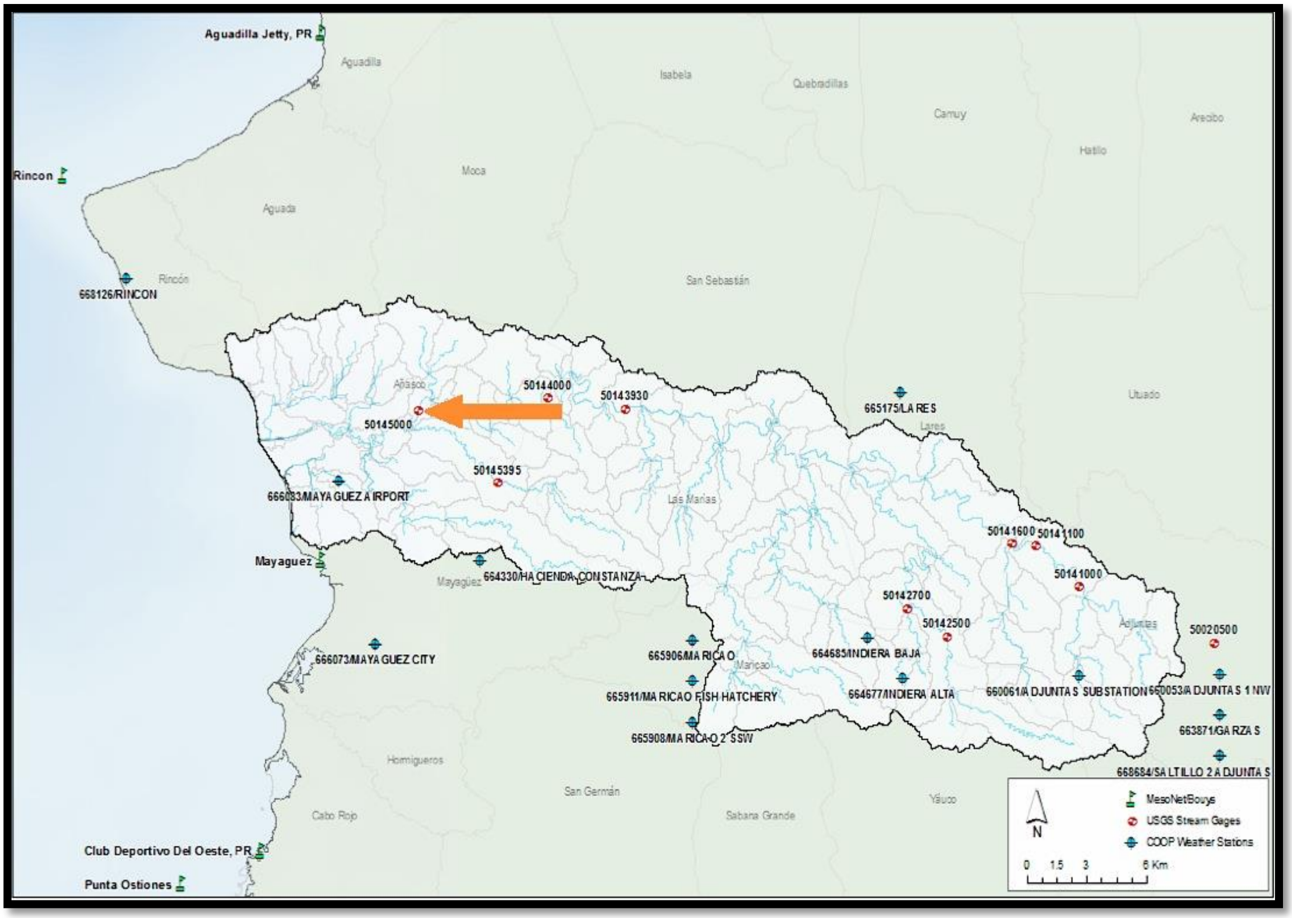


Figure 3. Discharge values represent water discharge in the middle of the basin and not in the mouth. It is difficult to determine how long it would it take the water to get from the gauging station (USGS 50144000, see arrow) to the mouth because there are not any gauging stations near the RGA’s mouth. From Ramos and Gilbes (2013).

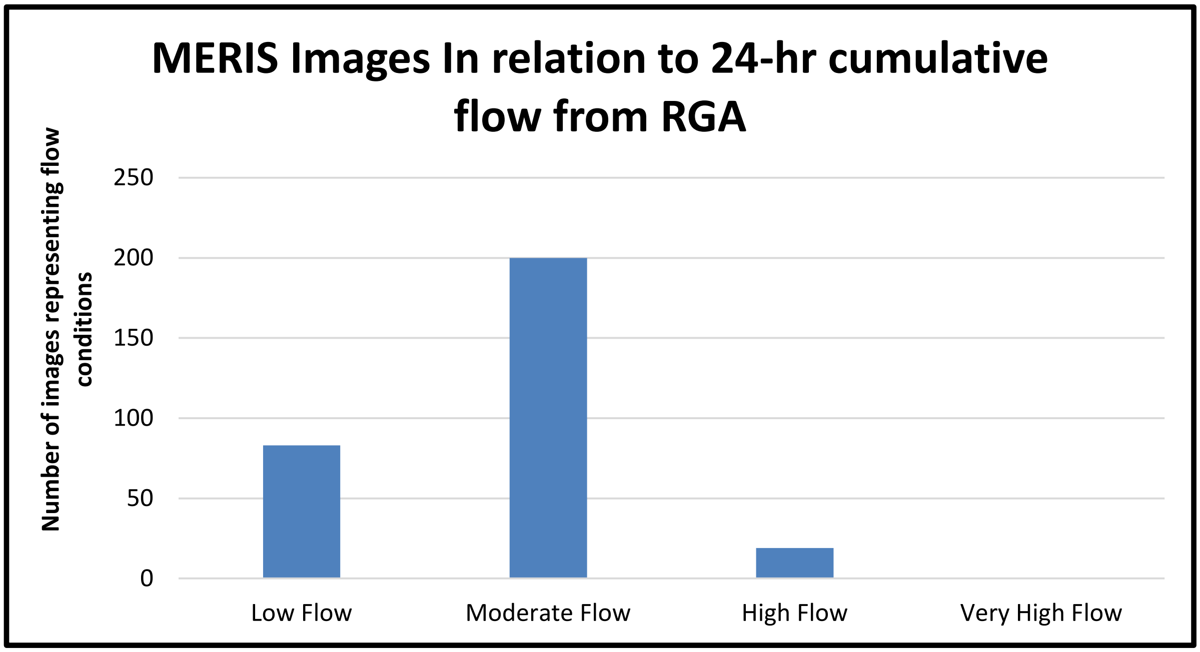
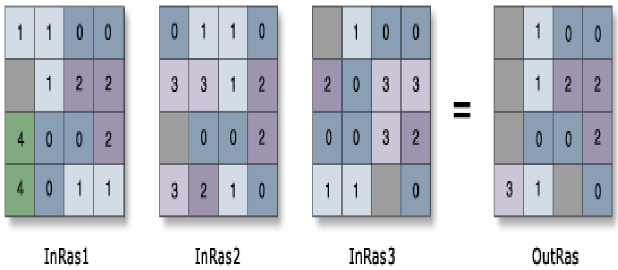


Figure 4. Graph showing images representing the different flow categories based on cumulative discharge for 24 hours prior to the time when the image was obtained. This period was selected because it showed the best correlation between cumulative discharge and TSM. Created by Dr. Carlos Ramos Scharron

Median

- Determines the median value of the inputs on a cell-by-cell basis.
- If the number of inputs is odd, the median value is calculated by ranking the values and selecting the middle value. If the number of inputs is even, the values will be ranked, and the middle two values will be averaged. This value will be truncated to an integer if all the input grids are of integer type.
- If all the inputs are integer, the output is integer. If any of the inputs are floating point, the output is floating point.




```
OutRas = CellStatistics([InRas1, InRas2, InRas3], "Median")
```

Figure 5. Cell statistics, median calculation description. Cell Statistics tool calculates statistics (Majority, Maximum, Mean, Median, Minimum, Minority, Range, Standard Deviation, Summary, and Variety) per-pixel from multiple raster images and creates a whole new raster image representing the statistical analysis. From ArcGIS Desktop 10.1 Help.

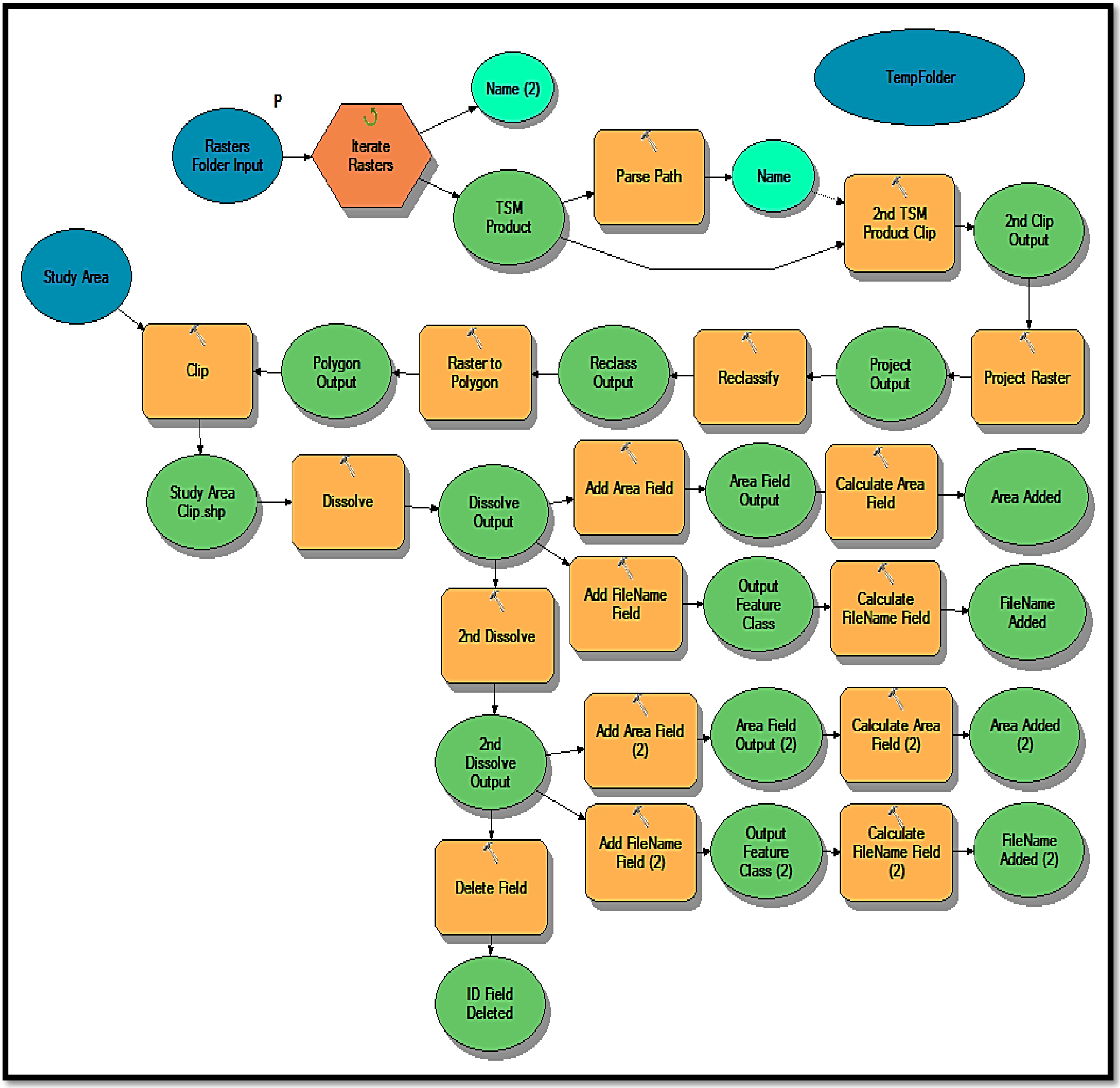


Figure 6. Complete Area Coverage Model. The model was used to calculate suspended sediment area coverage from 2005-2011. Model created by Vilmaliz Rodríguez using ArcGIS Desktop 10.1.

