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# MBES SWATH ANGLE IN RELATION WITH DATA PROCESSING QUALITY, TIME AND COST

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## Abstract

The goal of this research was to investigate and determine the differences in uncertainty at different beam angle limits. To achieve this objective, six MBES data sets were each processed by five surveyors with different levels of experience in MBES data processing. Each project was processed three times, using 45°, 60° and 75° beam angle filter limits in the HYSWEEP MBES Editor. Each surveyor was timed to determine the total time spent editing each MBES data set, using each of the three beam angle limits. An analysis was conducted for the time taken to process each data set, along with the resultant sounding uncertainty. Finally, a virtual area was created to determine the cost of the survey as a function of swath angle.

This research was conducted in cooperation with HYPACK Inc. (www.hypack.com), and the Hydrographic Survey Research Group (HSRG) in the Arab Academy for Science and Technology and Maritime Transport (AASTMT) (www.aast.edu). HYPACK provided the project with a work station for data processing, sample MBES data, and five HYSWEEP licenses. HSRG conducted the data processing, analysis and the documentation.

## Résumé

Le but de cette recherche est d'étudier et de déterminer les variations d'incertitude à différentes limites d'ouverture de faisceau. Pour atteindre cet objectif, six ensembles de données multifaisceaux ont été traités par cinq hydrographes ayant des niveaux d'expérience différents dans le traitement des données multifaisceaux. Chaque projet a été traité trois fois à l'aide des limites d'ouverture de bande de 45°, 60° et 75° dans l'éditeur HYSWEEP MBES. Chaque hydrographe devait déterminer le temps total passé à éditer chaque ensemble de données multifaisceaux, à l'aide chacune de trois limites d'ouverture de bande. Une analyse a été conduite sur le temps consacré au traitement de chaque ensemble de données, et de l'incertitude des levés Finalement une zone virtuelle a été créée pour déterminer le coût du levé en tant que fonction d'ouverture de bande.

Cette recherche a été menée en coopération avec HYPACK Inc. (www.hypack.com), et l'Hydrographic Survey Research Group (HSRG) de l'Académie arabe pour les sciences, la technologie et le transport maritime (AASTMT) (www.aast.edu). HYPACK a fourni au projet une station de travail pour le traitement des données, des échantillons de données multifaisceaux et cinq licences HYSWEEP. L'HSRG a dirigé le traitement, l'analyse et la documentation des données.

## Resumen

El objetivo de esta investigación fue estudiar y determinar las diferencias en la incertidumbre, en límites de ángulos del haz diferentes. Para lograr este objetivo, cada una de las seis colecciones de datos MBES fue procesada por cinco hidrógrafos con diferentes niveles de experiencia en el procesado de datos MBES. Cada proyecto fue procesado tres veces, utilizando los límites del filtro del ángulo del haz a 45°, 60° y 75° en el Editor HYSWEEP MBES. Se cronometró a cada hidrógrafo para determinar el tiempo total empleado

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en la edición de cada colección de datos MBES, utilizando cada uno de los tres límites del ángulo del haz. Se efectuó un análisis del tiempo empleado en el procesado de cada colección de datos, junto con la incertidumbre de sonda resultante. Finalmente, se creó una zona virtual para determinar el coste del sondeo en función del ángulo de corte.

Esta investigación fue llevada a cabo en cooperación con HYPACK Inc. (www.hypack.com), y con el “Hydrographic Survey Research Group” (HSRG) de la “Arab Academy for Science and Technology and Maritime Transport” (AASTMT) (www.aast.edu). HYPACK proporcionó para el proyecto una estación de trabajo para el procesado de datos, de datos-muestra MBES, y cinco licencias HYSWEEP. El HSRG realizó el procesado de datos, su análisis y la documentación.

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### Scope of the work

The work flow consisted of four stages; training, processing, analysis and documentation. Five members of HSRG were trained in the basic theory of MBES data processing and processing MBES data in HYSWEEP. Standard Operation Procedures (SOPs) were developed for different HYSWEEP tools during the surveyor's training and were used in the actual data processing. Two projects were processed using the SOPs and the time needed to process the data was logged. The results for the surveyor's first two projects were used as the 'non-expert' basis, while the results for the surveyor's final three projects were considered the 'expert' basis. Total Propagation Uncertainty (TPU) was computed and the Standard Deviation (SD) was determined and exported as a part of Phase III of the data processing. These results allowed us to analyze the time and the resultant SD associated with each data set. Finally a virtual survey area was created to compute the total cost of survey using different swath angles.

### Survey Projects Data

HYPACK provided several MBES data sets that were used in conducting the research. These projects were used for either basic training of the surveyors or to measure their actual processing performance and the resultant uncertainty. The project that was used for training the survey team was named **Sample HYSWEEP Survey**. Projects that were used in measuring processing performance are named **Philadelphia**, **New York**, **Before Dredging**, **After Dredging** and **Artificial Reef**. All system offsets, described in the following sections, used the HYPACK coordinate convention.

### Sample HYSWEEP Survey

The Sample HYSWEEP Survey, as illustrated in *Figure 1*, is one of survey projects that are included in the HYPACK training Compact Disk. The main objective for this data set was to familiarize the survey team with HYSWEEP processing module and following its SOP. The project consists of one single MBES line of 500 meter length. Hardware used in the project included the TSS Dynamic Motion Sensors (DMS) for Motion Reference Unit (MRU) and the Reson SEABAT 8101. The positioning is not known. *Table 1* lists the hardware linear and angular offsets.

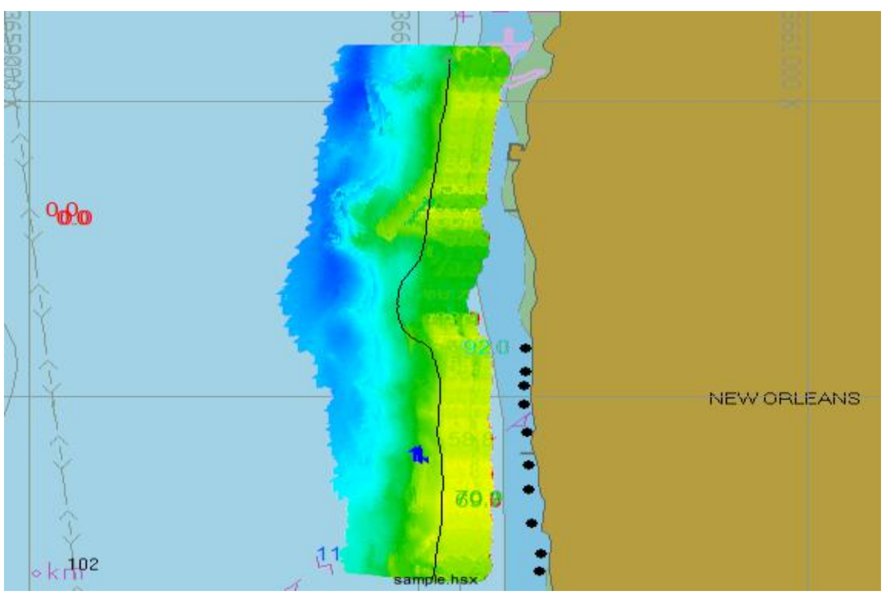



***Figure 1*** : Sample HYSWEEP survey project

| | X | Y | Z | YAW | PITCH | ROLL | LATENCY |
|---|---|---|---|---|---|---|---|
| Pos | -0.9 | 0.7 | -8.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| MBES | -5.0 | 2.1 | 3.1 | 0.0 | 0.0 | 0.2 | 0.0 |
| MRU | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

***Table 1*** Linear and angular offsets for Sample HYSWEEP Survey project

## Philadelphia

Philadelphia was the first MBES survey project the team used in measuring data processing performance. The Philadelphia project, as illustrated in *Figure 2*, has a total survey length of 9.5km.

Hardware used in the project were an Applanix POS MV for both positioning and MRU and a Reson SEABAT 7101 MBES. *Table 2* lists the hardware linear and angular offsets.

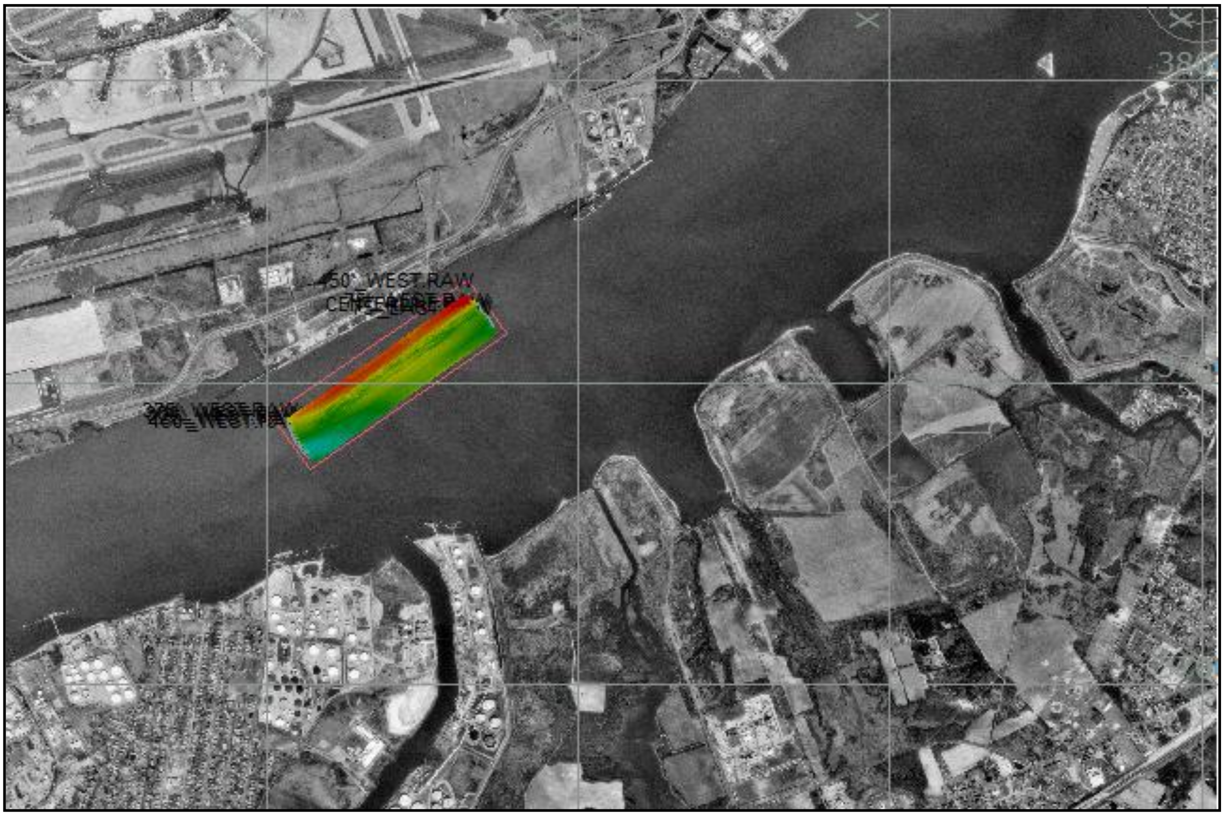


***Figure 2*** : Philadelphia survey project.

| | X | Y | Z | YAW | PITCH | ROLL | LATENCY |
|---|---|---|---|---|---|---|---|
| RTK | 0.0 | 0.0 | -1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| MBES | -0.6 | 3.8 | 2.7 | +0.5 | -2.25 | 0.95 | 0.0 |
| MRU | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

***Table 2*** : Linear and angular offsets for Philadelphia

## New York

New York was the second MBES survey project used in measuring data processing performance The New York project, as illustrated in **Figure 3**, has a total survey length of 1.86 Km.

