Turbidity in Faga’alu Stream: The Sources, Impacts, and Solutions

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ABSTRACT:

The Faga’alu Stream on the island of Tutuila, American Samoa is classified by the American Samoa Environmental Protection Agency as a 303(d) stream. This signifies that the stream is impaired or threatened. Numerous potential sources of sediment have been identified throughout the watershed: the landslide up Matafao Peak; the active quarry; the ongoing bridge and road construction; and the Lyndon B. Johnson Hospital. The sediment impacts the overall health of the stream and the coral in Faga’alu Bay. This study aimed to quantify sediment throughout the stream by measuring turbidity as an indicator of the amount of sediment. With this information, statistical tests were used to show that the quarry and road construction are statistically significant sources of sediment. With this conclusion, suggestions for environmental management practices were made to reduce the impact of sediment on the ecosystem within the watershed and bay area. This includes planting coastal vegetation such as vetiver grass to reduce erosion of the stream bank or building and maintaining sediment traps to reduce impacts of runoff. With proper management practices, the impact on the stream and coral may be mitigated.
INTRODUCTION:

Surface water quality on the island of Tutuila, American Samoa is a concern to many local government agencies and community members. Stream water is used in various capacities and impacts both human activities and the local watershed. Local stream water is used for irrigation, drinking water, and other human activities. It also impacts the health of the stream and the inhabitants there within. Streams then discharge into the Pacific Ocean which has implications on the overall health of the coral and other marine wildlife populations. Moreover, population pressure continues to put stress on local water capacity. As of 2009, the population on Tutuila was approximately 69,000 and growing at a rate of 1.5% per year (Craig, 2009).

In order to assess and improve environmental management practices on the island with regards to water quality, a long-term watershed monitoring program was established in the Village of Faga‘alu, American Samoa. The village sits just to the southwest of Pago Pago Harbor at the coordinates of 14° 17’ 47” S, 170° 41’ 1” W. In 2006, Faga‘alu had a population of approximately 1,006 people and has maintained a steady population since (American Samoa Department of Commerce, 2006). Historically, numerous sources of sediment and other pollutants have surfaced within Faga‘alu. In the 1960’s, the Lyndon B. Johnson (LBJ) Hospital was built (GPS point). Nestled in the mountainside sits a commercial quarry which was introduced to the area in 1996 and has remained active since (GPS Point). In 2001, an initial landslide occurred up on the slope of Matafao Peak leaving portions of the mountainside free of vegetation (GPS Point). Since then, the unstable land has continued to shift introducing fresh earth to the easily erodible landscapes. More recently, road and bridge construction is ongoing through much of 2011 (GPS Point).

The Faga‘alu Stream begins in the upper regions of Matafao Peak within the Faga‘alu Watershed. The stream has an approximate length of 1.33 miles and a drainage area of 0.42 square miles (Wong, 1996). The average slope of the stream is rather significant at about a 13.6% grade which significantly impacts the rate of erosion in the area (DiDonato, 2005). The soil is identified as terrigenous which is descriptive of soil derived from relatively recent parent material within the watershed. The riparian zone, especially along the stream at and below the quarry, lacks any significant or working erosion and sediment control management practices. The stream has a significant and observed impact on the local Faga‘alu Bay through the introduction of large amounts of suspended sediments, especially during active rains. Many locals describe the water in the bay after a rain event as looking like chocolate milk.

The long-term monitoring project aims to assess water quality within the Faga‘alu Stream, in particular the sediment load. Given the poor management practices throughout the watershed, population pressures, and the numerous possible sources of sediment, the Faga‘alu Stream is identified by the American Samoa Environmental Protection Agency as a 303(d) stream. This classification signifies that the Faga‘alu Stream is impaired or threatened in relation to the standards outlined in the Clean Water Act (US Environmental Protection Agency, 2010). The purpose of this study aims to identify significant sources of sediment and suggest management practices to reduce the impacts. Through water quality measurements, specifically turbidity, the study aims to quantify the amount of sediment throughout the stream. Turbidity, typically measured in Nephelometric Turbidity Units (NTU), is a
measure of water clarity and is an indicator used to quantify how much sediment is in a particular water sample. With this data, one can determine significant sources of sediment throughout the watershed. Comparing this data with the observed impacts on the coral reef within the bay, environmental management practices will be suggested in order to improve the health of the watershed and reduce the effects on the coral within the bay.