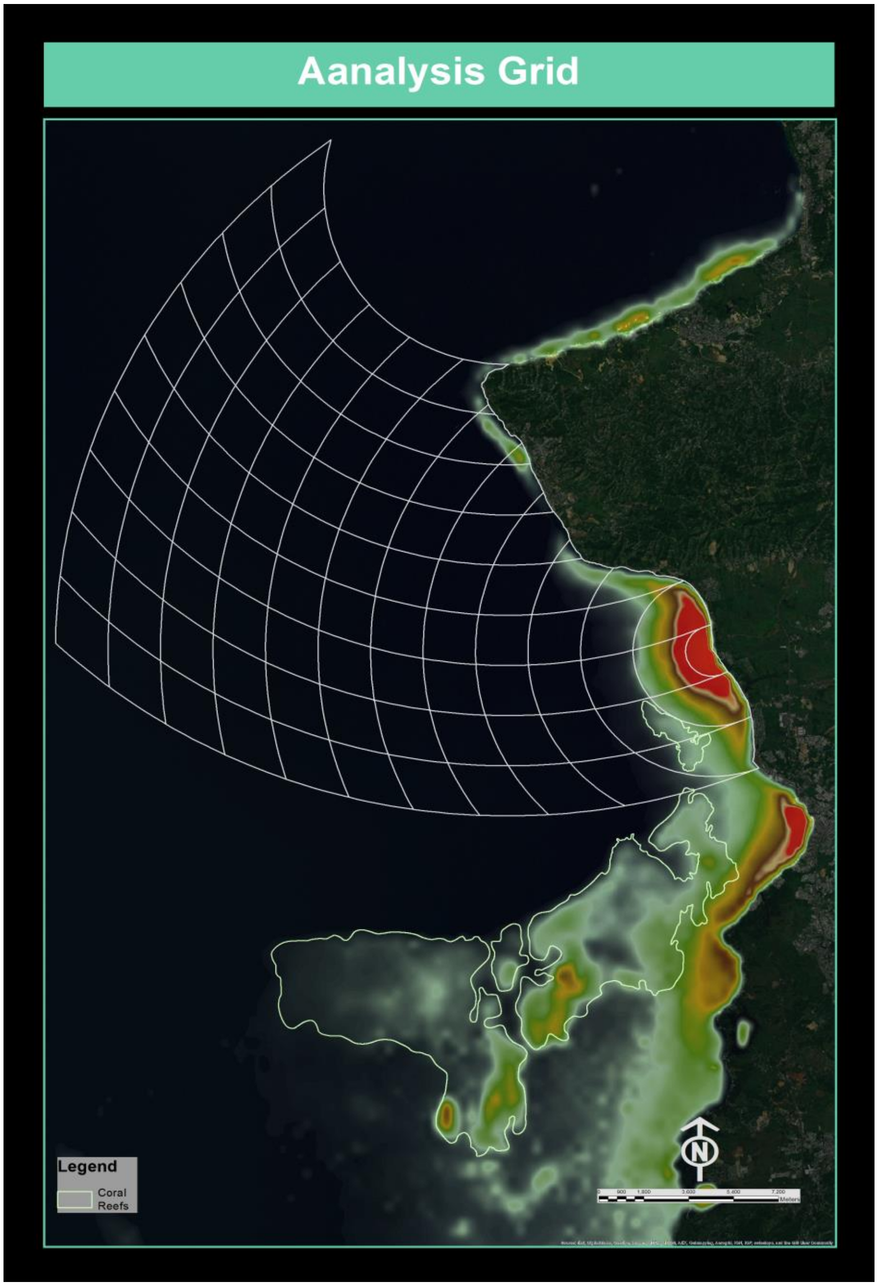


Figure 7. Analysis grid over the Añasco bay, created by Vilmaliz Rodríguez. Some nearby coral reefs (South of the grid) were not considered for this analysis grid, they are in shallow waters and their spectral signal is confused with TSM signal on the MERIS sensor making it difficult to differentiate them. Only one coral reef zone did not display this issue. Map Created by Josué Aceituno Díaz using ArcGIS Desktop 10.1.

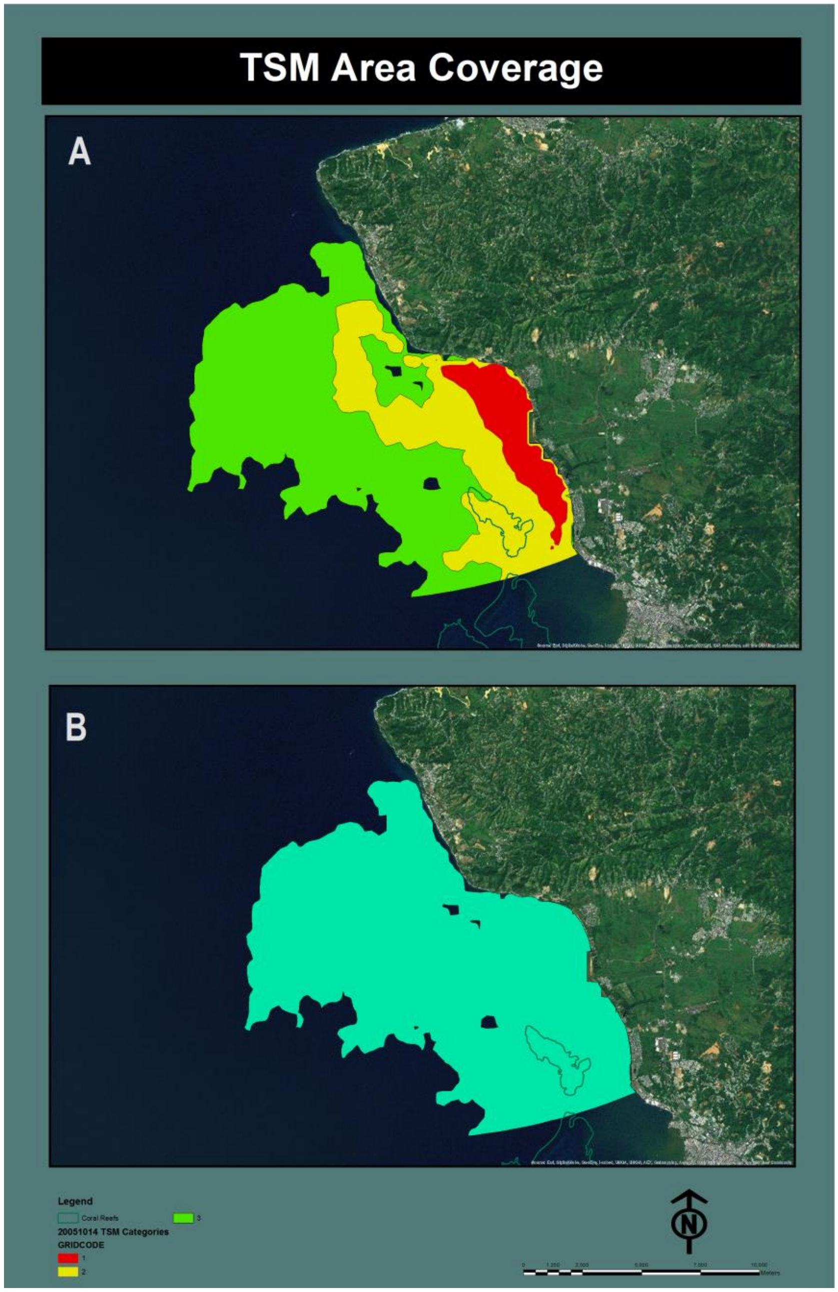


Figure 8. Example of an Area Coverage Model product. Map A are the categorized polygon shape files created, it shows the area coverage of each TSM class; class 1 in red, class 2 in yellow and class 3 in green. Map B is the general uncategorized polygon shape file showing the overall TSM area coverage. Map Created by Josué Aceituno Díaz using ArcGIS Desktop 10.1.

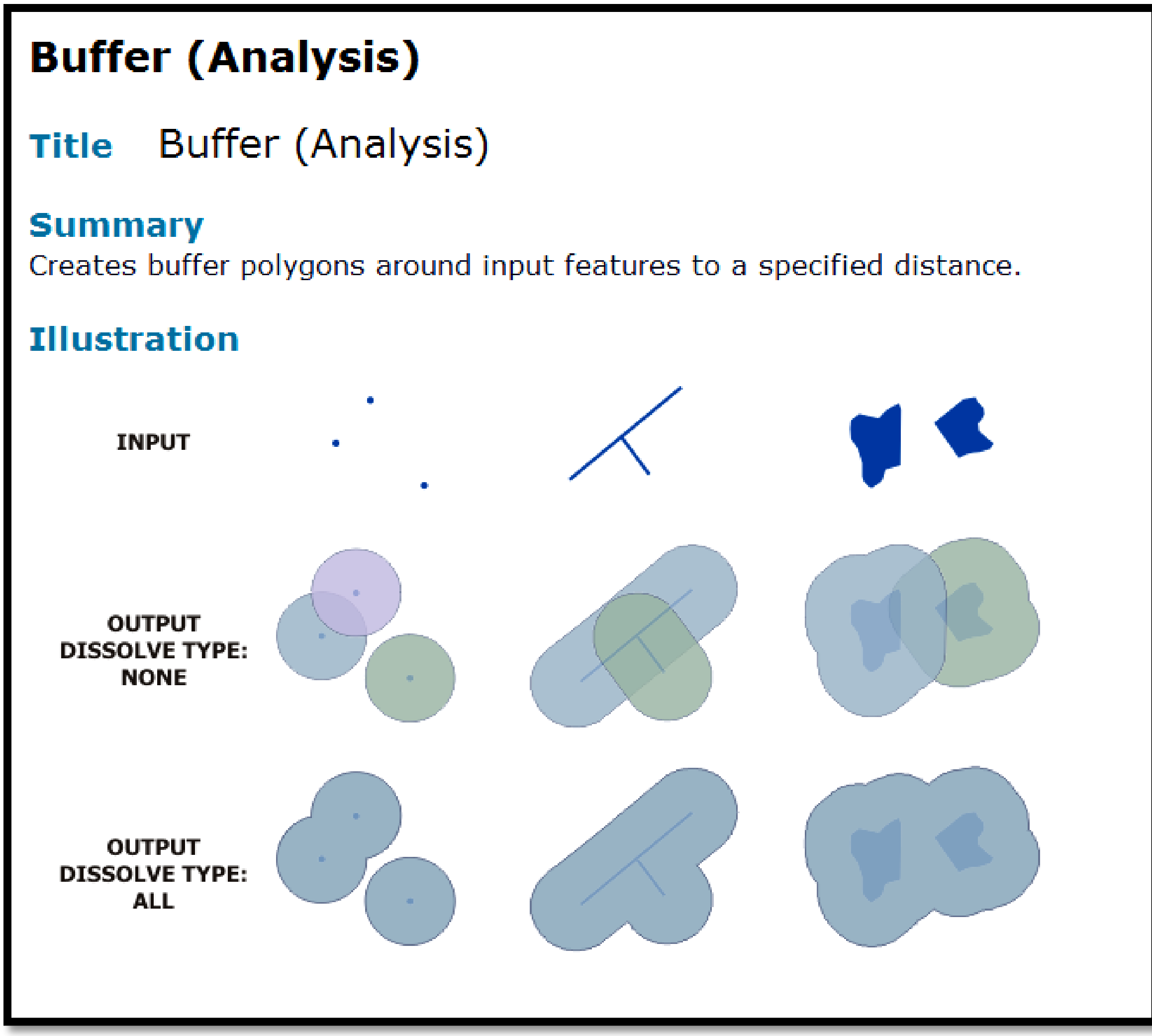


Figure 9. ArcGIS buffer analysis tool description. The tool was used to create a buffer zone of 2.5 km of length away from the mouth pixel. From ArcGIS Desktop 10.1 Help.