Hardware used in the project is the same as in Philadelphia project. **Table 3** lists the hardware linear and angular offsets.

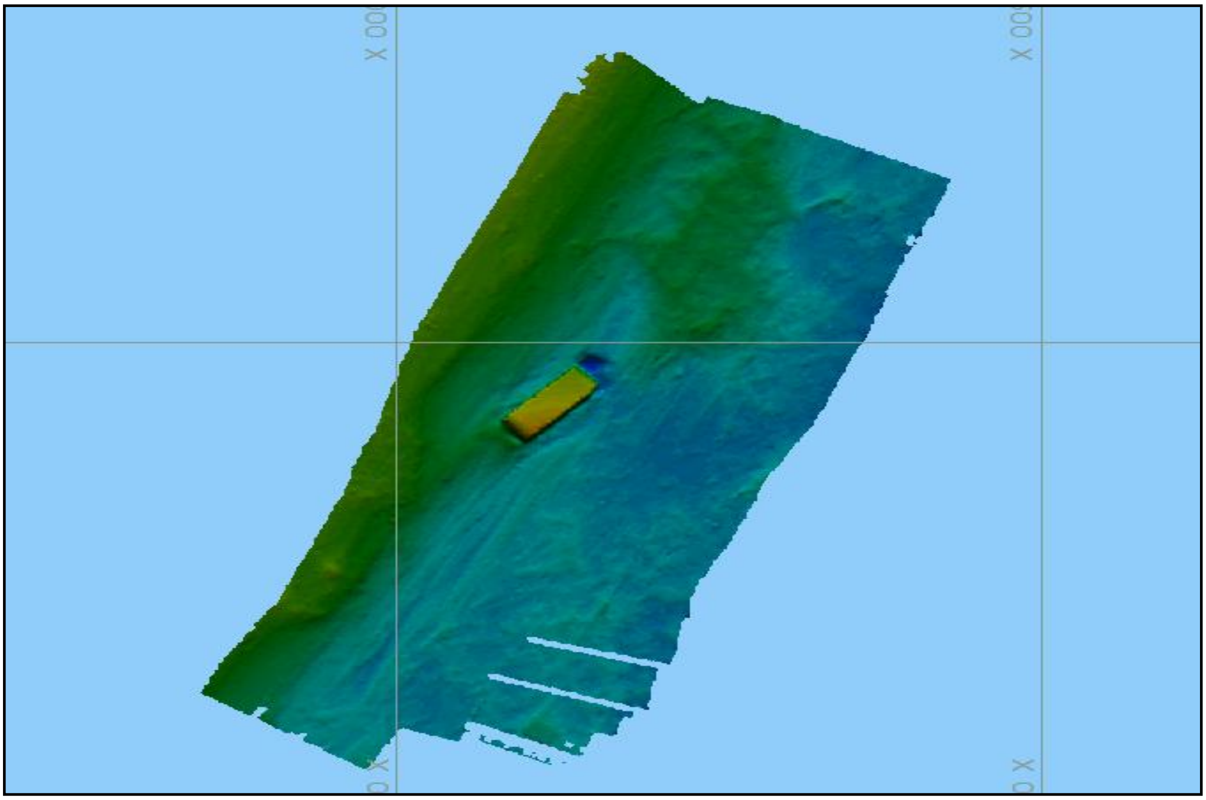


***Figure 3**: New York survey project.*

| | X | Y | Z | YAW | PITCH | ROLL | LATENCY |
|---|---|---|---|---|---|---|---|
| RTK | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| MBES | 2.34 | 1.03 | 0.73 | -1.0 | -0.5 | -0.1 | 0.0 |
| MRU | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

***Table 3** Linear and angular offsets for New York project*

### Before Dredging and After Dredging

Before Dredging and After Dredging are two survey data sets of the same area, as illustrated in *Figure 4*. ‘Before Dredging’ was surveyed before the dredging took place and ‘After Dredging’ took place after the dredging had taken place.

Each project contains 30 MBES lines with total length of 10 km. the Hardware used in the project is the same as in Philadelphia project. *Table 4* lists the hardware linear and angular offsets.

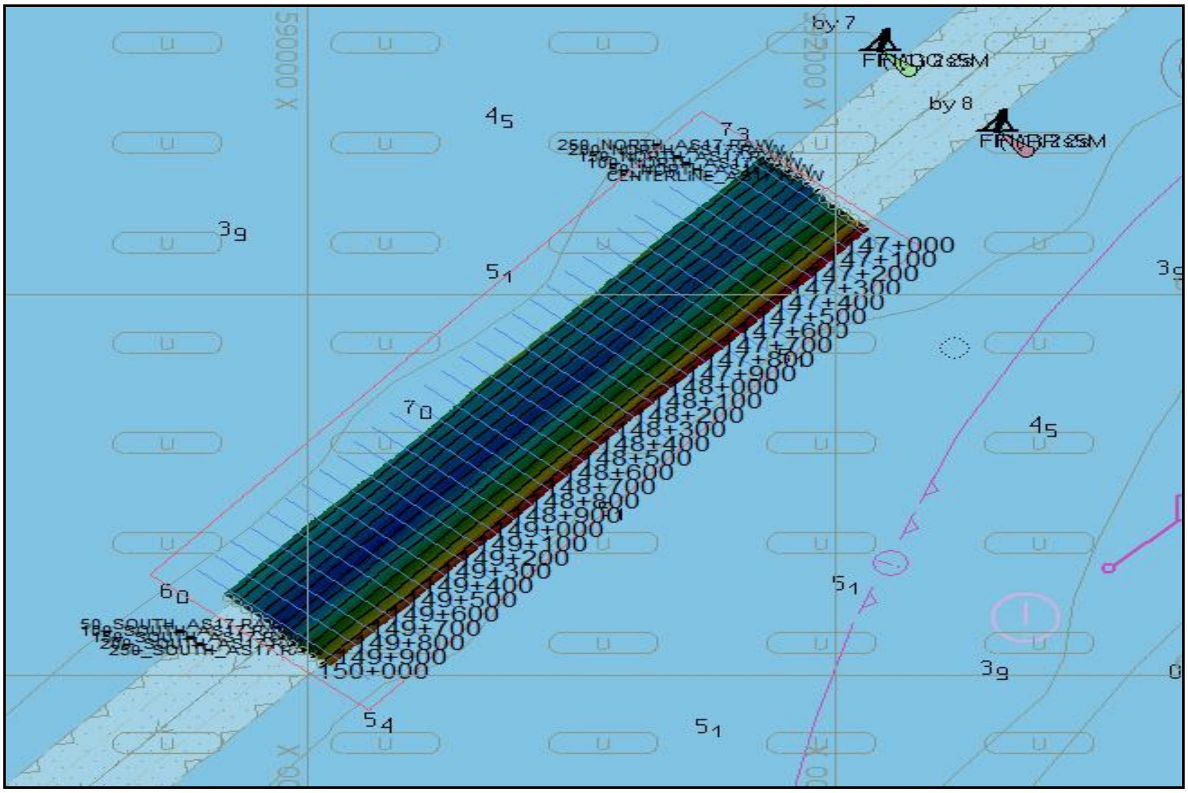



***Figure 4***: *Before Dredging and After Dredging survey projects*

| | X | Y | Z | YAW | PITCH | ROLL | LATENCY |
|---|---|---|---|---|---|---|---|
| RTK | 0.0 | 0.0 | -1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| MBES | -0.6 | 3.8 | 2.8 | +0.5 | -2.25 | 0.95 | 0.0 |
| MRU | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

***Table 4:*** *Linera and angular offsets for Before Dredging and after Dredging projects*

### Artificial Reef

Last survey project is Artificial Reef, as illustrated in *Figure 5*. The project contains 24 MBES lines with total length of 100 km. The Hardware used in this project were the Applanix POS MV for both positioning and MRU and the Reson SEABAT 8101. *Table 5* lists the hardware linear and angular offsets.

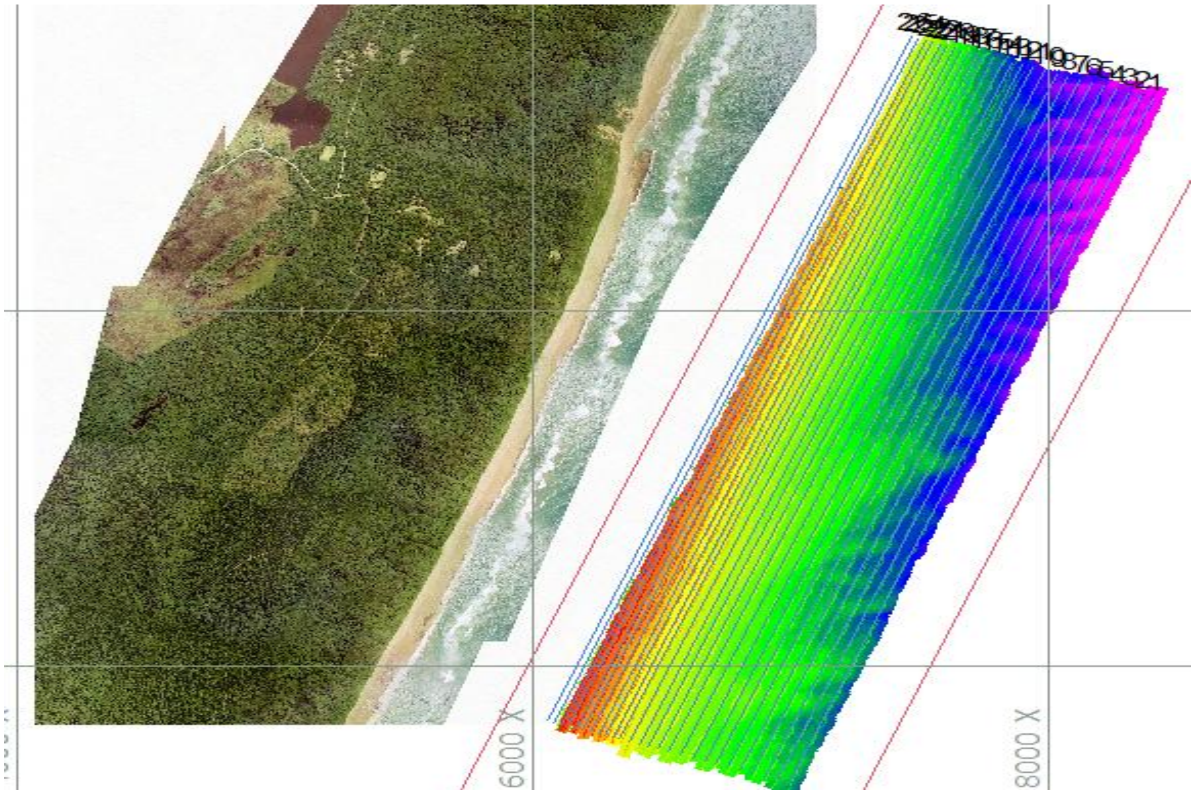



*Figure 5: Artificial Reef survey project*

| | X | Y | Z | YAW | PITCH | ROLL | LATENCY |
|---|---|---|---|---|---|---|---|
| RTK | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| MBES | 0 | 0 | 0 | +1.1 | -1.0 | +3.0 | 0.0 |
| MRU | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*Table 5 : Linear and angular offsets for Artifical Reef project*

## Standard Deviation Computation

As a preparation for the data processing the Total Propagated Uncertainty (TPU) was computed for each sounding to ensure that the processed data met the International Hydrographic Organization (IHO) standards [2]. The TPU EDITOR was used in computing TPU for each project. The TPU EDITOR has 3-tabbed dialog where the user must enter the general, environmental and sensor information.