**METHODS:**

A study similar in nature to the current study has never been conducted in American Samoa. Prior to any sampling, it was imperative to understand the watershed of Faga’alu and the cultural impacts on the land. Moreover, it was necessary to develop concise and measureable objectives in order to reach achievable goals. The objectives include:

1) Quantify sediment load / turbidity of discharge throughout Faga’alu watershed

2) Use YSI Sonde to measure turbidity, dissolved oxygen, pH, conductivity, and temperature of discharge at numerous locations throughout the stream, both upstream- and downstream- of potential sources of sediment

3) Survey stream riparian zone including vegetation and soil type

Through several site visits to the watershed along with conversations with the village, possible significant sources of sediment were established: the landslide up Matafa’o Peak; the quarry; the road / bridge construction; and the hospital (Figure 1).

Utilizing the information gleamed from the site visits along with the objectives, scientific questions were posed to help lead the direction of the study. The proposed scientific questions are:

1) Is there evidence that significant amount of sediments are entering the watershed as a result of the identified potential sources?

2) Does the sediment introduced into the water have an effect on other water properties (pH, dissolved oxygen, temperature, light, and other water quality issues) that may affect the reef?

3) What land management practices would best prevent or reduce sediment impact on watershed?

Utilizing the knowledge of potential sources of sediment, the goal was to select stream sampling sites that would capture both above and below the potential source of pollution. Limitations existed in site locations as the terrain limits how far upstream one can sample. In locations where the stream would be accessible due to
terrain, it ran through private property. Despite the limitations, nine stream sampling sites were selected that captured the essence of the study and enabled one to assess water quality above and below potential sources of sediment (Appendix 1).

The study utilized the YSI Sonde to capture water quality measurements throughout Faga’alu Stream. The Sonde measures water quality standards such as temperature, specific conductivity, salinity, dissolved oxygen, pH, turbidity, and volts. The Sonde was used for ex situ measurements and utilized the USDA specifications for sampling. A sample would be collected at the same location each sample iteration. A sample iteration is defined as each time that all nine sites were sampled once consecutively without interruption. The sampling cup was filled with the water from the stream and used to rinse the probes. The probes were rinsed slightly downstream of sampling site to avoid disturbing the area where water sample was collected. At this time, a water sample was taken in the sampling cup from at least two inches, where applicable, below the surface of the water. Otherwise, a sample that was sufficient to submerge the sensors was taken. The Sonde was allowed to equilibrate before measurements were recorded. The turbidity measurement was often recorded first as the sediment began to settle as the water sample was held still. The Sonde was calibrated at the beginning of each week during the sampling period. Sonde calibrations were in compliance with American Samoa Environmental Protection Agency protocol.

A data sheet was created to record measurements from each sample site up to twice a day. The data sheet also allows you to note any observations that may be of importance during sampling (i.e. quarry active, construction active, precipitation, flow pattern, debris, water disturbed by human influences, etc.).

The data was collected and archived from the daily data logs. Observations from the daily data logs were also recorded. Those observations that dealt with the activity of the quarry or construction site were particularly important. Samples were collected over a period of four weeks starting June 2, 2011. In total, twenty-four sample iterations were performed at each site yielding 215 total samples.

RESULTS:

In order to identify significant sources of sediment, several methods were used. Using Geographic Information Systems (GIS) Software, one will show spatially how turbidity measurements change throughout the stream. Using descriptive statistics, significant sources of sediment will be identified. Next, several statistical tests will be used including the Kruskal-Wallis test and the Mann-Whitney test.

SPATIAL DISTRIBUTION:

To best illustrate the location of potential sources of sediment, displaying how turbidity measurements vary spatially is used. GIS was used to spatially show how turbidity measurements vary when the quarry was active, when the construction was active, and during a heavy rain (Appendix 2).