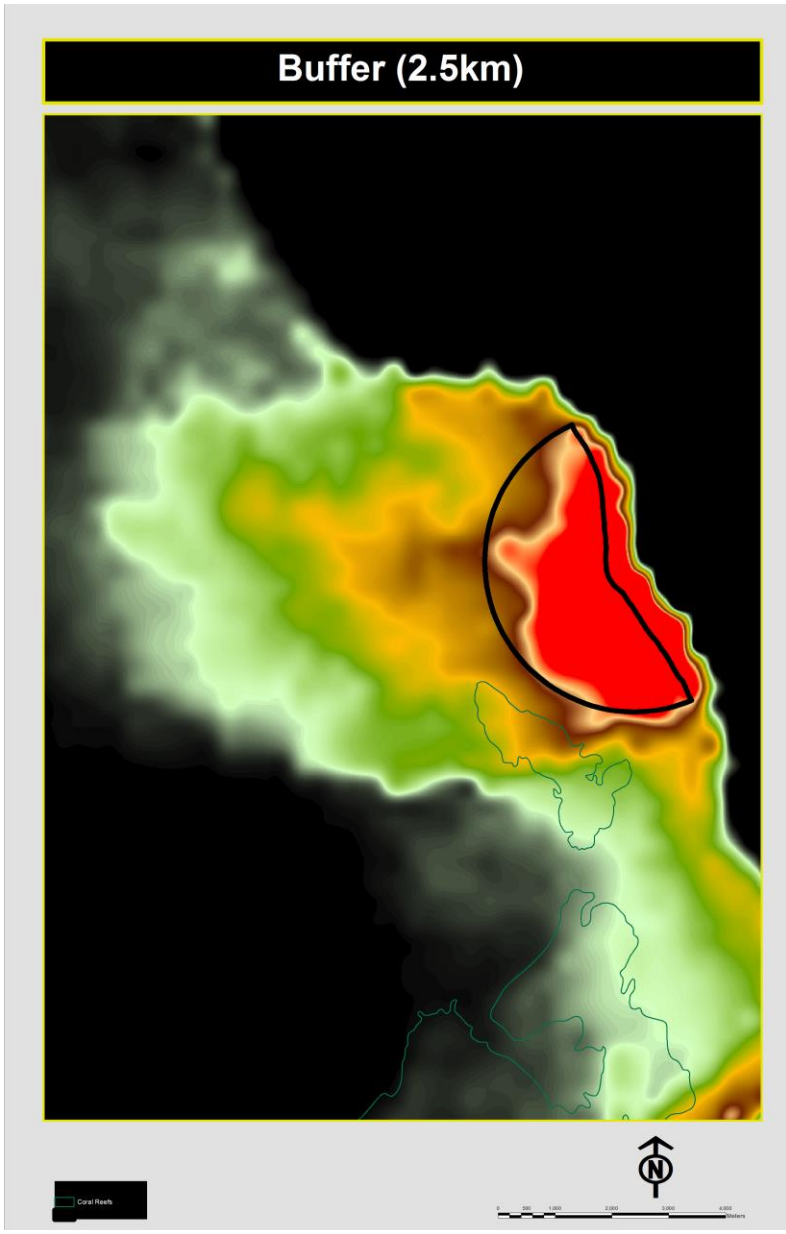


Figure 10. Buffer zone of 2.5 km. Created by Josué Aceituno Díaz using ArcGIS Desktop 10.1

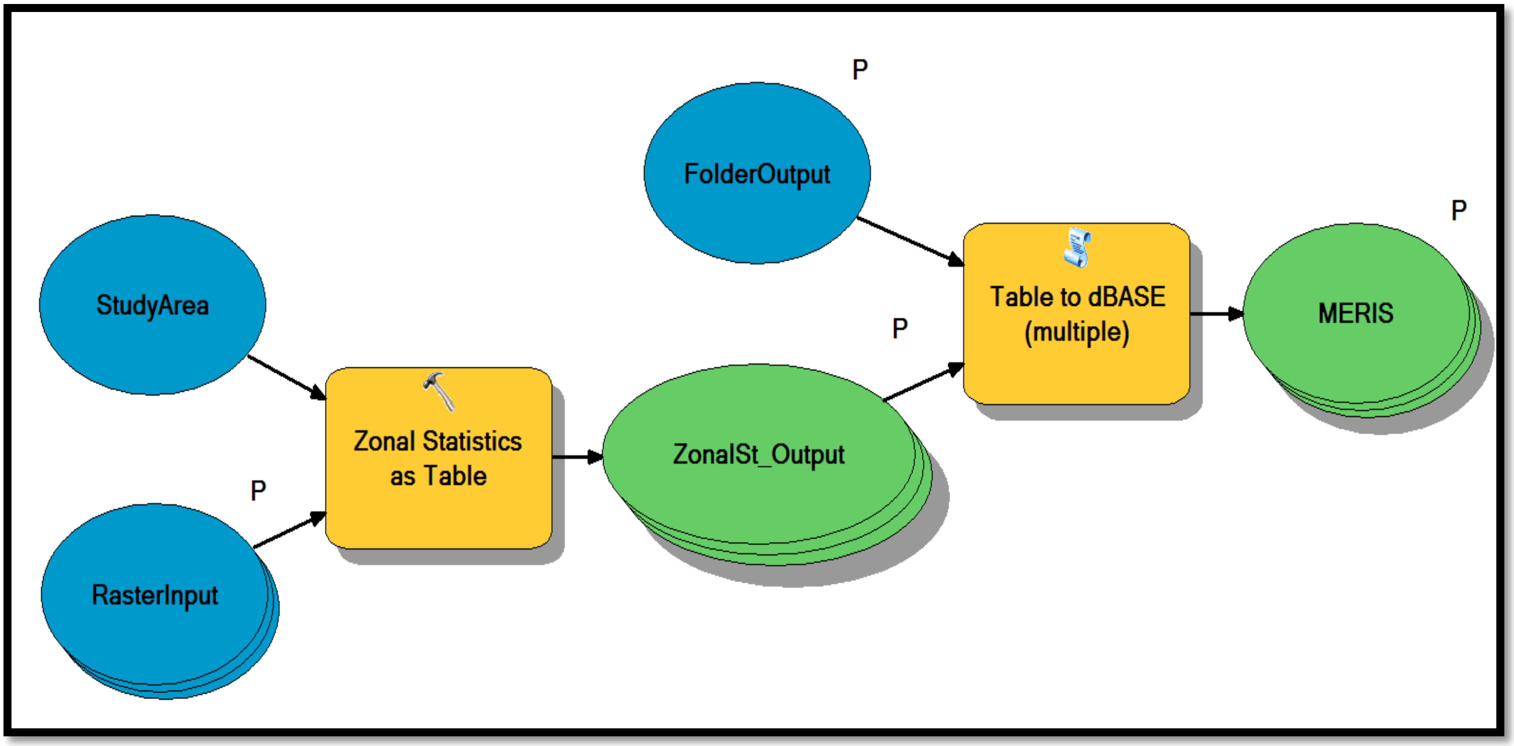


Figure 11. Complete Zonal Statistics Model used to run statistical analyses (maximum, minimum, sum, mean, standard deviation and range) on the 2.5km buffer zone from 2005-2011. Model created by Vilmaliz Rodríguez using ArcGIS Desktop 10.1.

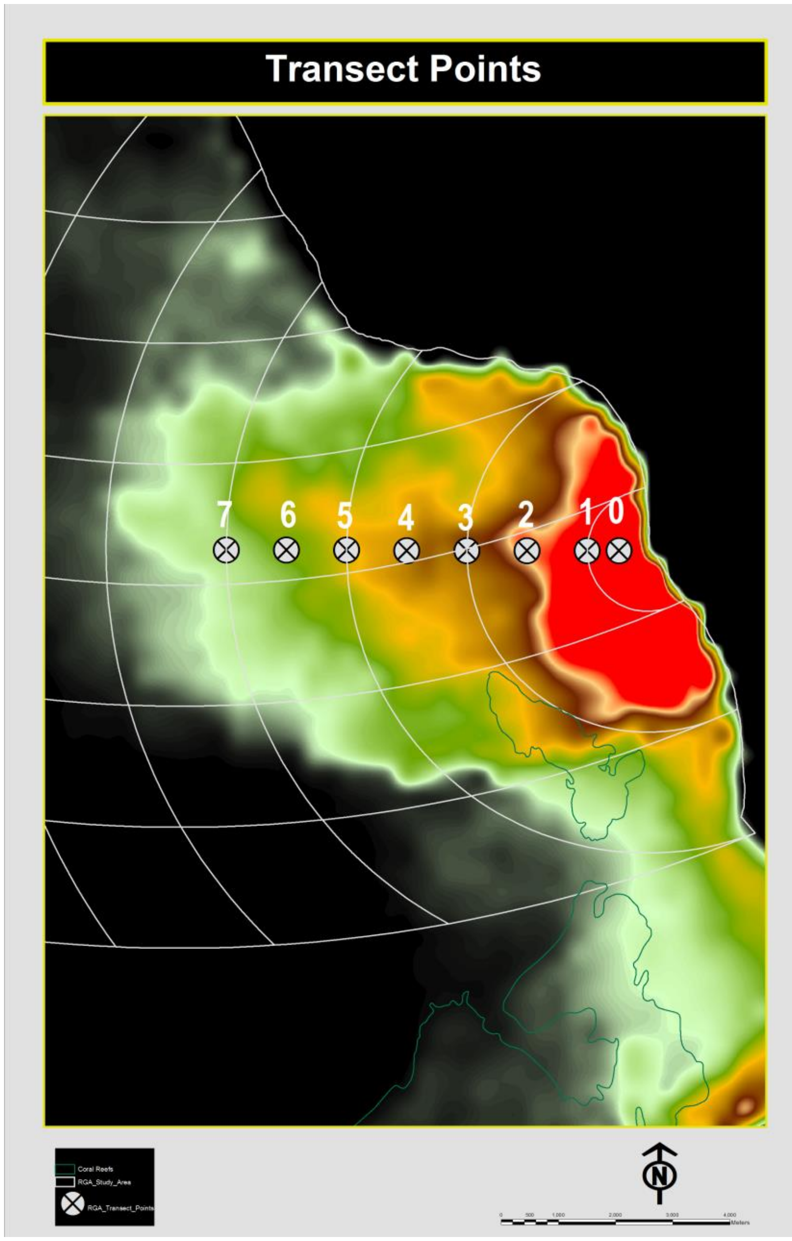


Figure 12. 6.5 km transect points with the analysis grid added. Created by Josué Aceituno Díaz using ArcGIS Desktop 10.1