The 'General' tab contains over 14 parameters including angular coverage, maximum ping rate, along track beam width, across track beam width, pulse length, sector steering angle, frequency and the receive beam. All these parameter could be set to manufacturer defaults by selecting the Sonar from the TPU Editor's database. For each project the appropriate sonar was selected. An important parameter in this tab is to configure the surveying order to the adopted standard. For the current research, IHO Special Order was selected.

The 'Environmental' tab of the TPU Editor contains several environmental settings. Most of the default values were used.

The 'Sensor Information' tab contains physical offsets and the uncertainty associated with these offsets along with other information. The uncertainty related to the positioning system and MRU were populated from TPU Editor database by selecting the appropriate sensor. Other information related to the sensor offsets have been extracted from HYSWEEP Editor and entered in the TPU Editor.

**Figure 6** illustrates the TPU graph for the last three survey projects. In the Graphs, the yellow horizontal line represents the estimated standard deviation computed according to IHO Special Order.


*Figure 6 : Depth uncertainty for the survey projects*

The IHO depth uncertainty is then extracted from the Depth Uncertainty graph (m) and then converted to one-sigma standard deviation according to the associated project depth unit. The computed one-sigma standard deviation is used in MBES data processing in Phase III of the HYSWEEP Editor. Table 6 lists the standard deviations of the survey projects.

### MBES Data Processing

MBES data processing went through several steps: applying corrections, reading parameters, raw data review (Phase I), swath-based editing (Phase II), area-based editing (Phase III) and saving the results. During data processing, the processing time was kept between the start of the first step and the end data storage.

Tide corrections and sound velocity were applied in Phase I of the HYSWEEP Editor after reading the MBES raw data. In the second step the hardware offsets were checked. If the patch test results [3] were not applied during data acquisition, they can be applied in the second step.

In Phase I, the surveyor can examine the raw data from the sensors, checking line by line. The raw pitch, roll and heading were reviewed to make sure they are appropriate and that there is no heave drift. The track lines can also be examined and position spikes corrected. The surveyor also reviews the tide and draft corrections to make sure they are reasonable.

In Phase II, the surveyor examines the corrected MBES data swath by swath. Depth spikes can be eliminated either manually or by applying combinations of geometric filters. Available geometric filters include Min Depth/Max Depth, Beams, Port/Starboard Offset Limits, Spike Limit, Quality Limit, Intensity Limits and Savitsky-Golay.

Each survey project was edited three times by each surveyor, each time applying a different Beam Angle filter (45°, 60° and 75°). A Beam Angle filter of 45°, would remove any data points that were collected with a beam greater than 45° from nadir.

In Phase III the entire survey was sub-divided into cells. Based on the z-values that are contained in a cell, cell statistics were generated that can be used when applying statistical filters. The distribution of MBES data in each cell or across a collection of cells that creates a 'profile' can be reviewed and edited.

For each cell, the HYSWEEP Editor computes the SD, based on the distribution of z-values contained in the cell. Cells with an SD value that exceeded the value derived in **Standard Deviation Computation** were then visually examined in order to remove any remaining outliers. Finally the data is stored in two XYZ ASCII format files. The first file stored the depth value for each data point as the Z-value. The second file stored the SD value for each data point as the Z-value.

### Uncertainty Analysis

The goal of this step was to examine the changes to the standard deviation of each data set, upon completion of processing, according to the surveyor (editor) and the beam angle limit.

The SD output HYSWEEP Editor Phase III stores the data in three columns; the X and the Y (Easting and Northing), the 3rd column represents the 1σ SD. For each data set, every surveyor generated a separate 'SD' file using the 45°, 60° and 75° Beam Angle limits.

The resulting files were imported into an Excel spreadsheet, converted to 2σ SD, and correlated according to its SD value from 0.00 to 0.91 (US Survey feet or metres according to the project depth unit) using separation steps of 0.02 horizontally. At the end of each column, the total number of occurrences for each SD step value is shown.

Each graph represents the relationship between the SD steps (0,0.01,0.03,…….) horizontally, and the numbers of occurrences on each of these values vertically. Since the results of the three surveyors are similar, only the graphs of the first surveyor are represented.

### Before Dredging

The Before Dredging project data estimated uncertainty (2σ SD) was 0.6ft as listed in *Table 6.* As shown in *Figure 7*, the histogram for beam angle 45° for the first surveyor, most of the SD lies in a narrow range around 0.17ft. Most of the uncertainty values were within the estimated IHO Special Order limit. When the beam angle limit is increased from 45° to 60° the histogram shows a similar distribution, as illustrated in *Figure 8*. Increasing the beam angle limit to 75° increases the broadness dramatically, as shown in *Figure 9*, where most of the SD lies around 0.27ft.

| Project | New York | Philadelphia | Before Dredging | After Dredging | Artificial Reef |
|---|---|---|---|---|---|
| Predicted Uncertainty (2σ) | 0.6 ft | 0.6 ft | 0.6 ft | 0.6 ft | 0.2 m |
| Standard Deviation (1σ) | 0.3 ft | 0.3 ft | 0.3 ft | 0.3 ft | 0.1 m |

*Table 6 : The Standard Deviations of the survey projects*

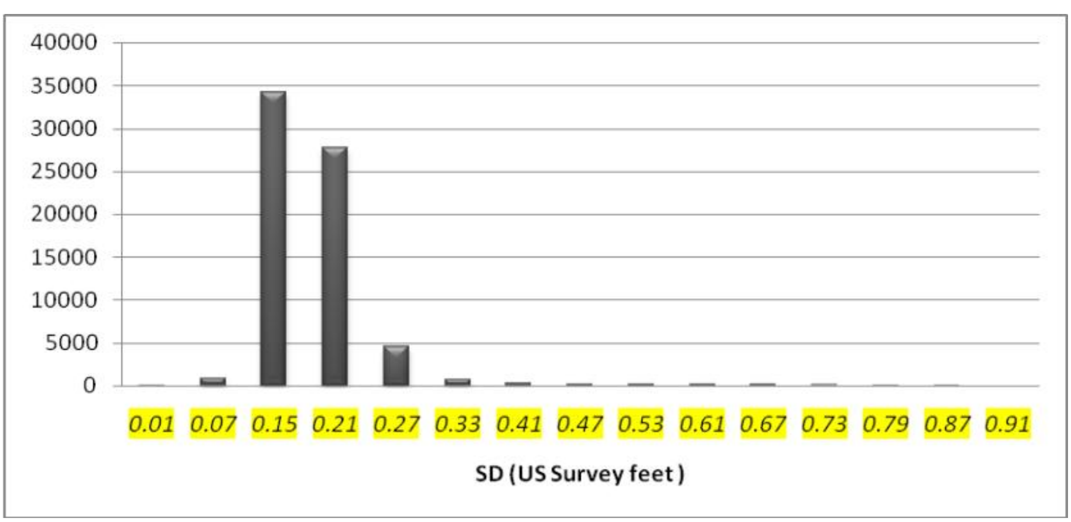



*Figure 7 : SD histogram of the 1st surveyor for beam angle 45°, Before Dredging.*

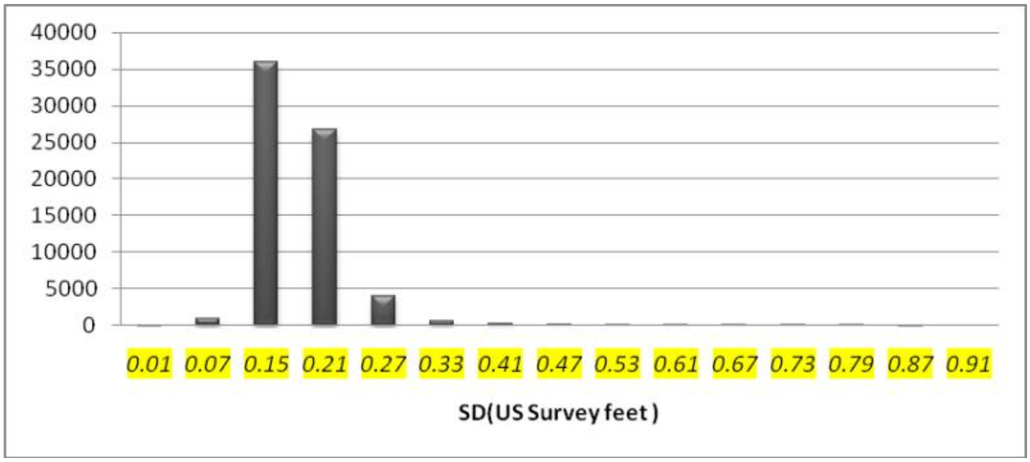



*Figure 8 : SD histogram of the 1st surveyor for beam angle 60°, Before Dredging.*

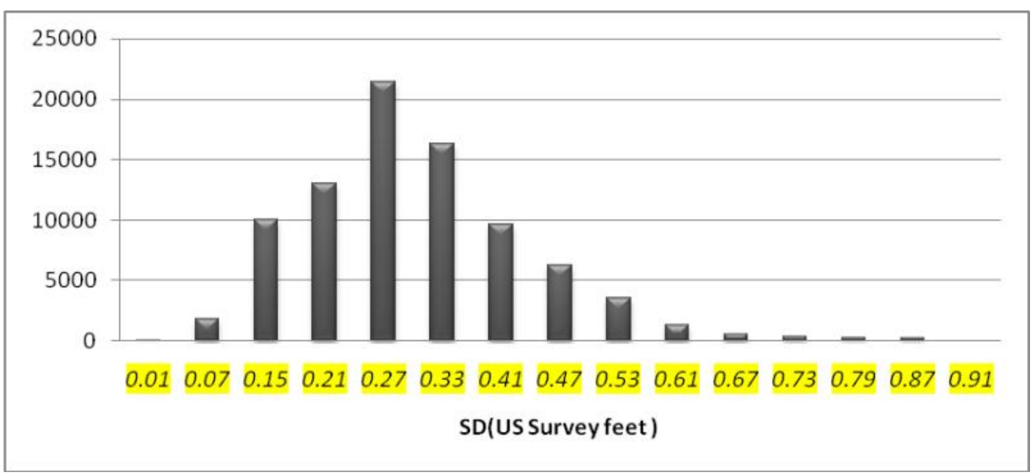



*Figure 9 : SD histogram of the 1st surveyor for beam angle 75°, Before Dredging.*

### After Dredging

The After Dredging project had an exceptionally rough seabed and the presence of sediment in the water column resulted in more outliers when compared with the Before Dredging project. This would lead us to surmise that it would have a higher SD.