DESCRIPTIVE STATISTICS:

The water quality measurements were separated based on site location. In order to begin assessing variability or trends in turbidity measurements throughout the stream, descriptive statistics were determined for each site (Table 1) and include mean, standard error, median, mode, standard deviation, sample variance,
### Table 1. Shows descriptive statistics for each sample site.

<table>
<thead>
<tr>
<th></th>
<th>Site # 1</th>
<th>Site # 2</th>
<th>Site # 3</th>
<th>Site # 4</th>
<th>Site # 5</th>
<th>Site # 6</th>
<th>Site # 7</th>
<th>Site # 8</th>
<th>Site # 9</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>9.1</td>
<td>9.2</td>
<td>8.9</td>
<td>1.3</td>
<td>57.7</td>
<td>42.0</td>
<td>2.3</td>
<td>2.8</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>Standard Error</strong></td>
<td>0.8</td>
<td>1.2</td>
<td>1.1</td>
<td>0.4</td>
<td>29.8</td>
<td>18.2</td>
<td>0.2</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>7.8</td>
<td>6.7</td>
<td>7.0</td>
<td>0.9</td>
<td>15.2</td>
<td>8.1</td>
<td>2.0</td>
<td>2.0</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Mode</strong></td>
<td>6.0</td>
<td>5.3</td>
<td>4.7</td>
<td>0.3</td>
<td>#N/A</td>
<td>5.6</td>
<td>1.7</td>
<td>1.6</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>4.0</td>
<td>5.8</td>
<td>5.4</td>
<td>1.8</td>
<td>146.2</td>
<td>91.1</td>
<td>0.9</td>
<td>2.1</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Sample Variance</strong></td>
<td>16.3</td>
<td>33.6</td>
<td>28.7</td>
<td>3.1</td>
<td>21374.5</td>
<td>8300.8</td>
<td>0.9</td>
<td>4.3</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Kurtosis</strong></td>
<td>1.2</td>
<td>1.4</td>
<td>1.0</td>
<td>14.0</td>
<td>20.7</td>
<td>15.4</td>
<td>4.1</td>
<td>2.8</td>
<td>12.6</td>
</tr>
<tr>
<td><strong>Skewness</strong></td>
<td>1.2</td>
<td>1.5</td>
<td>1.3</td>
<td>3.5</td>
<td>4.5</td>
<td>3.8</td>
<td>1.8</td>
<td>1.8</td>
<td>3.3</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>16.5</td>
<td>20.9</td>
<td>20.0</td>
<td>8.6</td>
<td>716.4</td>
<td>431.2</td>
<td>4.2</td>
<td>8.2</td>
<td>6.4</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>3.7</td>
<td>3.9</td>
<td>2.5</td>
<td>0.1</td>
<td>6.0</td>
<td>3.6</td>
<td>1.2</td>
<td>0.9</td>
<td>1.6</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>20.2</td>
<td>24.8</td>
<td>22.5</td>
<td>8.7</td>
<td>722.4</td>
<td>434.8</td>
<td>5.4</td>
<td>9.1</td>
<td>8.0</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>217.2</td>
<td>221.6</td>
<td>212.5</td>
<td>31.9</td>
<td>1384.3</td>
<td>1049.1</td>
<td>55.4</td>
<td>66.7</td>
<td>54.6</td>
</tr>
<tr>
<td><strong>Count</strong></td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>25</td>
<td>24</td>
<td>24</td>
<td>20</td>
</tr>
</tbody>
</table>

### Analysis

- **1) Sample Site #5 and #6 have the highest median and mean values of measured turbidity**

Without using any statistical tests, one can determine that the Sample Site #5 and #6 have the highest values of measured turbidity. Sample Site #5 is located just below the active construction site. Sample Site #6 is located just below the active quarry. This suggests that these sites contribute significant amounts of sediment.

### Commentary

There were many observations that were made at each site location during the sampling period as well as interpreting the data.