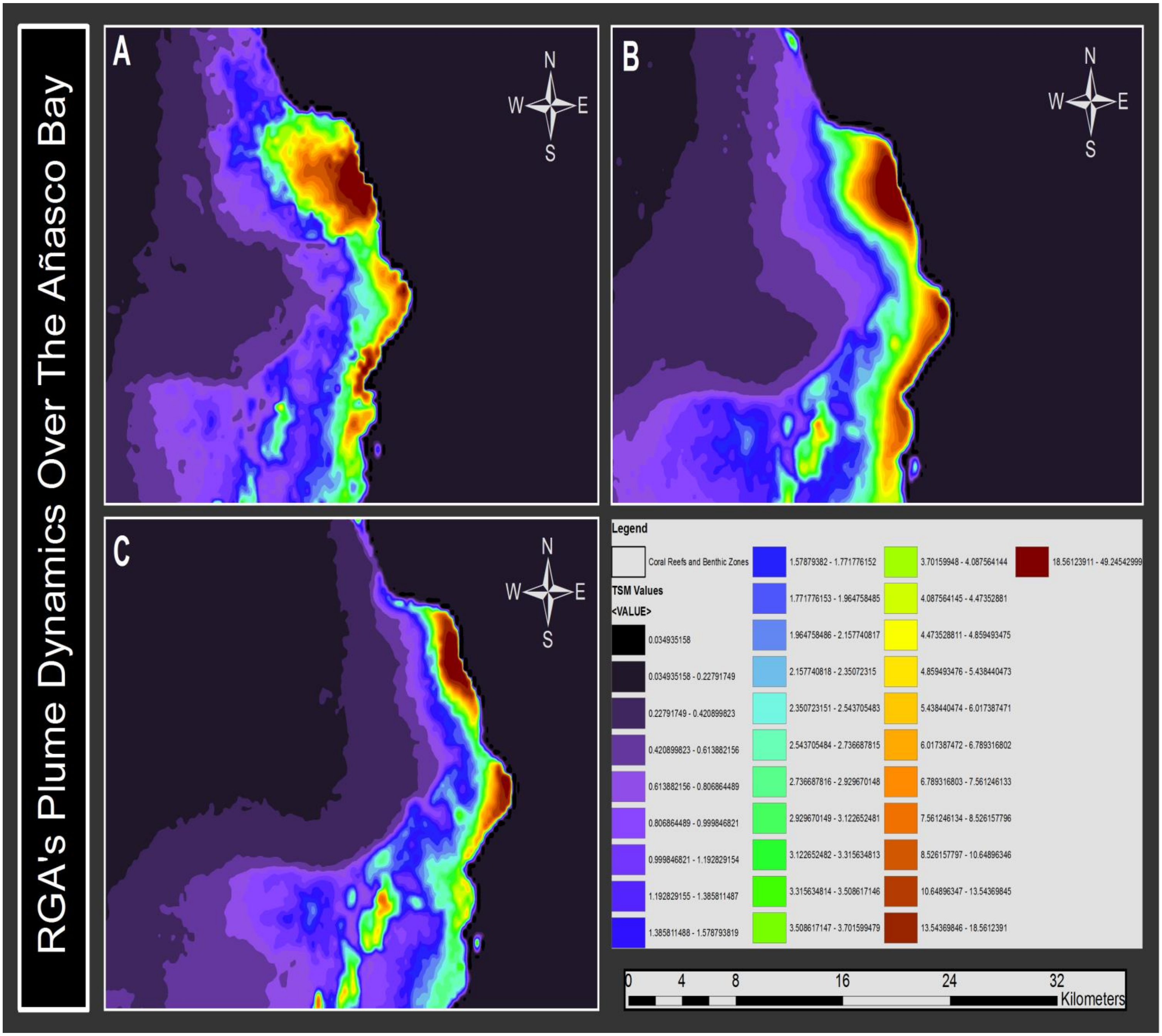


Figure 13. Map results from cell statistics analysis showing the Rio Grande de Añasco's plume dynamics over the Añasco bay. These maps represent median TSM values of the 128 images from 2005-2011. Map A shows plume dynamics under the influence of high flow discharges. Map b shows plume dynamics under the influence of moderate flow discharges. Map C shows plume dynamics under the influence of low flow discharges. Maps were created by Josué Aceituno Díaz using ArcGIS Desktop 10.1

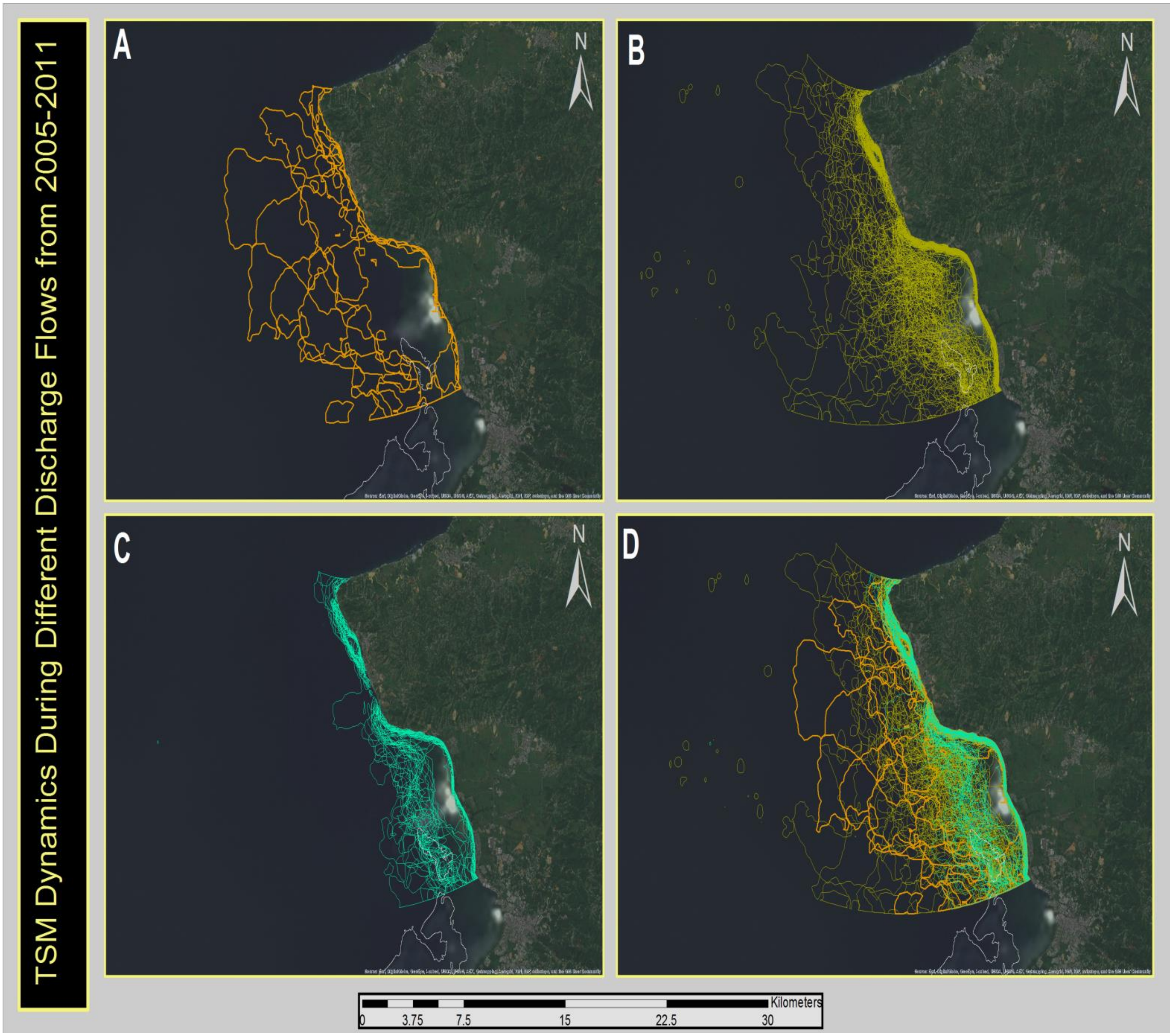


Figure 14. Maps showing the area outlines of the resulting polygons created by the Area Coverage Model and based on the TSM dynamics under the influence of High, Moderate and Low Flow 24-hr cumulative discharge for the 2005-2011 period. Map A represents TSM movement during High Flow discharges; Map B represents TSM movement during Moderate Flow discharges; Map C represents TSM movement during Low flow Discharges and Map D represent the combination of the three. Maps were created by Josué Aceituno Díaz using ArcGIS Desktop 10.1

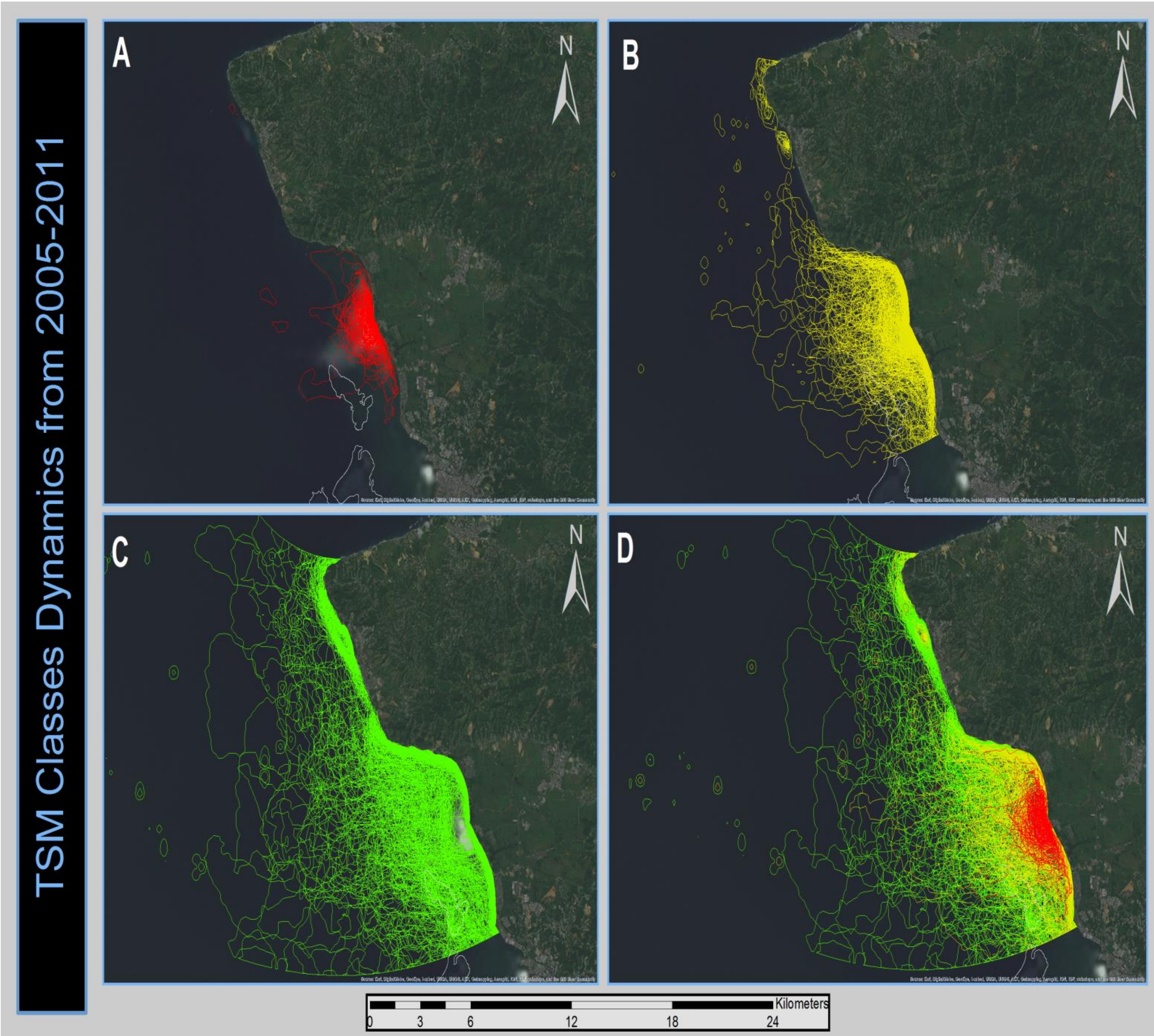


Figure 15. Maps showing the area outlines of the resulting polygons created by the Area Coverage Model and based on TSM classes (High (1), Medium (2) and Low (3) TSM values) on the Añasco bay from 2005-2011. Map A shows class 1 dynamics over the Añasco bay. Map B shows class 2 dynamics over the Añasco bay. Map C shows class 3 dynamics over the Añasco bay. Map D is a map combining all three classes. Maps were created by Josué Aceituno Díaz using ArcGIS Desktop 10.1