The histogram, illustrated in *Figure 10*, for the 45° shows that most of the uncertainty values lies between 0.01ft and 0.33ft. Increasing beam angle limit to 60° causes the maximum SD value to jump up to 0.15ft, as in *Figure 11*. Processing with a beam angle of 75° causes most of the distribution to be much wider and centered around 0.53ft, as illustrated in *Figure 12*.

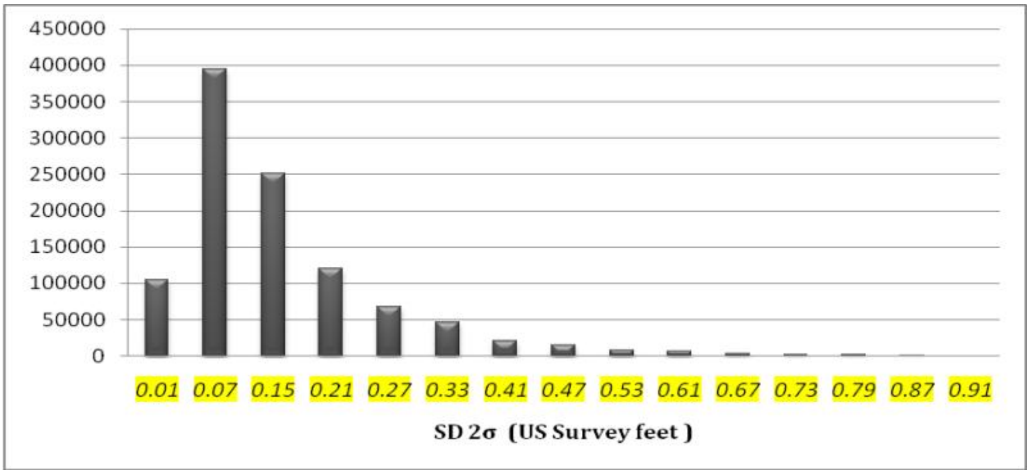



*Figure 10 : SD histogram of the 1st surveyor for beam angle 45°, After Dredging.*

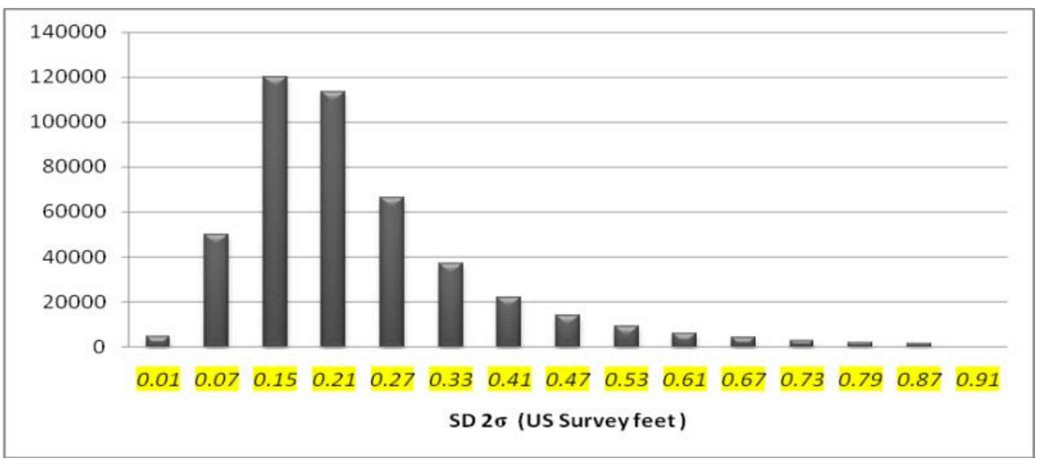



*Figure 11 : SD histogram of the 1st surveyor for beam angle 60°, After Dredging.*

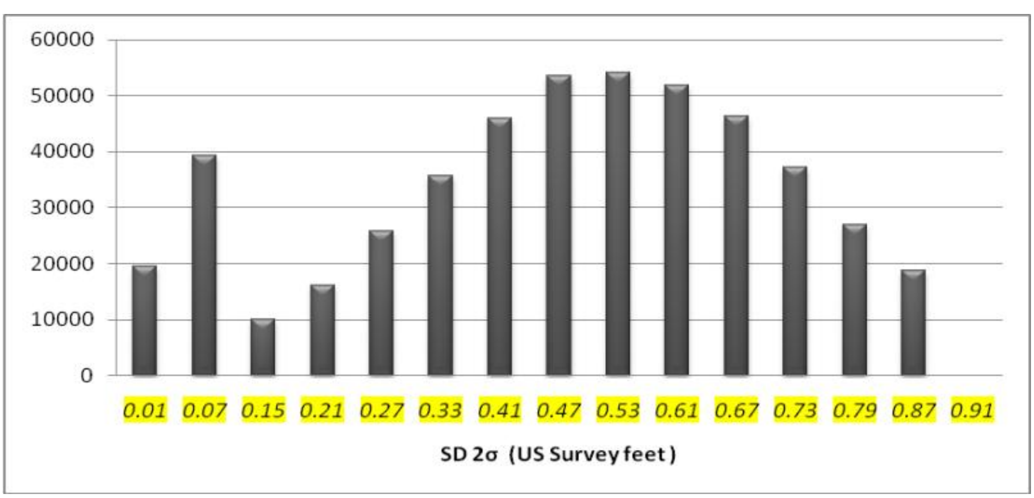



*Figure 12 : SD histogram of the 1st surveyor for beam angle 75°, After Dredging.*

**Artificial Reef**

The Artificial Reef histograms show similar performance to Before Dredging, as illustrated in *Figures 13, 14* and *15*. The histogram shows right skew in 45° and moves more toward the right as beam angle increases indicating an increase of the uncertainty.

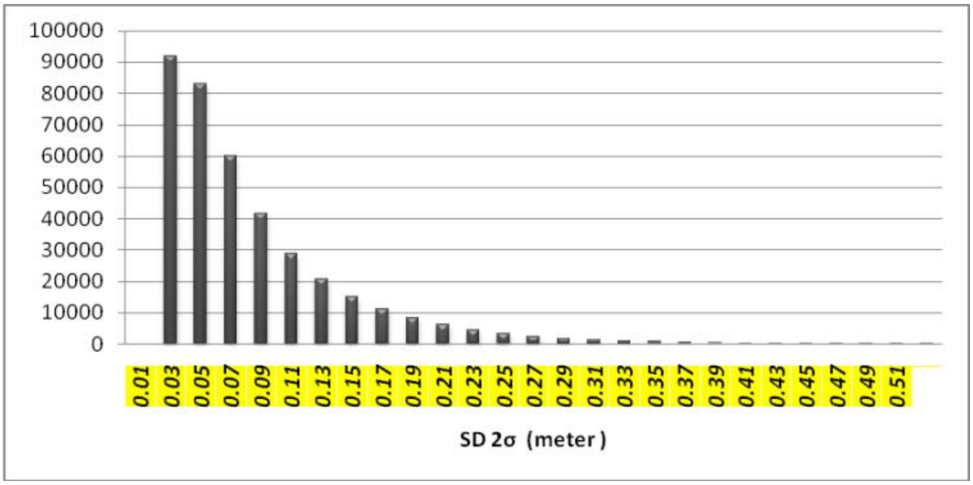



*Figure 13 :*
*SD histogram of the 1st surveyor for beam angle 45°, Artificial Reef.*

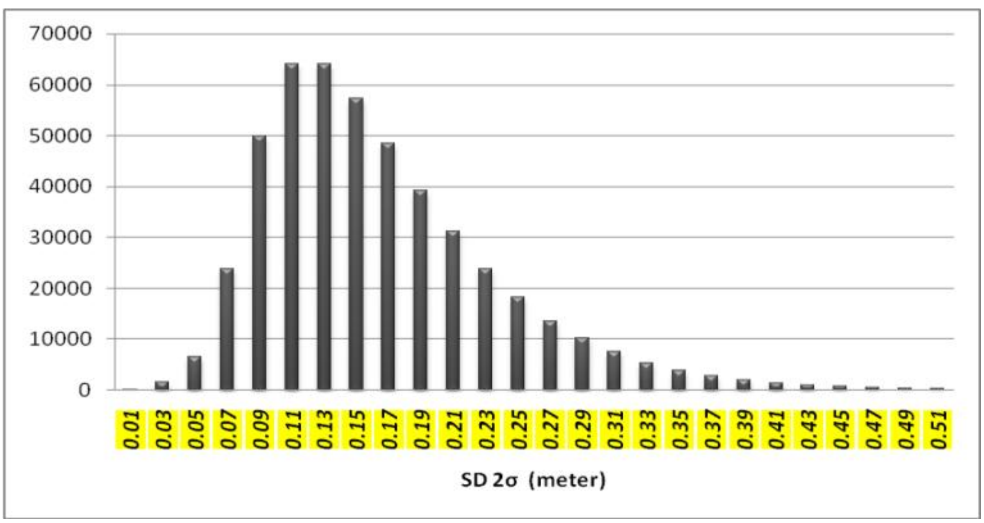



*Figure 14 : SD histogram of the 1st surveyor for beam angle 60°, Artificial Reef.*

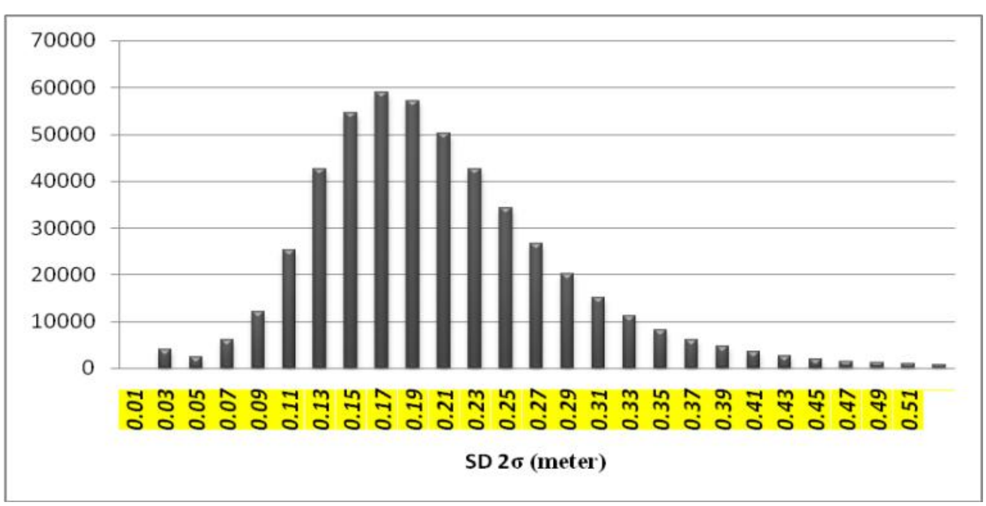



*Figure 15 :*
*SD histogram of the 1st surveyor for beam angle 75°, Artiticial Reef.*

## Uncertainty analysis summary

The uncertainty analysis is summarized in Table 7 where the second and third rows summarize the σ SD of 68% and 2σ SD 95% of the data points for each project. The last row summarizes the percentage of data points that meets IHO Special Order standards.