1) **Sample Site #5 and #6 have the highest median and mean values of measured turbidity**

Without using any statistical tests, one can determine that the Sample Site #5 and #6 have the highest values of measured turbidity. Sample Site #5 is located just below the active construction site. Sample Site #6 is located just below the active quarry. This suggests that these sites contribute significant amounts of sediment.

2) **Sample Site #5 and #6 have the highest variability among turbidity measurements**

These two sample sites have greatest variability in there distributions. The data suggests that when the quarry or construction site is active, there tends to be a larger amount of sediment entering the stream compared to when either are inactive. When the quarry was active, the maximum turbidity measurement was 434.8 NTU. During active construction, the maximum turbidity measurement was 722.4 NTU.

3) **Sample Site #1, #2, and #3 have similar distributions amongst turbidity measurements**

These sample sites taken as a whole tend to have similar turbidity measurements which are higher in turbidity values than Sample Site #7, #8, and #9. This suggests that there is some impact on the amount of sediment downstream from the quarry and construction site.

4) **Sample Site #4 tends to have lower turbidity measurements than other sites**

Since Sample Site #4 is measuring water from a discharge pipe that then enters
the Faga’alu Stream, the turbidity measurements tend to not be representative of the overall stream turbidity. Moreover, Sample Site #4 is not seen as a significant source of sediment. However, often times during sampling, significant amounts of yellow discharge from the LBJ Hospital exits the drainage pipe and enters the stream. Moreover, when tested for total coliform, this was the only site that had zero indicators of e coli. This suggests that the water from this source may be treated with chlorine prior to entering the stream.

5) **Sample Site #7, #8, and #9 all have very similar distributions and lower turbidity measurements**

   These sample sites see similar distributions amongst measurements and have very low variance. Standard deviation for each sample population is about 2 NTU or less. The median turbidity value for these sample sites is 2 NTU and the maximum is 9.1 NTU. With significantly less observed turbidity amongst these sites, one can conclude that the landslide further up Matafao Peak is not a significant source of sediment for the stream.

**STATISTICAL TESTS:**

In order to address the posed scientific questions, statistical tests were utilized to show differences in sample populations and determine significant sources of sediment. The sample populations have a statistically small number of samples (<30) and the data is non-parametric with differing variances between each sample population. The first statistical test utilized was the Kruskal-Wallis Test. The Kruskal-Wallis test compares the median turbidity measurements between each site and

![Box-and-whisker plots for each sample site. The scale is logarithmic in order to capture entire samples.](image-url)
determines if sample populations are significantly different (Hirsch, 2010). This test is used when comparing populations between more than two groups, in this case between the nine sites. Using this test makes no assumptions about the distributions of the samples. This test in essence determines whether the sample sites are influenced by the same factor, or whether some sites tend to produce observations different than the other sample sites. With the null and alternative hypothesis established for the test, we perform the Kruskal-Wallis test with α = .05 significance.

Null Hypothesis (H₀) = All the sample sites have identical distributions and come from the same population

Alternative Hypothesis (Hₐ) = At least one sample site has a different distribution and the sample comes from different populations.

<table>
<thead>
<tr>
<th>Degrees of Freedom</th>
<th>X²0.95(8)</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>15.51</td>
<td>142.18</td>
</tr>
</tbody>
</table>

Given the Kruskal-Wallis test, at the α = .05 significance level, we can reject the null hypothesis and accept the alternative hypothesis that the sample sites have differing median values.

The outcome of this test demonstrates that the measurements taken at each site do not belong to the same population. Therefore, there must be other factors that are affecting the measurements that cause the difference in turbidity measurements between each site. These factors may be the sources of sediment.

Next, we will determine significant sources of sediment. Using the Mann-Whitney test, one can show that one sample site tends to produce higher turbidity measurements than another (Hirsch, 2010). The Mann-Whitney test is similar to a rank-sum test, a non-parametric test to determine if two samples differ. The Mann-Whitney test usually is used for sample sizes less than twenty. However, because our sample sizes are greater than twenty measurements, the found U-value must be converted to a Z-value. With the null and alternative hypothesis established for the test, the Mann-Whitney test is performed with α = .05 significance.