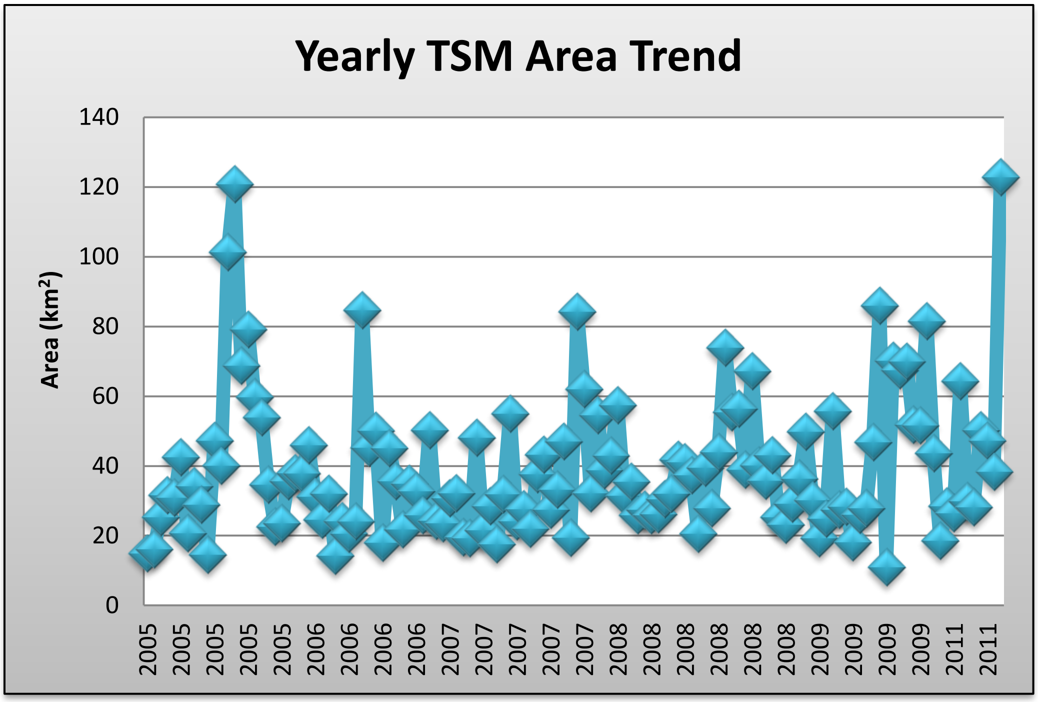


Figure 16. Yearly TSM area trend graph, the graph indicates one or two high peaks of sediment area coverage occurring each year. Created by Josué Aceituno Díaz using Microsoft's Excel.

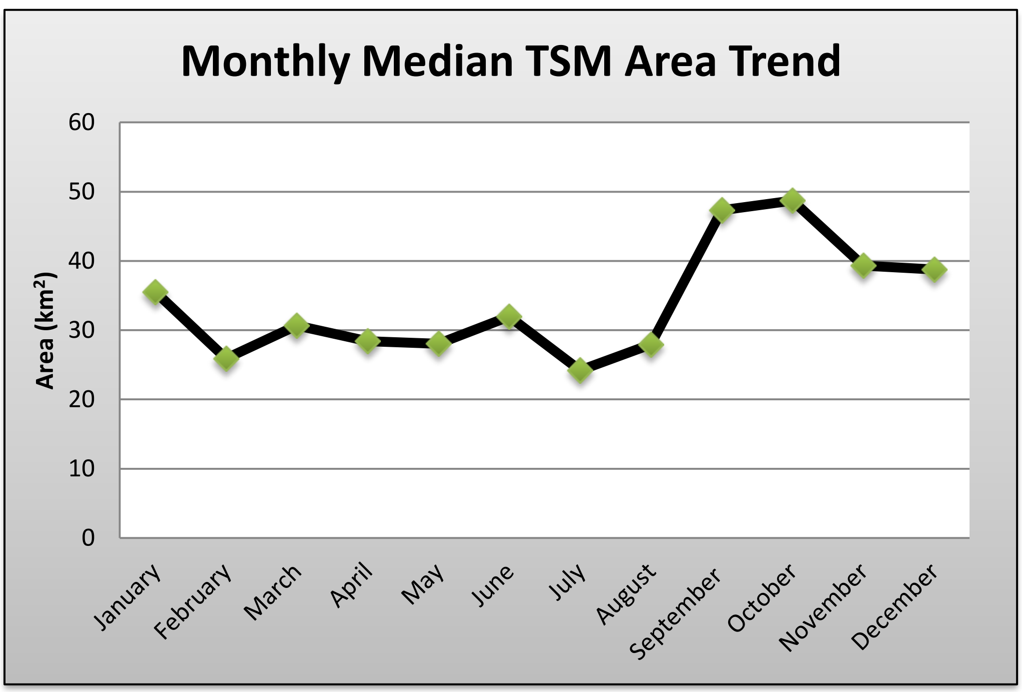


Figure 17. Median TSM area trend graph for each month from 2005-2011. High peaks occurred during the months of August, September, October and November which are the months of the wet season in Puerto Rico. Created by Josué Aceituno Díaz using Microsoft's Excel.

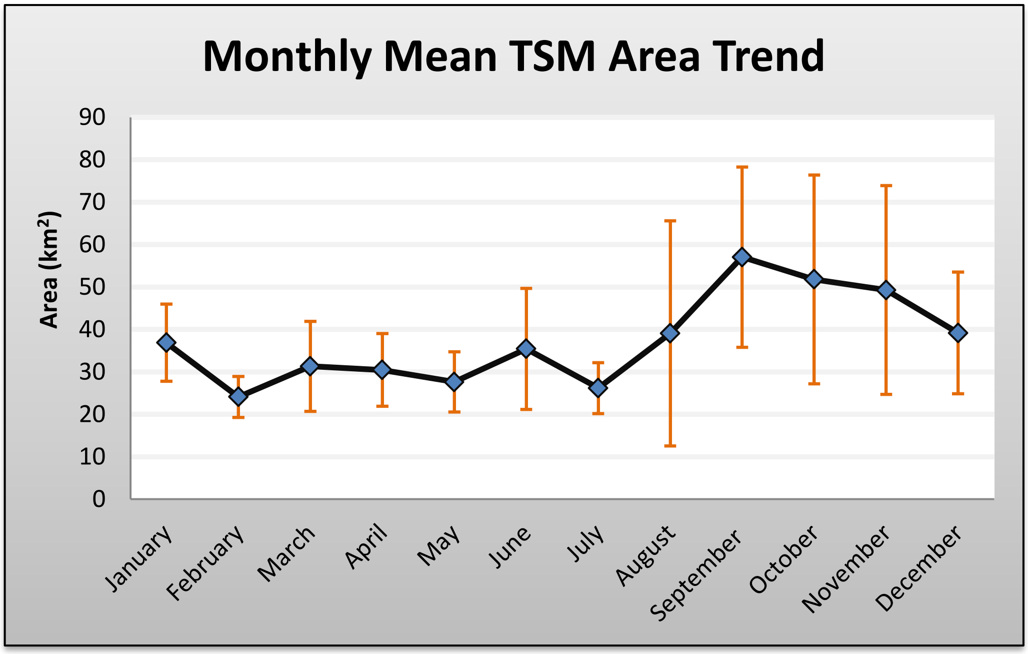


Figure 18. Mean TSM area trend graph for each month from 2005-2011 with their respective vertical error bar. High peaks occurred during the months of August, September, October and November which are the months of the wet season in Puerto Rico. Created by Josué Aceituno Díaz using Microsoft's Excel.

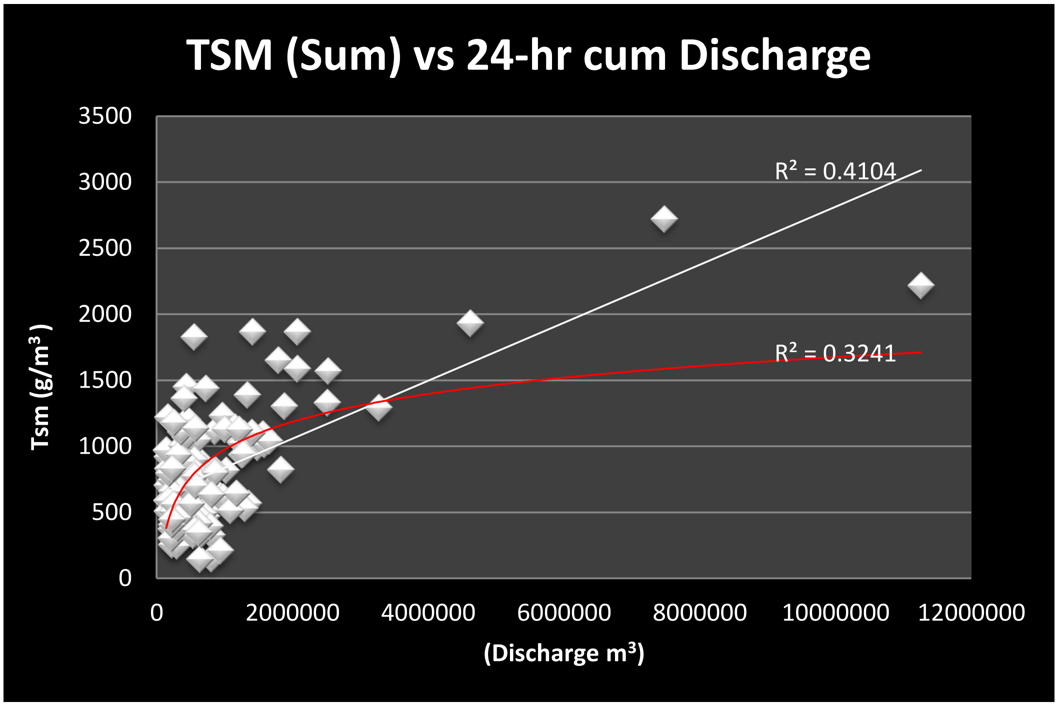


Figure 19. Correlation analysis between TSM (Summary of sediments) and 24 hour cumulative river discharge for the 2.5 km buffer zone near the RGA mouth. Created by Josué Aceituno Díaz using Microsoft's Excel.