The Beam Angle Limit has proven to have a significant effect on achieved uncertainty. This is shown in *Figure 16* where the SD increases as beam angle increases. Also the type of the survey has an effect on the uncertainty that can be achieved when comparing the Before Dredging and After Dredging survey projects. Seabed complexity, shown in *Figures 17 and 18*, and sea state also has a direct effect on the achieved uncertainty. This could be realized in comparing Before Dredging and Artificial Reef where a smaller oscillation has been observed during the Before Dredging project.

| | Before Dredging | | | After Dredging | | | Artificial Reef | | |
|---|---|---|---|---|---|---|---|---|---|
| | 45° | 60° | 75° | 45° | 60° | 75° | 45° | 60° | 75° |
| maximum | 0.53 | 0.55 | 0.57 | 1.55 | 1.74 | 2.25 | 1.62 | 3.09 | 6.43 |
| 68% | 0.06 | 0.06 | 0.09 | 0.04 | 0.08 | 0.20 | 0.07 | 0.17 | 0.2 |
| 95% | 0.08 | 0.08 | 0.15 | 0.12 | 0.15 | 0.29 | 0.13 | 0.29 | 0.33 |
| Special Order % | 98 | 98 | 95 | 98 | 95 | 56 | 87 | 74 | 62 |

*Table 7 : Uncertainty summary in* 2σ SD (metres). .

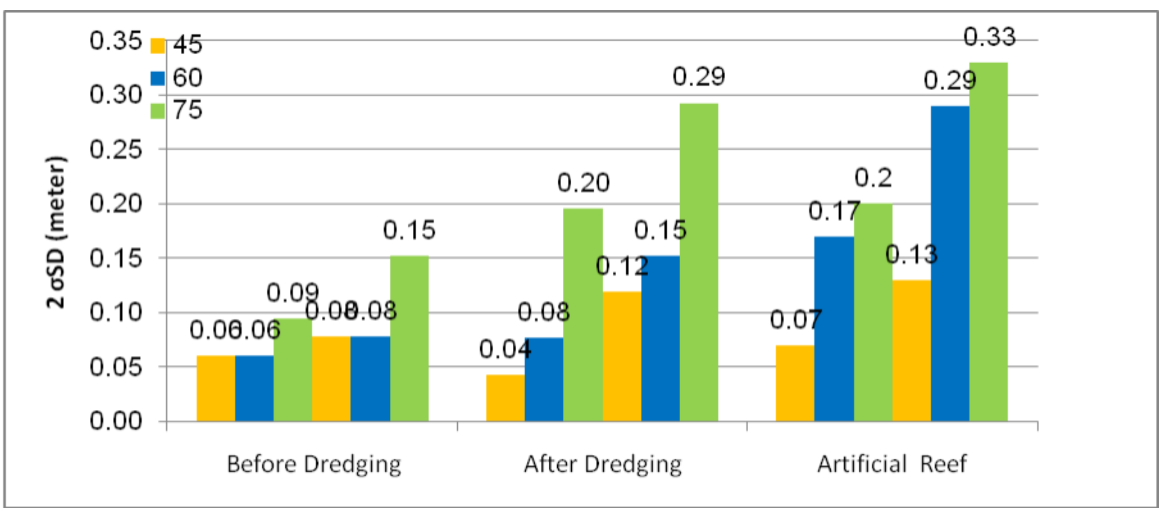



*Figure 16 : 68% and 95 %* 2σ SD sounding uncertainty (the first three bars from the right in each project is 68% and the second three bars is 95%).

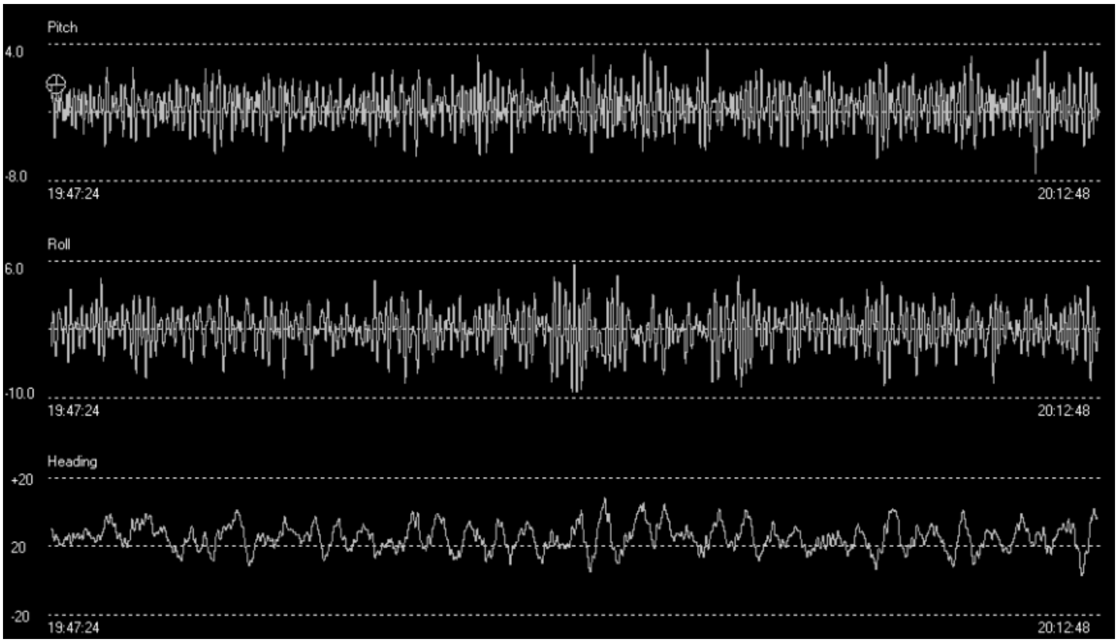



*Figure 17 : Survey vessel attitude (pitch/roll/heading) in Artificial Reef survey project.*

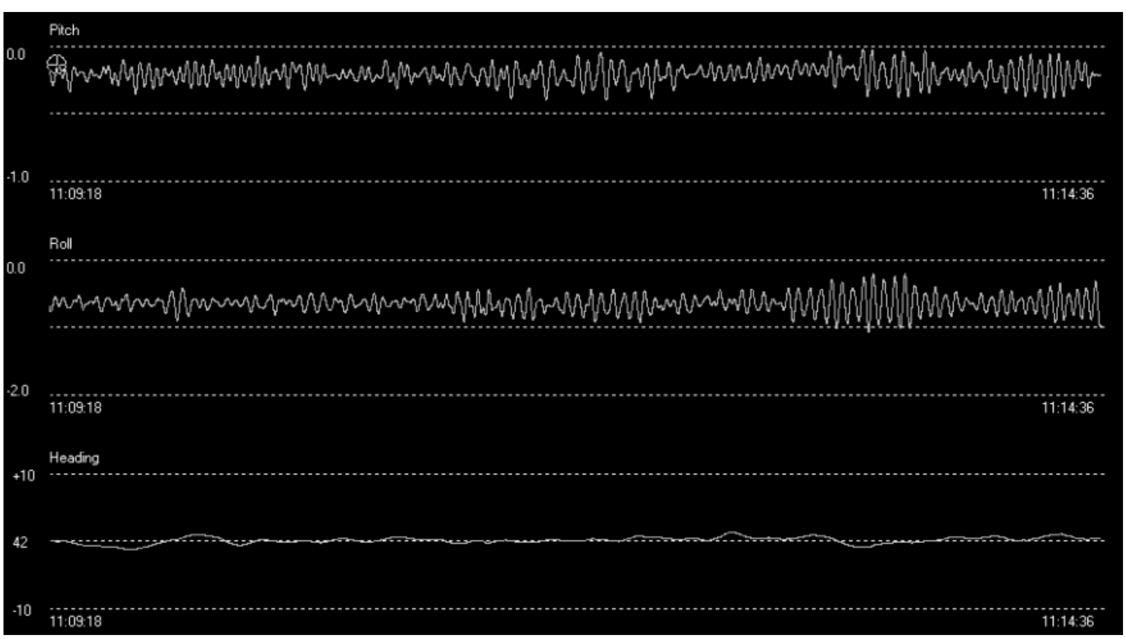



*Figure 18 : Survey vessel attitude (pitch/roll/heading) in Before Dredging survey project.*

*Figure 19* shows the percentage of the soundings that meets the IHO Special Order standard versus the Beam Angle Limit. Reducing the Beam Angle Limit from 75° to 60° or to 45° in Before Dredging didn't make much difference, probably due to the uniform sea bottom. As the seabed becomes more complex, or the sea state becomes more dynamic, reducing the Beam Angle Limit has a significant effect in improving the uncertainty. In all cases, decreasing the Beam Angle Limit will improve the uncertainty of the survey results.

## Processing Time Analysis

*Table 8* provides average processing times for the three surveyors for each survey project and the three processing angles are listed as the Beam Angle Limits of 45°, 60° and 75°.

The results show that four factors can affect the processing time: Processing angle, Experience level, Type of Survey and Seabed complexity. They are discussed as follows.