Null Hypothesis (H₀) = Turb(Site#6) = Turb(Site#7)
The turbidity values measured at Sample Site #6 are equal to those turbidity values measured at Sample Site #7

Alternative Hypothesis (Hₐ)
= Turb(Site#6) > Turb(Site#7)
Turbidity values measured at Sample Site #6 significantly tend to be higher than those turbidity values measured at Sample Site #7

<table>
<thead>
<tr>
<th>U-value</th>
<th>Z-score(0.95)</th>
<th>Converted Z-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>594</td>
<td>1.645</td>
<td>5.87</td>
</tr>
</tbody>
</table>

Given the Mann-Whitney test, at the α = .05 significance level, we can reject the null hypothesis and accept the alternative hypothesis that turbidity measurements at Site #6 tend to be greater than the turbidity measurement at Site #7. The application of this test is significant. This implies that the quarry is a statistically significant source of sediment into the stream.

In order to determine if the construction was a significant source of sediment, we looked at days in which the quarry was not active and the construction was active. This way, the activity of the quarry would not bias the turbidity measurements found at Site #5. Once again, we used the Mann-Whitney test with a α = .05 significance.

Null Hypothesis (H₀) = Turb(Site#5) = Turb(Site#7)
The turbidity values measured at Sample Site #6 are equal to those turbidity values measured at Sample Site #7
Alternative Hypothesis (Hₐ)
= Turb(Site#5) > Turb(Site#7)
Turbidity values measured at Sample Site #6 significantly tend to be higher than those turbidity values measured at Sample Site #7

<table>
<thead>
<tr>
<th>U-value</th>
<th>Critical U-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>&lt;25</td>
</tr>
</tbody>
</table>

Given the Mann-Whitney test, at the α = .05 significance level, we can reject the null hypothesis and accept the alternative hypothesis that turbidity measurements at Site #5 tend to be greater than the turbidity measurements at Site #7. With this test, we can say that the construction is a statistically significant source of sediment.

DISCUSSION:
Given the statistical evidence, the quarry and the construction sites have been established as statistically significant sources of sediment for Faga’alu Stream. Meanwhile, the effect of the landslide on sediment in the stream is negligible. The impacts of the sediment on the stream and subsequently Faga’alu Bay are significant. Qualitatively, in a stream assessment, one can visually see the sediment throughout the stream. During normal flow events, the sediment often settles to the bottom of the stream leaving a thick layer of sediment on plant life and rocks throughout the stream. During active rain events, the increased sediment enters the stream and disturbs settles sediment causing the water to become more turbid and flow into the bay.

The Clean Water Act states that for American Samoa, turbidity measurements are not to exceed 5 NTU. It is powerful to note that the mean and median for every sampling site below the quarry sees turbidity values that exceed this standard. However, sampling sites above the quarry have mean and median values much less than 5 NTU and are in compliance with the Clean Water Act for American Samoa.

Construction has a significant impact on the land and the subsequent erosion in the surrounding area. Depending on soil types, construction can see increased rates of erosion upwards of 200 times that of forested land (Georgia Soil and Water Conservation Commission, 2002). Moreover, the quarry also impacts the land significantly. During normal operations, the quarry clears the land to continue mining rock aggregate. This practice leaves much of the land uncovered and subject to erosion. The quarry also impacts the land in more than just introducing sediment into the stream. Other impacts include loss of habitat, noise, dust, chemical spills, etc. Many of these were brought up in conversations with community members. Quarries also can impact the quality of nearby stream water through introducing heavy metals, machinery oil, or other chemicals into the stream. There is a direct discharge pipe from the quarry into the stream with visible heavy metals, salts, and algae growth nearby. None of these other sources of pollution were measured in this study.

Lastly, the impacts on the coral within Faga’alu Bay may be irreversible. As sediment flows into the bay, it settles out of the water impacting the coral. The sediment slowly builds up and destroys habitat and kills coral within the bay. The coral community suffers and algae begins to develop on the dead or unhealthy coral. This transition from a coral dominated community to an algal dominated community forever changes the ecosystem within the bay. With the destruction of coral reef habitat, one can also expect the loss of populations that live within the coral reef ecosystem. Many populations that were once present in the bay may no longer be
sustainable given reduced habitat and poor water quality.