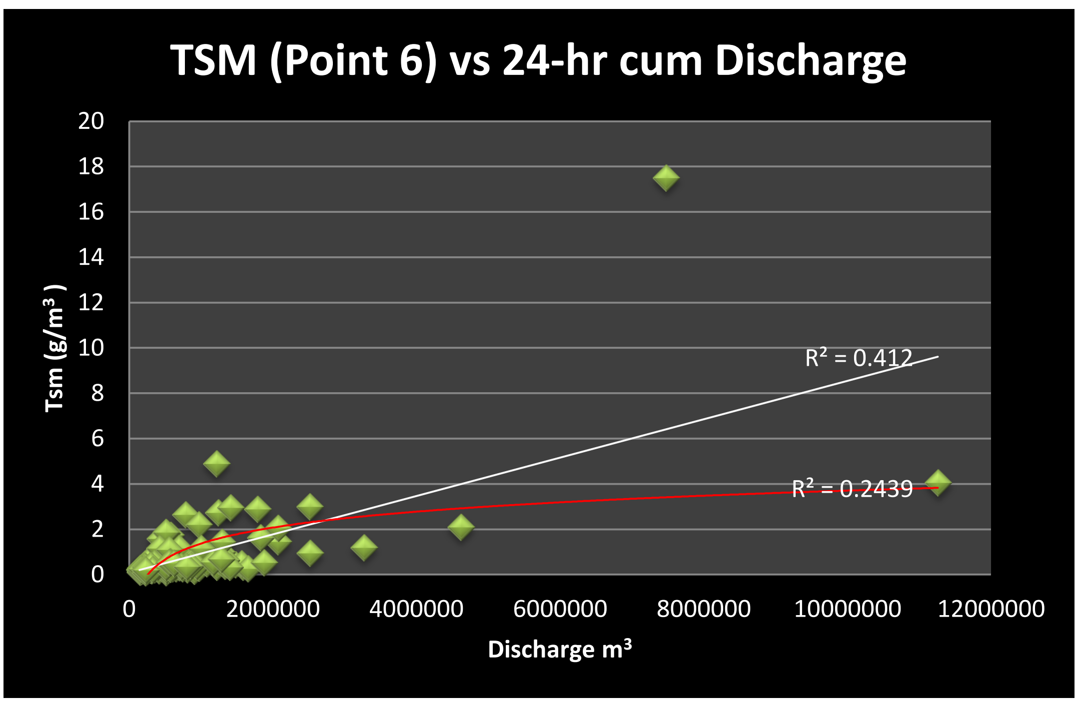


Figure 20. Correlation analysis between TSM from transect point 6 and 24 hour cumulative river discharge. Created by Josué Aceituno Díaz using Microsoft's Excel.

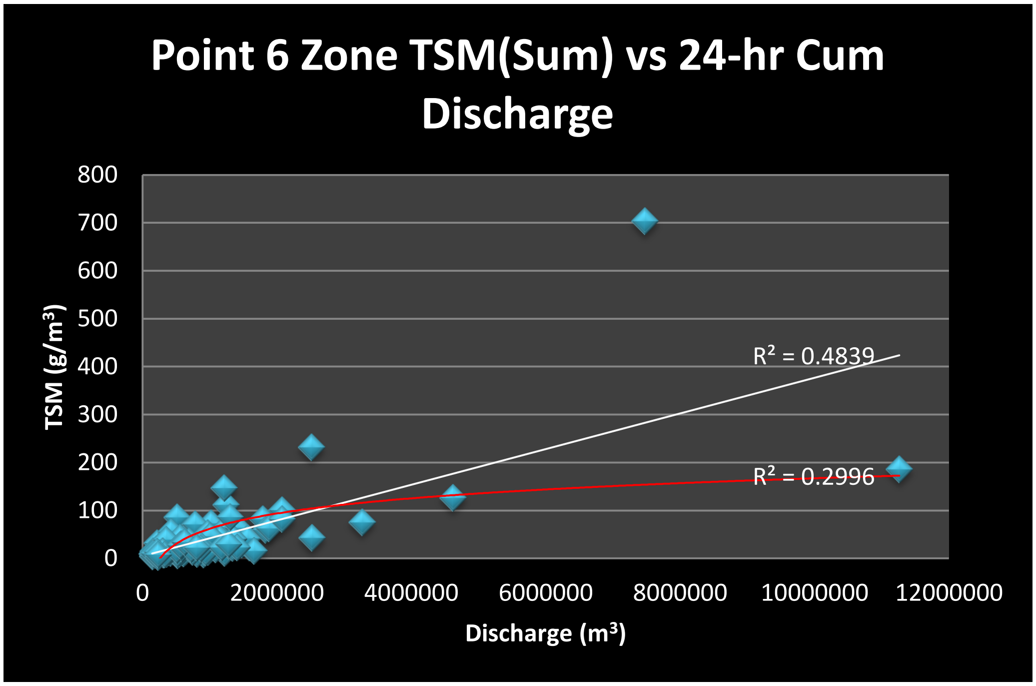


Figure 21. Correlation analysis between TSM from the 4 km^2 area that covered the transect point 6 when integrating the analysis grid and 24 hour cumulative river discharge. Created by Josué Aceituno Díaz using Microsoft's Excel

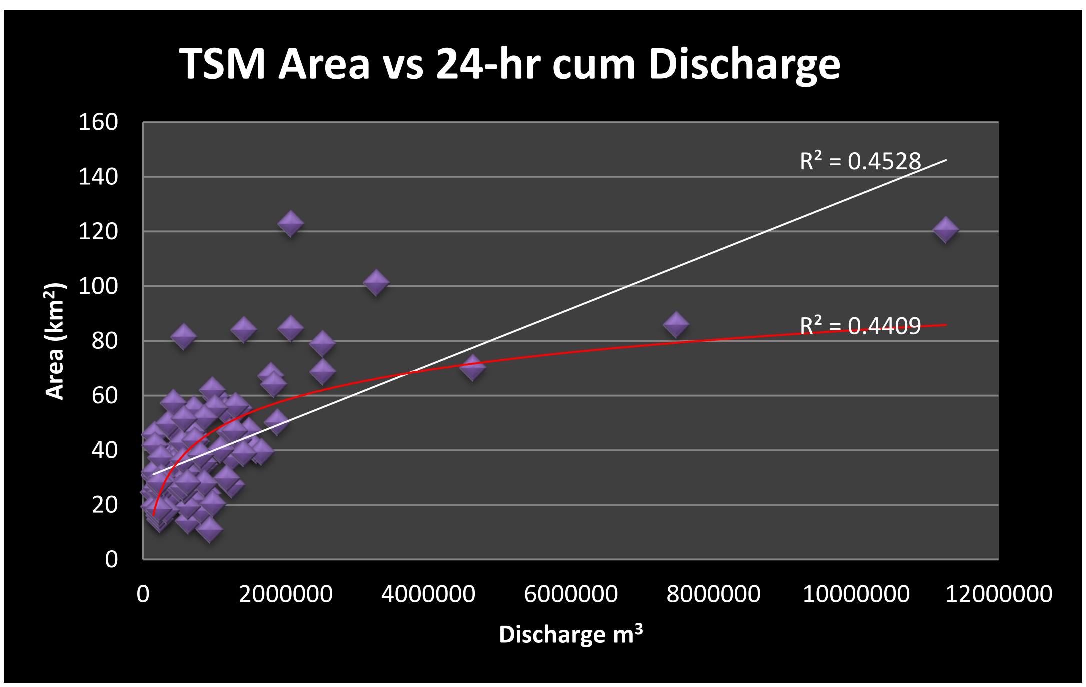


Figure 22. Correlation analysis between TSM area coverage and 24 hour cumulative river discharge. Created by Josué Aceituno Díaz using Microsoft's Excel.

Tables

Table 1. The MERIS 15 programmable spectral bands. Shows bandwidth from 412.5nm to 900nm with improved spectral resolution and its applications.
(From: http://wdc.dlr.de/sensors/meris/)

MERIS Channel Number	Centre Wavelength ± Bandwidth (nm)	Application
1	412.5 ± 10	Yellow substance and detrial pigments
2	442.5 ± 10	Chlorophyll absorption maximum
3	490 ± 10	Chloropyll and other pigments
4	510 ± 10	Suspended sediment, red tides
5	560 ± 10	Chlorophyll absorption minimum
6	620± 10	Suspended sediment
7	665± 10	Chlorophyll absorption and fluorescence reference
8	681.25 ± 7.5	Chlorophyll fluorescence peak
9	708.75 ± 10	Fluorescence reference, atmospheric corrections
10	753.75 ± 7.5	Vegetation, cloud
11	760.625 ± 3.75	Oxygen absorption R-branch
12	778.75 ± 15	Atmosphere corrections
13	865 ± 20	Vegetation, water vapour reference
14	885 ± 10	Atmosphere corrections
15	900 ± 10	Water vapour, land

Table 2. Shows the 128 images and their category for the 24 hour cumulative discharge. Created by Josué Aceituno Díaz using Microsoft's Excel.

Date	24hr-Cum Discharge Category
2/24/2005	Low Flow
3/2/2005	Low Flow
3/5/2005	Low Flow
3/8/2005	Low Flow
3/24/2005	Low Flow
3/12/2006	Low Flow
3/22/2006	Low Flow
3/25/2006	Low Flow
7/15/2006	Low Flow
12/27/2006	Low Flow
1/18/2007	Low Flow
1/31/2007	Low Flow
3/7/2007	Low Flow
5/16/2007	Low Flow
2/20/2008	Low Flow
2/23/2008	Low Flow
2/26/2008	Low Flow
3/10/2008	Low Flow
3/13/2008	Low Flow
3/26/2008	Low Flow
3/29/2008	Low Flow
5/19/2008	Low Flow
1/19/2009	Low Flow
2/4/2009	Low Flow
2/23/2009	Low Flow
2/26/2009	Low Flow
3/27/2009	Low Flow
4/18/2009	Low Flow
3/15/2010	Low Flow
1/27/2011	Low Flow
4/22/2005	Moderate Flow
4/25/2005	Moderate Flow
5/27/2005	Moderate Flow
6/15/2005	Moderate Flow
8/5/2005	Moderate Flow
9/12/2005	Moderate Flow
9/19/2005	Moderate Flow
11/8/2005	Moderate Flow
11/15/2005	Moderate Flow
11/18/2005	Moderate Flow
12/13/2005	Moderate Flow

12/23/2005	Moderate Flow
12/29/2005	Moderate Flow
1/1/2006	Moderate Flow
3/9/2006	Moderate Flow
5/15/2006	Moderate Flow
6/19/2006	Moderate Flow
7/8/2006	Moderate Flow
8/19/2006	Moderate Flow
9/3/2006	Moderate Flow
10/24/2006	Moderate Flow
11/3/2006	Moderate Flow
11/6/2006	Moderate Flow
11/9/2006	Moderate Flow
11/12/2006	Moderate Flow
11/22/2006	Moderate Flow
11/25/2006	Moderate Flow
12/8/2006	Moderate Flow
12/11/2006	Moderate Flow
1/2/2007	Moderate Flow
3/29/2007	Moderate Flow
4/11/2007	Moderate Flow
4/30/2007	Moderate Flow
6/23/2007	Moderate Flow
6/29/2007	Moderate Flow
7/25/2007	Moderate Flow
7/28/2007	Moderate Flow
8/13/2007	Moderate Flow
8/29/2007	Moderate Flow
9/1/2007	Moderate Flow
9/11/2007	Moderate Flow
10/3/2007	Moderate Flow
10/9/2007	Moderate Flow
10/19/2007	Moderate Flow
11/7/2007	Moderate Flow
11/10/2007	Moderate Flow
11/23/2007	Moderate Flow
12/18/2007	Moderate Flow
12/31/2007	Moderate Flow
1/6/2008	Moderate Flow
1/9/2008	Moderate Flow
1/22/2008	Moderate Flow
1/25/2008	Moderate Flow
4/30/2008	Moderate Flow
7/25/2008	Moderate Flow
7/28/2008	Moderate Flow

8/16/2008	Moderate Flow
8/29/2008	Moderate Flow
10/6/2008	Moderate Flow
10/9/2008	Moderate Flow
10/28/2008	Moderate Flow
11/26/2008	Moderate Flow
11/29/2008	Moderate Flow
12/2/2008	Moderate Flow
12/12/2008	Moderate Flow
12/31/2008	Moderate Flow
1/22/2009	Moderate Flow
1/25/2009	Moderate Flow
3/1/2009	Moderate Flow
5/1/2009	Moderate Flow
5/4/2009	Moderate Flow
5/30/2009	Moderate Flow
6/8/2009	Moderate Flow
8/14/2009	Moderate Flow
11/27/2009	Moderate Flow
12/6/2009	Moderate Flow
12/22/2009	Moderate Flow
12/26/2009	Moderate Flow
1/1/2010	Moderate Flow
7/18/2011	Moderate Flow
9/16/2011	Moderate Flow
10/5/2011	Moderate Flow
10/16/2011	Moderate Flow
10/19/2011	Moderate Flow
10/27/2011	Moderate Flow
11/1/2011	Moderate Flow
11/12/2011	Moderate Flow
9/28/2005	High Flow
10/14/2005	High Flow
10/17/2005	High Flow
10/20/2005	High Flow
8/11/2009	High Flow
9/18/2009	High Flow
8/12/2006	NO DATA
3/20/2007	NO DATA
9/17/2008	NO DATA
11/10/2008	NO DATA
12/3/2009	NO DATA

Table 3. Uncategorized TSM area coverage in square kilometers calculated by the Area Coverage Model for the 128 images. Created by Josué Aceituno Díaz using Microsoft's Excel.