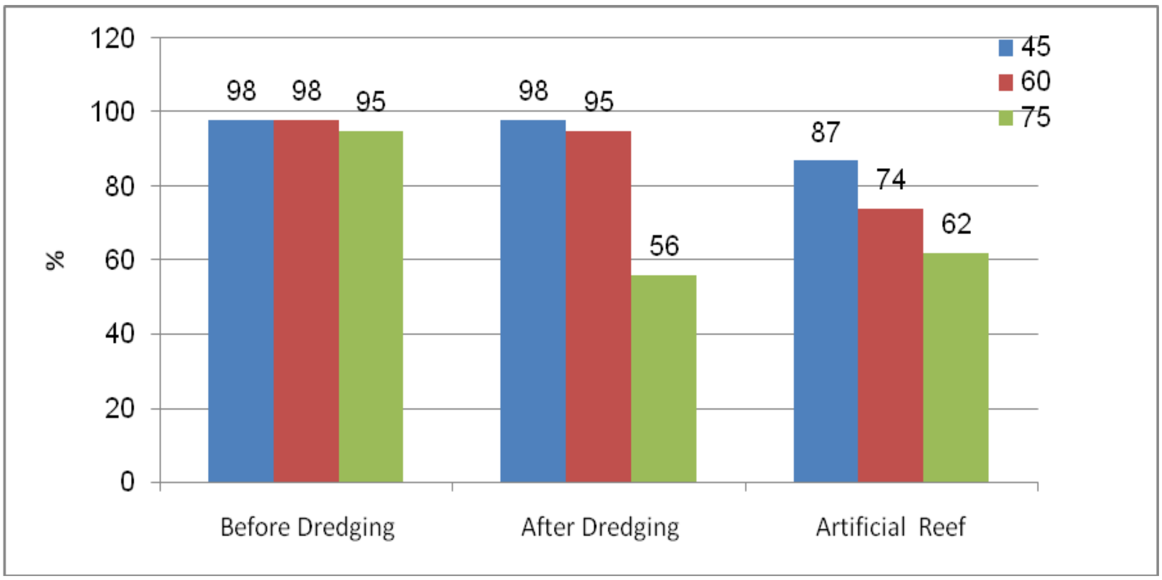



*Figure 19 : Percentage of sounding uncertainty that meets the IHO Special Order standards*.

| Processing Angle | Philadelphia | New York | Before Dredging | After Dredging | Artificial Reef |
|---|---|---|---|---|---|
| 45° | 20 | 33 | 5 | 7 | 2 |
| 60° | 28 | 42 | 8 | 17 | 2 |
| 75° | 49 | 68 | 11 | 25 | 3 |

*Table 8: Processing time (Min per km) for the Beam angle 45°, 60° and 75°.*

## Processing angle

In all projects, using smaller beam angle during data collection leads to a decrease in the processing time as illustrated in *Figure 20*.

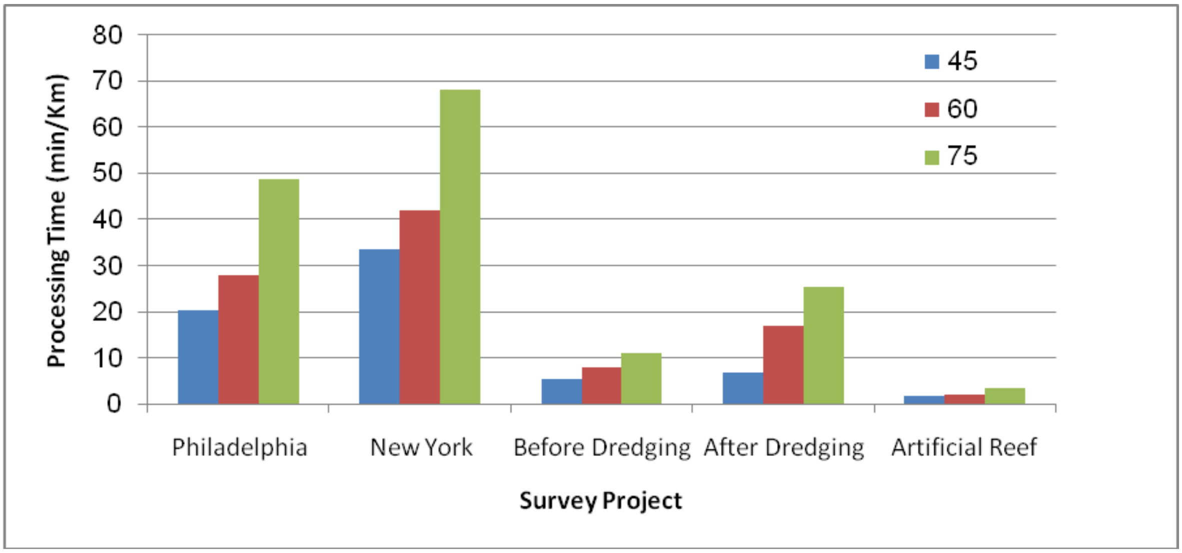
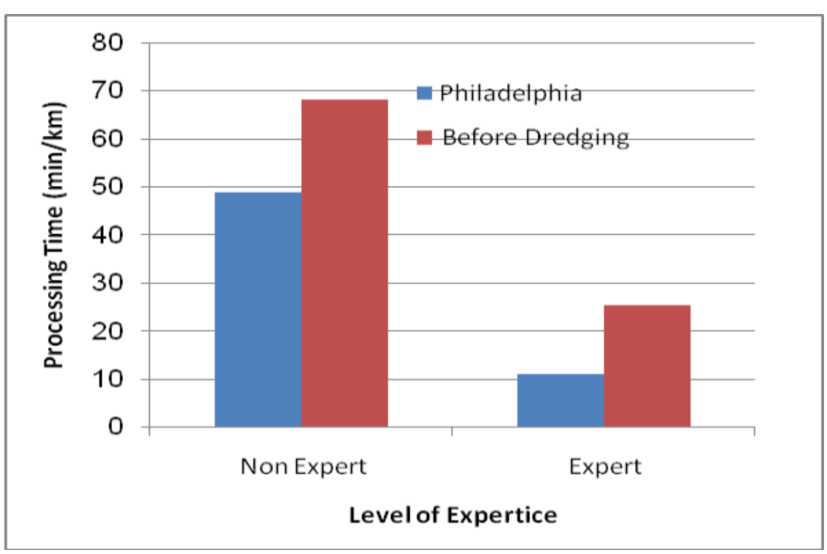



***Figure 20*** *: Processing time for each project in terms of its processing angle limit.*

## Experience level

Level of experience of the data processing team, in the first two projects, was elementary. The processing time decreases after getting experience with data processing generally and HYSWEEP specifically. This result is illustrated in *Figure 21*, where the first set shows the processing time (min/km) for both the Philadelphia and Before Dredging (processing angle limit 45°), before the surveyor team got experience with MBES data processing and the second after getting the required experience and enhancing the data processing SOPs. There was a three-fold increase (300%) in processing rates as the surveyors gained experience.

***Figure 21*** *: Processing time for expert and non-expert surveying team.*



## Type of Survey

After the survey team obtained the required experience, the same dredging area was processed twice (Before Dredging and After Dredging). The processing time is illustrated in *Figure 22*. In all processing angles (45°, 60° and 75°), the processing time for Before Dredging is less than After Dredging. The saved time is inversely proportional to the processing angle. The increase in processing time was due to two factors. First, the complexity of the seafloor increased in the After Dredging survey. Second, nearby dredging operations during the After Dredging survey caused an increase in the amount of suspended sediment in the water column.

## Seabed complexity

To illustrate the seabed complexity, contour images were built for each project. The contour interval is fixed every foot. A capture of 1 × 1 Km is taken for each project as shown in the *Figures 23, 24, and 25*. A grid of 100m is overlaid over each plot.