As the village of Faga’alu continues to grow and population pressure continues to be a problem on the island, natural resources throughout the village will become important. In conversations with the community, it was identified that the village hopes to provide its own water supply utilizing wells and other water sources. If ongoing pollution continues throughout the watershed, using the water as drinking water may not be possible. Moreover, the village may rely heavily on reef fish for sustaining the population. However, if the habitat continues to be destroyed, the viability of using the sea as a means to help maintain the population may decrease.

With identified statistically significant sources of sediment, it is important to identify management practices to aid in the reduction of sediment in the stream. At the conclusion of the study, observations were completed of the entire stream from the mouth up until the quarry.

Downstream of the construction site, there currently is a silt fence in the stream. This is an improper use of sediment control practices (Figure 3) and does little in affecting the sediment in the stream. Silt fences deployed along the riparian zone of the stream throughout the construction site would help reduce sediment from entering the stream. Moreover, exposed land can be covered with straw or organic matter to reduce erosion and the effects of runoff. While the construction is not an ongoing practice in Faga’alu, proper and maintained management practices should be deployed.

Little erosion and sediment control practices have been established at the quarry. Walking through the stream near the quarry, there are locations where the quarry’s edge is less than ten feet from the bank of the stream. The riparian zone is heavily eroded. Sediment traps that had been installed are neglected and not maintained. In order to address management concerns, one should employ coastal vegetation such as vetiver grass or other soil binding plants with extensive root systems to reduce stream bank erosion. Moreover, sediment traps would be installed at proper locations where observed runoff may enter the stream. The responsible party must then also commit to dredging the sediment traps at least three times a year. Ideally, in order to be in compliance with American Samoa Environmental Protection Agency protocol, the quarry should move machinery to at least fifty feet from the stream bank.

CONCLUSION:

With issues such as population pressure, poor environmental management practices, and numerous sources of pollution, the health of the Faga’alu Stream is impaired. Through improved management practices, it is the hope that impact of sediment throughout the stream and bay is
reduced. Continued efforts in community outreach and improving erosion and sediment control practices hope to address the issue. While the effects on the coral in the bay may be irreversible, changes now in management can forever improve the health of the stream and restore Faga’alu Stream to pristine waters.

REFERENCES:
## Appendix 1. Site Description

<table>
<thead>
<tr>
<th>Site #</th>
<th>Description</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site #1</td>
<td>Located at the mouth of Faga’alu Stream as it enters the Pacific Ocean. As a result, the water at times is influenced by tides.</td>
<td>W 170.683638</td>
<td>S 14.291330</td>
</tr>
<tr>
<td>Site #2</td>
<td>Found slightly upstream of discharge pipe from LBJ Hospital. The discharge pipe was established by the community as a potential source of pollution.</td>
<td>W 170.684973</td>
<td>S 14.291472</td>
</tr>
<tr>
<td>Site #3</td>
<td>Site located slightly downstream of same discharge pipe. Used to determine impact of discharge pipe on water quality.</td>
<td>W 170.684970</td>
<td>S 14.291482</td>
</tr>
</tbody>
</table>
Site #4: This site is another discharge pipe from LBJ Hospital and was also identified by the community as a potential source of pollution.

W 170.684565  
S 14.290905

Site #5: Located just downstream of the active construction site.

W 170.688153  
S 14.289862
Site #6: Found just downstream from the quarry.

W 170.690775
S 14.288678

Site #7: Located in pool created by waterfall above the quarry.

W 170.692930
S 14.288187
Site #8: This site is located just upstream from the first waterfall. The water is flowing and usually not very deep.

W 170.693362
S 14.288057

Site #9: This site marks the furthest upstream that samples were taken. The site is located at the second waterfall upstream from the quarry.

W 170.693847
S 14.288205
Appendix 2. GIS Maps Illustration Turbidity