Date	Area (km)
2/24/2005	14.9123
3/2/2005	16.250099
3/5/2005	25.416201
3/8/2005	31.6535
3/24/2005	30.898701
4/22/2005	42.5574
4/25/2005	20.7638
5/27/2005	34.247398
6/15/2005	28.9559
8/5/2005	14.541
9/12/2005	47.324402
9/19/2005	40.122002
9/28/2005	101.348
10/14/2005	120.853996
10/17/2005	68.823898
10/20/2005	79.1399
11/8/2005	59.689201
11/15/2005	53.925701
11/18/2005	34.709499
12/13/2005	22.5466
12/23/2005	23.5511
12/29/2005	35.6441
1/1/2006	37.951599
3/9/2006	37.875301
3/12/2006	45.934101
3/22/2006	31.241199
3/25/2006	24.636499
5/15/2006	31.979
6/19/2006	14.2659
7/8/2006	24.2211
7/15/2006	20.5851
8/12/2006	24.100201
8/19/2006	84.639503
9/3/2006	45.362099
10/24/2006	50.160999
11/3/2006	17.9673
11/6/2006	45.123798
11/9/2006	35.661999

11/12/2006	21.8599
11/22/2006	34.933102
11/25/2006	32.843399
12/8/2006	25.9123
12/11/2006	50.240898
12/27/2006	24.2929
1/2/2007	23.635201
1/18/2007	30.7645
1/31/2007	32.187401
3/7/2007	19.5968
3/20/2007	19.3311
3/29/2007	48.093399
4/11/2007	21.5581
4/30/2007	28.412399
5/16/2007	17.6126
6/23/2007	31.9473
6/29/2007	55.093899
7/25/2007	24.187901
7/28/2007	27.5956
8/13/2007	21.983601
8/29/2007	37.5882
9/1/2007	43.187801
9/11/2007	27.556999
10/3/2007	33.237301
10/9/2007	47.097099
10/19/2007	19.489901
11/7/2007	84.188499
11/10/2007	62.099899
11/23/2007	32.272499
12/18/2007	54.6343
12/31/2007	38.771301
1/6/2008	42.9702
1/9/2008	57.506302
1/22/2008	31.4305
1/25/2008	35.5354
2/20/2008	25.928101
2/23/2008	27.4681
2/26/2008	25.902201
3/10/2008	26.2577
3/13/2008	30.4772
3/26/2008	32.136002
3/29/2008	41.875702
4/30/2008	41.127102

5/19/2008	37.430401
7/25/2008	20.5707
7/28/2008	39.558601
8/16/2008	27.948299
8/29/2008	44.069401
9/17/2008	73.961304
10/6/2008	55.408199
10/9/2008	56.435001
10/28/2008	38.9188
11/10/2008	67.126801
11/26/2008	40.208
11/29/2008	35.7728
12/2/2008	43.134499
12/12/2008	25.2759
12/31/2008	23.245001
1/19/2009	29.143999
1/22/2009	36.395901
1/25/2009	49.8321
2/4/2009	30.301399
2/23/2009	19.234699
2/26/2009	24.9732
3/1/2009	55.727501
3/27/2009	27.5595
4/18/2009	28.3664
5/1/2009	18.1495
5/4/2009	26.080999
5/30/2009	28.0191
6/8/2009	46.869701
8/11/2009	85.981697
8/14/2009	11.0174
9/18/2009	70.300102
11/27/2009	67.469299
12/3/2009	69.960701
12/6/2009	51.9217
12/22/2009	51.6297
12/26/2009	81.597099
1/1/2010	43.656101
3/15/2010	18.635799
1/27/2011	28.4037
7/18/2011	26.522699
9/16/2011	64.314201
10/5/2011	29.870899
10/16/2011	28.2808

10/19/2011	50.319698
10/27/2011	47.285099
11/1/2011	38.423302
11/12/2011	122.885002

Table 4. Area coverage in square kilometers calculated by the Area Coverage Model for suspended sediment classes (High (1), Medium (2) and Low (3) TSM values) present on each image throughout the 7 years. High sediment values are in red color, medium sediment values are in yellow color and low sediment values are green colors. Created by Josué Aceituno Díaz using Microsoft's Excel.

Date	Category	Area Coverage (km)
2/24/2005	2	3.97803
2/24/2005	3	10.5865
2/24/2005	1	0.347861
3/2/2005	2	3.76948
3/2/2005	3	12.4806
3/5/2005	2	5.57539
3/5/2005	3	19.840799
3/8/2005	2	8.63014
3/8/2005	3	22.747101
3/8/2005	1	0.276248
3/24/2005	2	8.59586
3/24/2005	3	21.803801
3/24/2005	1	0.499088
4/22/2005	2	12.9853
4/22/2005	3	27.2187
4/22/2005	1	2.35335
4/25/2005	2	3.35127
4/25/2005	3	16.923599
4/25/2005	1	0.488884
5/27/2005	2	6.56564
5/27/2005	3	26.955299
5/27/2005	1	0.726492
6/15/2005	2	6.05757
6/15/2005	3	22.3699
6/15/2005	1	0.528395
8/5/2005	2	0.936502
8/5/2005	3	13.6045
9/12/2005	2	9.92626

9/12/2005	3	35.338501
9/12/2005	1	2.05961
9/19/2005	2	7.70139
9/19/2005	3	30.6525
9/19/2005	1	1.76814
9/28/2005	1	5.98457
9/28/2005	2	28.959
9/28/2005	3	66.4049
10/14/2005	1	11.0787
10/14/2005	2	33.4823
10/14/2005	3	76.293503
10/17/2005	1	4.15412
10/17/2005	2	28.016701
10/17/2005	3	36.653099
10/20/2005	2	25.156401
10/20/2005	3	51.526001
10/20/2005	1	2.4576
11/8/2005	2	23.5926
11/8/2005	3	36.020901
11/8/2005	1	0.075712
11/15/2005	2	17.814899
11/15/2005	3	33.615299
11/15/2005	1	2.49551
11/18/2005	2	14.2585
11/18/2005	3	18.996799
11/18/2005	1	1.45418
12/13/2005	2	5.57174
12/13/2005	3	16.961901
12/13/2005	1	0.012922
12/23/2005	2	7.34072
12/23/2005	3	16.177401
12/23/2005	1	0.032977
12/29/2005	2	14.0079
12/29/2005	3	21.355301
12/29/2005	1	0.280885
1/1/2006	2	9.77265
1/1/2006	3	27.0679
1/1/2006	1	1.11105
3/9/2006	1	3.59089
3/9/2006	2	11.5287
3/9/2006	3	22.7558
3/12/2006	2	11.558
3/12/2006	3	32.8176

3/12/2006	1	1.5585
3/22/2006	2	9.99689
3/22/2006	3	21.0329
3/22/2006	1	0.211413
3/25/2006	2	5.32194
3/25/2006	3	17.154699
3/25/2006	1	2.1598
5/15/2006	2	7.76212
5/15/2006	3	23.494301
5/15/2006	1	0.722625
6/19/2006	2	2.28503
6/19/2006	3	11.9808
7/8/2006	2	7.7973
7/8/2006	3	15.7271
7/8/2006	1	0.696746
7/15/2006	2	2.28917
7/15/2006	3	18.2959
8/12/2006	2	5.16916
8/12/2006	3	18.931
8/19/2006	1	4.2021
8/19/2006	2	17.968901
8/19/2006	3	62.468498
9/3/2006	2	6.0714
9/3/2006	3	38.619999
9/3/2006	1	0.67076
10/24/2006	2	8.74609
10/24/2006	3	41.096802
10/24/2006	1	0.318061
11/3/2006	2	4.52256
11/3/2006	3	13.3581
11/3/2006	1	0.086602
11/6/2006	2	11.6847
11/6/2006	3	32.383499
11/6/2006	1	1.05553
11/9/2006	2	15.5284
11/9/2006	3	19.5825
11/9/2006	1	0.551007
11/12/2006	2	7.42639
11/12/2006	3	14.4322
11/12/2006	1	0.001342
11/22/2006	2	13.2226
11/22/2006	3	19.694599
11/22/2006	1	2.01586

11/25/2006	2	15.8259
11/25/2006	3	15.9107
11/25/2006	1	1.10678
12/8/2006	2	8.22803
12/8/2006	3	16.2773
12/8/2006	1	1.40692
12/11/2006	1	3.16428
12/11/2006	2	20.566299
12/11/2006	3	26.5103
12/27/2006	2	9.32466
12/27/2006	3	14.6894
12/27/2006	1	0.278836
1/2/2007	2	7.28651
1/2/2007	3	15.9176
1/2/2007	1	0.431052
1/18/2007	2	7.95642
1/18/2007	3	21.455
1/18/2007	1	1.35311
1/31/2007	2	13.6172
1/31/2007	3	18.1563
1/31/2007	1	0.413954
3/7/2007	2	7.12097
3/7/2007	3	12.3234
3/7/2007	1	0.152389
3/20/2007	2	5.24989
3/20/2007	3	13.7112
3/20/2007	1	0.369962
3/29/2007	1	2.72408
3/29/2007	2	15.083
3/29/2007	3	30.286301
4/11/2007	2	4.27946
4/11/2007	3	17.160299
4/11/2007	1	0.118298
4/30/2007	2	7.33967
4/30/2007	3	19.791201
4/30/2007	1	1.28158
5/16/2007	2	2.91929
5/16/2007	3	14.6933
6/23/2007	2	4.78951
6/23/2007	3	26.683399
6/23/2007	1	0.474374
6/29/2007	2	13.4078
6/29/2007	3	40.4123