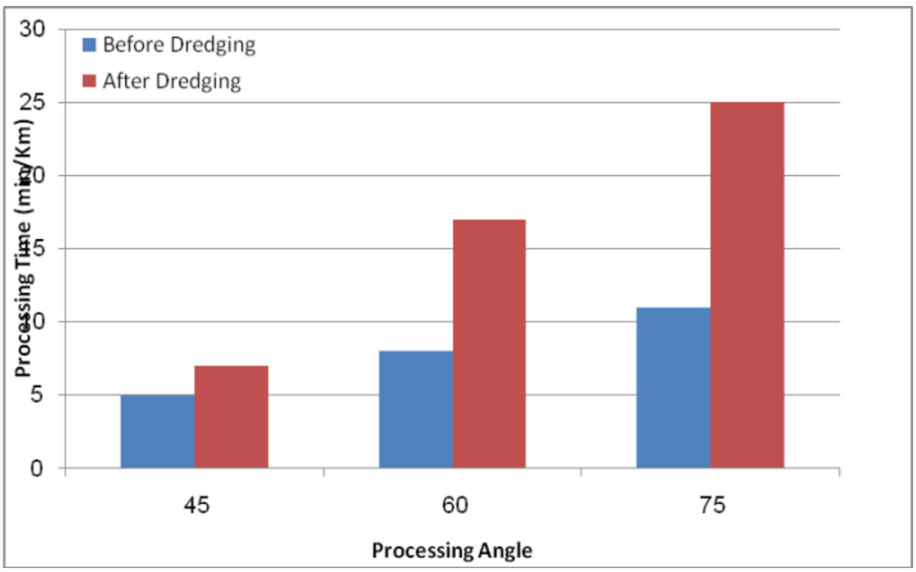



***Figure 22*** *: Processing time for Before Dredging and After Dredging.*

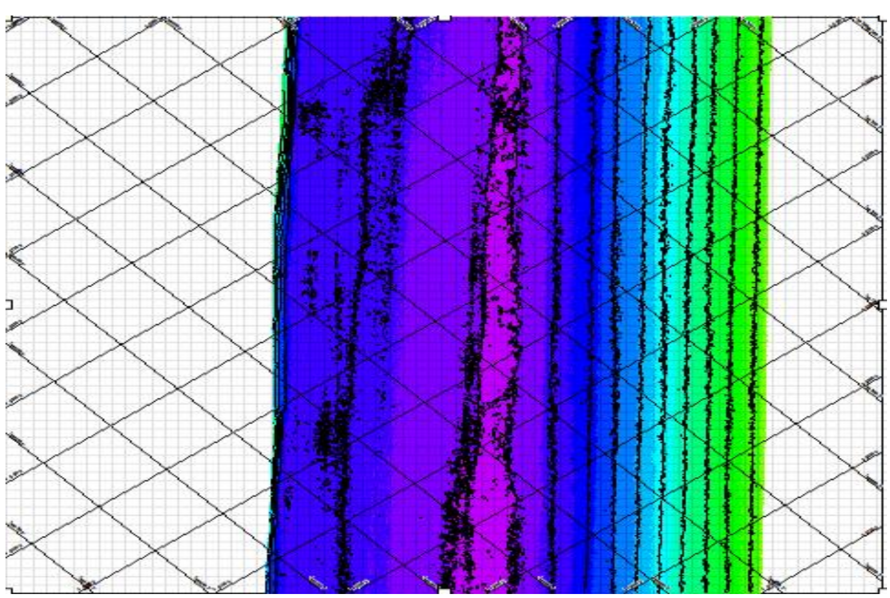


***Figure 23*** *: Before Dredging project contouring.*

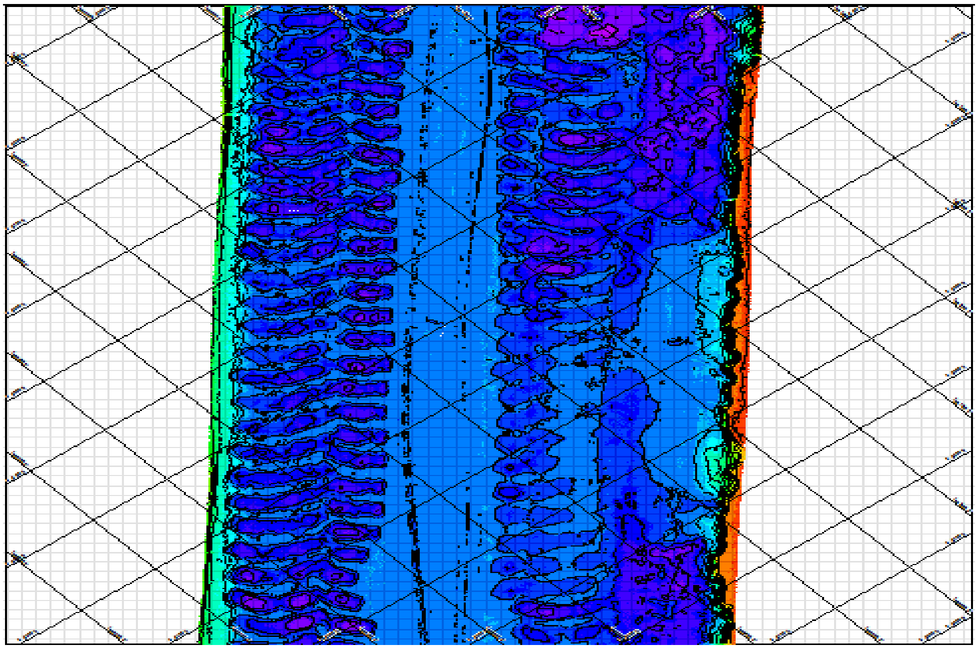


***Figure 24*** *: Processing time for Before Dredging and After Dredging.*

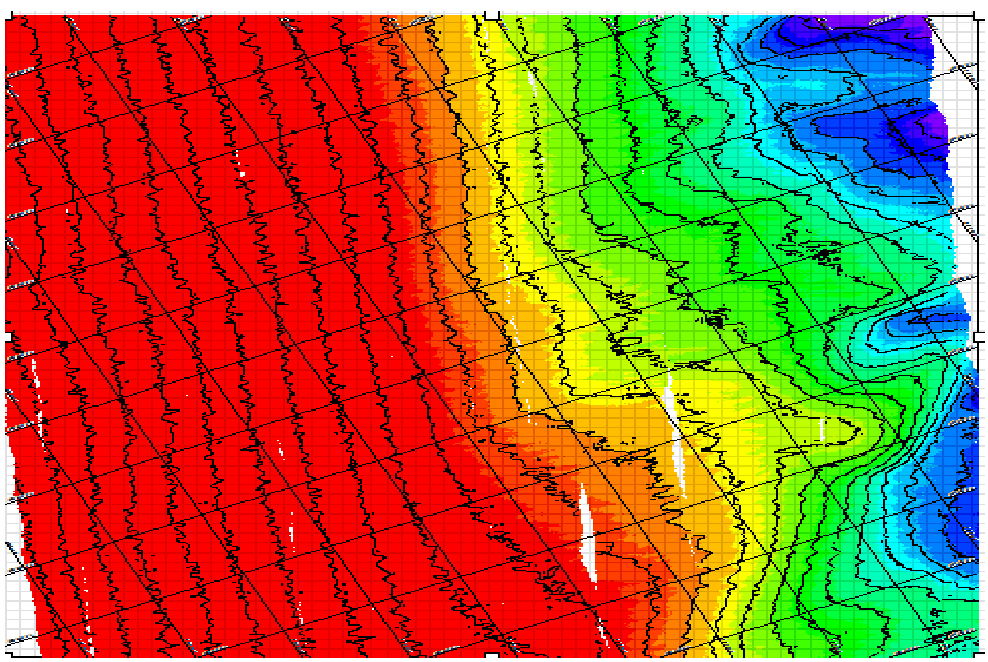


***Figure 25*** *: Artificial Reef project contouring.*

Comparing the Before Dredging and After Dredging contours makes it clear that the complexity of seabed has increased after dredging. This explains the increased processing times (5, 8 and 11 min/Km) vs. (7, 17 and 25 min/Km). As a conclusion, increasing the seabed complexity will increase the processing time. A contradiction to this rule is illustrated when comparing Before Dredging and the Artificial Reef project. Whilst the seabed in the Artificial Reef survey is more complex than Before Dredging (see *Figures 23* and *25*), the processing time is smaller (5,8 and 11 min/Km) and (2,2 and 3 min/Km). This is probably due to the size of the Artificial Reef raw data being smaller.

The 45° swath angle

The survey speed = 1500 tan (1.5) cos (45°) = 27 m/s = 53 knots

The survey speed = 1500 tan (1.5) cos (45°) = 27 m/s = 53 knots

The 60° swath angle

The survey speed = 1500 tan (1.5) cos (60°) = 19 m/s = 38 knots

The 75° swath angle

The survey speed = 1500 tan (1.5) cos (75°) = 10 m/s = 19 knots

| Project | Raw Data Size (Mb per km) | Processing time (Min per km) |
|---|---|---|
| Before Dredging | 81.5 | 5, 8 and 11 |
| After Dredging | 67.5 | 7, 17 and 25 |
| Artificial Reef | 30 | 2, 2 and 3 |

***Table 9***: *Raw data size along with the equivalent processing time.*

## Raw Data Size

Raw data size has a direct impact on the processing time. The raw data size per Km is computed for the last three projects and is listed in *Table 9* along with the processing time.

Comparing the Before Dredging and Artificial Reef surveys, the effect of the raw data size on processing time is dominant over the seabed complexity. Comparing the Before Dredging and the After Dredging surveys, the effect of type of the survey and seabed complexity is dominant over the raw data size.

## Virtual Survey Area

A 'virtual' survey area was created to investigate the previous results in terms of time, and its equivalent cost, for both field and office work. The dimension of the survey area was taken 1km x 10km and the investigation was conducted twice; first using an average depth of 30m and then using an average depth of 10m. It is assumed that the area is parallel to the coastline along with its 10km side. Three scenarios were used for conducting the survey by using the Beam Angle Limits of 45°, 60° and 75°. In all the three cases the swath to swath overlap was set to 30%.

Using the equation :

$$v_{overlap} = \min(v_{\min}, C\tan(\alpha)\cos(\theta/2))$$

| | |
|---|---|
| $v_{overlap}$ | speed that maintain ping to ping overlap (m/s) |
| $v_{min}$ | Minimum speed (m/s) |
| C | Speed of sound in water |
| α | for-aft beam angle (degree) |
| ϑ | Swath width (degree) |

According to sonar configuration, the computed limits of the survey speed are very high. However, as a quality control measure, we have limited the maximum speed for our 'virtual' survey to 5 knots (9.26 km/hr).

According to the processing time analysis, there are several factors that could affect the estimated processing time for the virtual area other than the processing angle. For the purpose of illustrating the effect of processing angle on the office cost, two different scenarios were studied :

- First, for a simple seabed and standard survey operation where the average processing times are 5, 8 and 11 min/km. (45°, 60° and 75° degree Beam Angle Limits, respectively)
- Second, for a complex seabed or dredged area survey where the average processing times are 7, 17 and 25 min/km.

According to a 2010 survey conducted by HYPACK on several private hydrographic survey agencies, it was found that the average daily rate for a MBES survey ship is $5,000 and the office work is $1,200. This is based on 8 working hours per day. Based on this cost model, the estimated costs of collecting and processing the data from our virtual area could be computed and compared, using each of the Beam Angle Limits.

## Average depth of 10m

The costs for collecting data over our virtual area with a uniform depth of 10m, using different beam angle limits and our estimated cost of $5,000 per survey day are shown in *Table 10*.

| Swath (angle) | Depth (m) | Line Spac-ing (m) | line spacing with 30% overlap | Number of lines | Total Length (km) | Time (hr) | Time (Days) | Field Cost ($) |
|---|---|---|---|---|---|---|---|---|
| 90° | 10 | 20 | 17 | 60 | 598 | 65 | 8 | 40,000 |
| 120° | 10 | 35 | 29 | 35 | 350 | 38 | 5 | 25,000 |
| 150° | 10 | 75 | 63 | 17 | 168 | 18 | 2 | 10,000 |

***Table 10***: *Field cost computation for average depth of 10 metres.*

The costs for processing this data collected over our virtual area with a uniform depth of 10m are shown in *Table 11*.

| Swath (angle) | Total Length (km) | Processing time (hr) | Processing time (Days) | Office Cost ($) |
|---|---|---|---|---|
| 90° | 598 | 50 | 6.3 | 7,560 |
| 120° | 350 | 47 | 5.9 | 7,080 |
| 150° | 168 | 31 | 3.9 | 4,680 |

***Table 11***: *Office cost computation for standard survey operation in average depth of 10 metres.*

*Table 12* summarizes the total data collection (Field) and data processing (Office) costs, along with the total cost for each Beam Angle Limit.

| Swath (angle) | Field Cost ($) | Office Cost ($) | Total Cost ($) |
|---|---|---|---|
| 90° | 40,000 | 7,560 | 47,560 |
| 120° | 25,000 | 7,080 | 32,080 |
| 150° | 10,000 | 4,680 | 14,680 |

***Table 12***: *Total cost computation for standard survey operation in average depth of 10 metres.*

The costs for collecting data over our virtual area with a complex bottom and an average depth of 10m would be the same as the costs for collecting the data over the uniform bottom.