6/29/2007	1	1.27385
7/25/2007	2	4.17737
7/25/2007	3	19.927
7/25/2007	1	0.083517
7/28/2007	2	3.70765
7/28/2007	3	23.7003
7/28/2007	1	0.187629
8/13/2007	2	5.91775
8/13/2007	3	15.7691
8/13/2007	1	0.296747
8/29/2007	1	1.3937
8/29/2007	2	11.9045
8/29/2007	3	24.290001
9/1/2007	2	4.17846
9/1/2007	3	38.594601
9/1/2007	1	0.414784
9/11/2007	1	1.7101
9/11/2007	2	11.5706
9/11/2007	3	14.2763
10/3/2007	2	7.27325
10/3/2007	3	25.900101
10/3/2007	1	0.063974
10/9/2007	2	7.51658
10/9/2007	3	38.4949
10/9/2007	1	1.08566
10/19/2007	2	7.68337
10/19/2007	3	11.5715
10/19/2007	1	0.235003
11/7/2007	1	4.27651
11/7/2007	2	47.8582
11/7/2007	3	32.053799
11/10/2007	1	2.47982
11/10/2007	2	17.3335
11/10/2007	3	42.286598
11/23/2007	1	3.43247
11/23/2007	2	13.4482
11/23/2007	3	15.3918
12/18/2007	1	2.48407
12/18/2007	2	13.9979
12/18/2007	3	38.152302
12/31/2007	1	1.69837
12/31/2007	2	12.7918
12/31/2007	3	24.281099

1/6/2008	1	4.4911
1/6/2008	2	23.400499
1/6/2008	3	15.0786
1/9/2008	2	18.9645
1/9/2008	3	37.800201
1/9/2008	1	0.7416
1/22/2008	2	10.337
1/22/2008	3	20.5945
1/22/2008	1	0.498971
1/25/2008	1	1.42973
1/25/2008	2	13.7837
1/25/2008	3	20.322001
2/20/2008	1	1.09559
2/20/2008	2	7.43804
2/20/2008	3	17.394501
2/23/2008	1	0.784048
2/23/2008	2	10.0115
2/23/2008	3	16.6726
2/26/2008	2	7.34679
2/26/2008	3	18.3902
2/26/2008	1	0.165154
3/10/2008	1	1.78235
3/10/2008	2	5.22588
3/10/2008	3	19.2495
3/13/2008	2	6.76048
3/13/2008	3	23.4079
3/13/2008	1	0.308845
3/26/2008	2	8.96829
3/26/2008	3	22.546
3/26/2008	1	0.621686
3/29/2008	1	2.71963
3/29/2008	2	16.1061
3/29/2008	3	23.0499
4/30/2008	1	2.2024
4/30/2008	2	12.0757
4/30/2008	3	26.8491
5/19/2008	2	8.16259
5/19/2008	3	29.267799
7/25/2008	1	0.883796
7/25/2008	2	8.14289
7/25/2008	3	11.544
7/28/2008	1	2.87293
7/28/2008	2	9.0713

7/28/2008	3	27.614401
8/16/2008	2	3.40657
8/16/2008	3	24.1621
8/16/2008	1	0.379582
8/29/2008	1	3.3315
8/29/2008	2	11.2071
8/29/2008	3	29.5308
9/17/2008	1	3.44291
9/17/2008	2	15.8992
9/17/2008	3	54.619099
10/6/2008	2	8.74481
10/6/2008	3	46.134399
10/6/2008	1	0.529032
10/9/2008	1	0.755202
10/9/2008	2	9.67361
10/9/2008	3	46.006199
10/28/2008	1	2.50373
10/28/2008	2	17.097799
10/28/2008	3	19.317301
11/10/2008	1	3.91245
11/10/2008	2	22.035601
11/10/2008	3	41.178699
11/26/2008	1	1.52303
11/26/2008	2	11.55
11/26/2008	3	27.134899
11/29/2008	1	1.01218
11/29/2008	2	17.9279
11/29/2008	3	16.832701
12/2/2008	1	1.26328
12/2/2008	2	11.8943
12/2/2008	3	29.9769
12/12/2008	1	0.791667
12/12/2008	2	9.8734
12/12/2008	3	14.6108
12/31/2008	1	0.493496
12/31/2008	2	8.96626
12/31/2008	3	13.7852
1/19/2009	1	2.00383
1/19/2009	2	10.9269
1/19/2009	3	16.213301
1/22/2009	1	1.21881
1/22/2009	2	6.14269
1/22/2009	3	29.034401

1/25/2009	1	2.54533
1/25/2009	2	13.5568
1/25/2009	3	33.73
2/4/2009	1	2.80926
2/4/2009	2	11.4732
2/4/2009	3	16.0189
2/23/2009	1	1.17167
2/23/2009	2	9.21513
2/23/2009	3	8.84785
2/26/2009	2	7.62735
2/26/2009	3	17.0516
2/26/2009	1	0.294245
3/1/2009	1	1.95019
3/1/2009	2	11.4606
3/1/2009	3	42.316601
3/27/2009	1	2.14663
3/27/2009	2	10.6618
3/27/2009	3	14.7511
4/18/2009	2	5.01856
4/18/2009	3	23.2367
4/18/2009	1	0.111108
5/1/2009	1	0.555413
5/1/2009	2	4.74875
5/1/2009	3	12.8454
5/4/2009	1	0.71486
5/4/2009	2	6.09374
5/4/2009	3	19.2724
5/30/2009	1	1.23309
5/30/2009	2	10.3203
5/30/2009	3	16.4657
6/8/2009	1	3.0715
6/8/2009	2	13.818
6/8/2009	3	29.9802
8/11/2009	1	11.4583
8/11/2009	2	39.966499
8/11/2009	3	34.5569
8/14/2009	2	2.00764
8/14/2009	3	8.98663
8/14/2009	1	0.023101
9/18/2009	1	5.0862
9/18/2009	2	22.954399
9/18/2009	3	42.259499
11/27/2009	1	3.63131

11/27/2009	2	15.8987
11/27/2009	3	47.939301
12/3/2009	1	1.43092
12/3/2009	2	10.189
12/3/2009	3	58.340698
12/6/2009	1	1.01924
12/6/2009	2	11.0158
12/6/2009	3	39.8867
12/22/2009	1	0.711816
12/22/2009	2	12.6202
12/22/2009	3	38.297699
12/26/2009	1	3.38041
12/26/2009	2	15.1709
12/26/2009	3	63.045799
1/1/2010	1	3.80838
1/1/2010	2	18.534599
1/1/2010	3	21.313101
3/15/2010	2	5.29489
3/15/2010	3	13.3409
1/27/2011	1	0.332167
1/27/2011	2	10.1838
1/27/2011	3	17.8878
7/18/2011	1	0.186015
7/18/2011	2	5.12783
7/18/2011	3	21.2089
9/16/2011	1	1.15952
9/16/2011	2	9.70029
9/16/2011	3	53.454399
10/5/2011	1	0.657174
10/5/2011	2	9.97279
10/5/2011	3	19.240999
10/16/2011	1	0.51686
10/16/2011	2	5.00355
10/16/2011	3	22.760401
10/19/2011	1	2.15156
10/19/2011	2	17.1677
10/19/2011	3	31.0005
10/27/2011	1	2.06051
10/27/2011	2	9.1486
10/27/2011	3	36.076
11/1/2011	1	0.75664
11/1/2011	2	7.9478
11/1/2011	3	29.7188

11/12/2011	1	3.39637
11/12/2011	2	27.576099
11/12/2011	3	91.9123

Table 5. Percent at which the river plumes sediments impacted the coral reef and the impact percent for each class.

Total TSM Coral Reef Impact Percent	TSM Category 1	TSM Category 2	TSM Category 3
75%	n/a	n/a	75%
98%	n/a	n/a	98%
45%	n/a	n/a	45%
85%	n/a	10%	75%
20%	n/a	n/a	20%
80%	n/a	n/a	80%
5%	n/a	n/a	5%
5%	n/a	n/a	5%
10%	n/a	n/a	10%
100%	n/a	n/a	100%
100%	n/a	60%	40%
100%	n/a	95%	5%
100%	n/a	95%	5%
100%	n/a	2%	98%
40%	n/a	n/a	40%
100%	n/a	10%	90%
15%	n/a	n/a	15%
10%	n/a	n/a	10%
30%	n/a	n/a	30%
100%	n/a	20%	80%
100%	n/a	20%	80%
100%	n/a	n/a	98%
100%	n/a	5%	95%
70%	n/a	n/a	70%
45%	n/a	n/a	45%
60%	n/a	n/a	60%
20%	n/a	n/a	20%
20%	n/a	n/a	20%
70%	n/a	n/a	70%
100%	n/a	n/a	100%

4%	n/a	n/a	4%
25%	n/a	n/a	25%
85%	n/a	10%	75%
70%	n/a	n/a	70%
95%	n/a	70%	25%
95%	n/a	n/a	95%
22%	n/a	n/a	22%
100%	n/a	60%	40%
80%	n/a	n/a	80%
40%	n/a	n/a	40%
95%	n/a	n/a	95%
92%	n/a	n/a	92%
15%	n/a	n/a	15%
50%	n/a	n/a	50%
100%	n/a	25%	75%
60%	n/a	n/a	60%
60%	n/a	n/a	60%
10%	n/a	n/a	10%
20%	n/a	n/a	20%
100%	n/a	n/a	100%
30%	n/a	n/a	30%
35%	n/a	n/a	35%
15%	n/a	n/a	15%
100%	n/a	n/a	100%
5%	n/a	n/a	5%
80%	n/a	n/a	80%
100%	n/a	90%	10%
100%	n/a	20%	80%
95%	n/a	35%	60%
20%	n/a	n/a	80%
15%	n/a	n/a	15%
95%	n/a	35%	65%
100%	n/a	15%	85%
50%	n/a	n/a	50%
85%	n/a	n/a	85%
45%	n/a	n/a	45%
55%	n/a	n/a	55%
50%	n/a	n/a	50%
80%	n/a	n/a	80%
80%	n/a	n/a	80%
98%	n/a	n/a	98%
100%	n/a	40%	60%
70%	n/a	n/a	70%

80%	n/a	n/a	80%
40%	n/a	n/a	40%
10%	n/a	n/a	10%
100%	n/a	5%	95%
23%	n/a	n/a	23%
60%	n/a	20%	40%
80%	n/a	n/a	80%
100%	n/a	25%	75%
100%	n/a	2%	98%
100%	n/a	28%	72%
100%	n/a	n/a	100%
80%	n/a	5%	75%
100%	n/a	n/a	100%
80%	n/a	n/a	80%
35%	n/a	10%	25%
40%	n/a	n/a	40%
45%	n/a	n/a	45%
80%	n/a	n/a	80%
100%	n/a	5%	95%
80%	n/a	n/a	80%
90%	n/a	n/a	90%
28%	n/a	8%	20%
25%	n/a	n/a	25%
5%	n/a	n/a	5%
45%	n/a	n/a	45%
100%	40%	15%	45%
10%	n/a	n/a	10%
50%	n/a	10%	40%
100%	n/a	n/a	100%
97%	n/a	n/a	97%
98%	n/a	n/a	98%
100%	n/a	n/a	100%
100%	n/a	60%	40%
90%	n/a	55%	35%
5%	n/a	n/a	5%
90%	n/a	n/a	90%
60%	n/a	n/a	60%
70%	n/a	n/a	70%
15%	n/a	n/a	15%
85%	n/a	n/a	85%
30%	n/a	n/a	30%
90%	n/a	n/a	90%
90%	n/a	n/a	90%

100%	n/a	95%	5%

Table 6. Shows the calculated mean, median and standard deviation for each month from 2005-2011. Created by Josué Aceituno Díaz using Microsoft's Excel.

Month	Median Area(km)	Mean Area(km)	SD Area(km)
January	35.5354	36.87791569	9.096207274
February	25.902201	24.10285714	4.858552622
March	30.6879505	31.31090578	10.63317574
April	28.3893995	30.46420017	8.582637462
May	28.0191	27.64557114	7.086495263
June	31.9473	35.42654	14.27934117
July	24.2211	26.17738586	5.996203358
August	27.948299	39.09658911	26.52634467
September	47.324402	57.05299	21.22992599
October	48.723049	51.808685	24.60560033
November	39.315651	49.28666667	24.58000093
December	38.771301	39.17538007	14.3277203