The costs for processing this data collected over our virtual area with a complex seabed and an average depth of 10m are shown in *Table 13*.

| Swath (angle) | Total Length (km) | Processing time (hr) | Processing time (Days) | Office Cost ($) |
|---|---|---|---|---|
| 90° | 598 | 70 | 8.8 | 10,560 |
| 120° | 350 | 99 | 12.4 | 14,880 |
| 150° | 168 | 70 | 8.8 | 10,560 |

***Table 13***: *Office cost computation for dredging survey operation in average depth of 10 metres.*

*Table 14* summarizes the total data collection (Field) and data processing (Office) costs for a complex bottom with an average depth of 10m, along with the total cost for each Beam Angle Limit.

| Swath (angle) | Field Cost ($) | Office Cost ($) | Total Cost ($) |
|---|---|---|---|
| 90° | 40,000 | 10,560 | 50,560 |
| 120° | 25,000 | 14,880 | 39,880 |
| 150° | 10,000 | 10,560 | 20,560 |

***Table 14***: *Total cost computation for dredging survey operation in average depth of 10 metres.*

## Average depth of 30m

The analysis is repeated, using a uniform bottom with the average depth increased to 30m. The results for data collection and data processing costs are shown in *Table 15* and *Table 16*. The Total Cost is shown in *Table 17*.

| Swath (angle) | Depth (m) | Line Spacing (m) | line spacing with 30% overlap | Number of lines | Total Length (km) | Time (hr) | Time (Days) | Field Cost ($) |
|---|---|---|---|---|---|---|---|---|
| 90° | 30 | 60 | 51 | 21 | 206 | 22 | 3 | 15,000 |
| 120° | 30 | 104 | 88 | 12 | 123 | 13 | 2 | 10,000 |
| 150° | 30 | 224 | 190 | 6 | 63 | 7 | 1 | 5,000 |

***Table 15***: *Field cost computation for average depth of 30 metres.*

| Swath (angle) | Total Length (km) | Processing time Time (H) | Processing Time (Days) | Office Cost ($) |
|---|---|---|---|---|
| 90° | 206 | 17 | 2.1 | 2,520 |
| 120° | 123 | 16 | 2 | 2,400 |
| 150° | 63 | 11 | 1.4 | 1,680 |

***Table 16***: *Office cost computation for standard survey operation in average depth of 30 metres.*

| Swath (angle) | Field Cost ($) | Office Cost ($) | Total Cost ($) |
|---|---|---|---|
| 90° | 15,000 | 2,520 | 17,520 |
| 120° | 10,000 | 2,400 | 12,400 |
| 150° | 5,000 | 1,680 | 6,680 |

***Table 17***: *Office cost computation for dredging survey operation in average depth of 10 metres.*

The analysis is repeated, using a complex bottom with the average depth increased to 30m. The results for data collection were the same as in Table 15. The data processing costs are shown in *Table 18*. The Total Cost is shown in *Table 19*.

| Swath (angle) | Total Length (km) | Processing time (hr) | Processing time (Days) | Office Cost ($) |
|---|---|---|---|---|
| 90° | 206 | 24 | 3 | 3,600 |
| 120° | 123 | 35 | 4.4 | 5,280 |
| 150° | 63 | 26 | 3.3 | 3,960 |

***Table 18****: Office cost computation for dredging survey operation in average depth of 30 metres.*

| Swath (angle) | Field Cost ($) | Office Cost ($) | Total Cost ($) |
|---|---|---|---|
| 90° | 15,000 | 3,600 | 18,600 |
| 120° | 10,000 | 5,280 | 15,280 |
| 150° | 5,000 | 3,960 | 8,960 |

***Table 19****: This conclusion is supported by both the uniform and complex seabeds shown in Figures 26 and 27.*

Decreasing the Swath Angle Limits from 150° to 120° to 90° increases the processing efficiency but it also increases the total processing time. Reducing the Beam Angle Limit requires you to decrease the line spacing, resulting in an increase to the total survey length. These results will give an increase to both the data collection and processing times.

This conclusion is supported by both the uniform and complex seabeds shown in *Figures 26* and *27*.

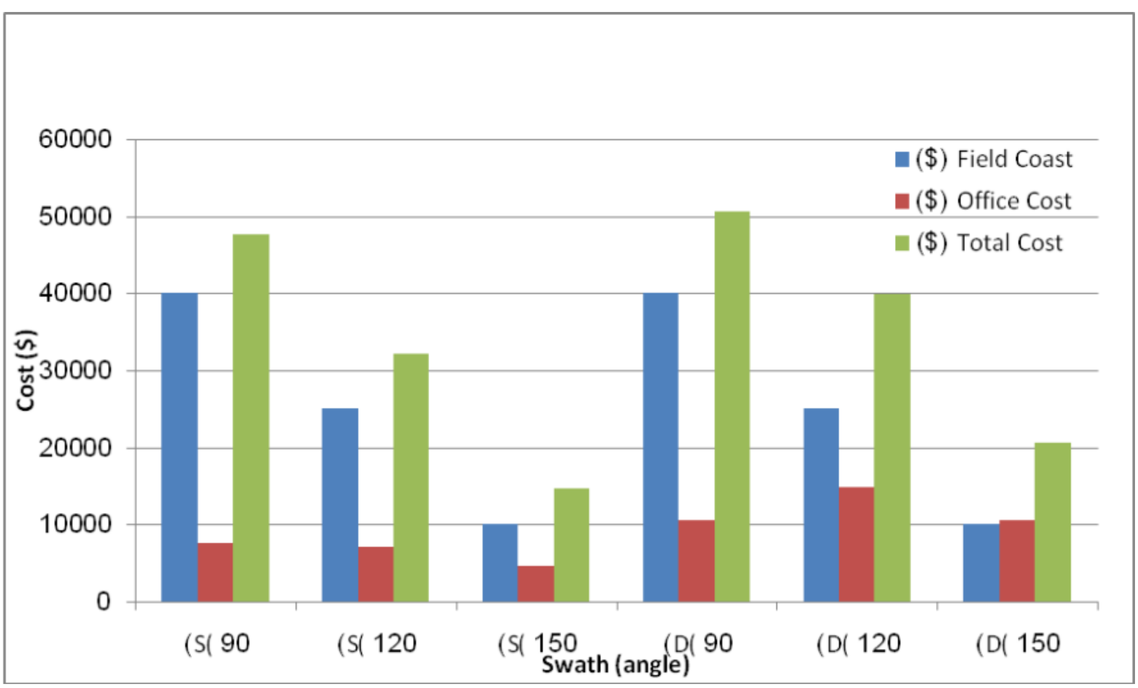



***Table 26****: Field, office and total survey cost for both Standard (uniform) survey (S) and dredging (complex bottom) survey (D) for three processing Swath Limits 90°, 120°, and 150° on average depth of 10m.*

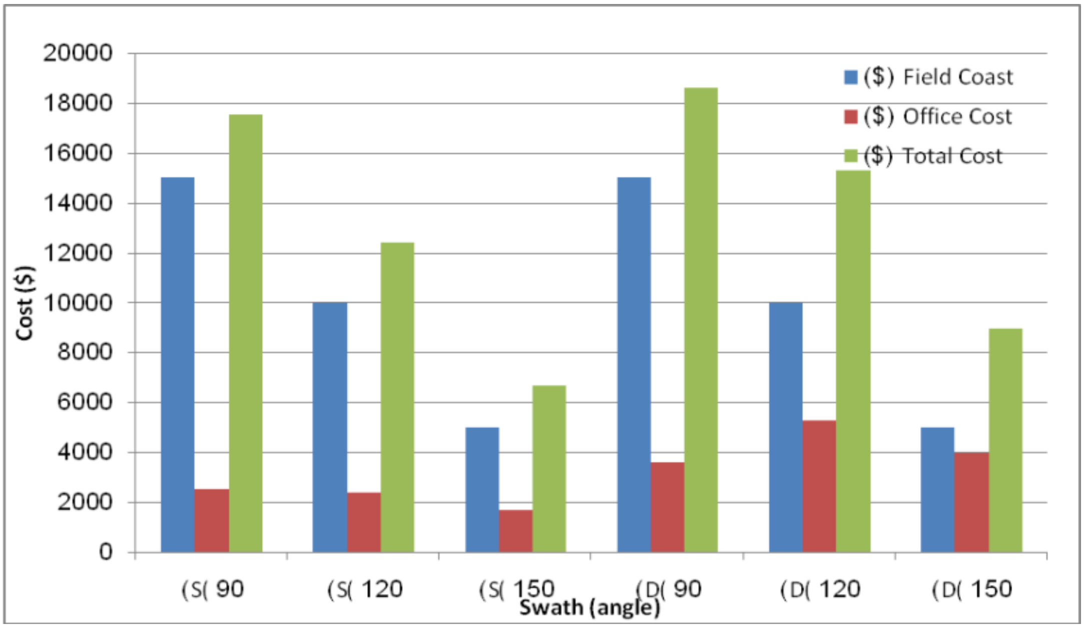



***Table 27**: Field, office and total survey cost for both Standard (uniform), survey (S) and Dredging (complex) survey (D) for three processing swath limits of 90°, 120°, and 150° on average depth of 30m.*

## Uncertainty vs Cost

Uncertainty versus cost could be inferred by combining the uncertainty results and virtual survey area costs for standard and complex area.

### Standard Area

Using the 95% of Uncertainty values for the Before Dredging study (as listed in Table 7):

- At 45° the 95% 2σSD: 0.08m
- At 60° the 95% 2σSD: 0.08m
- At 75° the 95% 2σSD: 0.15m

Total Costs for the Dredged, Complex , Area over the 10m deep seabed (as listed in Table 10):

- 45° Beam Angle Limit = $48,000
- 60° Beam Angle Limit = $32,000
- 75° Beam Angle Limit = $15,000

Savings vs. Uncertainty:

- Moving from 45° to 60° Beam Angle Limit
  Savings = $16,000
  Increased Uncertainty = 0 m
- $16,000 is saved and the uncertainty was not affected.
- Moving from 60° to 75° Beam Angle Limit

Savings = $17,000
Increased Uncertainty = 0.07m

Increasing the beam angle limit from 45° to 60° did not affect the uncertainly of the survey results and yielded a saving of $16,000. Increasing the beam angle limit from 60° to 75° yielded a saving of $17,000, but resulted in an increase of 7cm to the average uncertainty of each sounding.

### Complex Area

Using the 95% of Uncertainty values for the Artificial Reef study (as listed in Table 7):

- At 45° the 95% 2σSD: 0.13m
- At 60° the 95% 2σSD: 0.29m
- At 75° the 95% 2σSD: 0.33m

Total Costs for the Dredged, Complex, Area over the 10m deep seabed (as listed in Table 10):

- 45° Beam Angle Limit = $51,000
- 60° Beam Angle Limit = $40,000
- 75° Beam Angle Limit = $21,000

Savings vs. Uncertainty:

- Moving from 45° to 60° Beam Angle Limit
  Savings = $11,000
  Increased Uncertainty = 0.16m

- Moving from 60° to 75° Beam Angle Limit
  Savings = $19,000
  Increased Uncertainty = 0.04m

Increasing the beam angle limit from 45° to 60° resulted in a cost savings of $11,000, but increased the average uncertainty of each sounding by 16cm. Increasing the beam angle limit from 60° to 75° resulted in an additional saving of $19,000, but increased the average uncertainly of each sounding by an additional 4cm.

## Conclusions

Although using smaller MBES swath angles will reduce the processing time per km, the number of survey lines will increase causing both the total field and office times to increase. This results in a higher total survey cost.

Sounding uncertainty should be taken into account when selecting the swath angle. Different factors could affect the uncertainty such as seabed complexity, type of the survey and sea state. In all aspects, decreasing the Beam Angle will improve the uncertainty.

Factors that influence the time required for MBES data processing include the Beam Angle Limit, seabed complexity, and raw data size.

Increasing the beam angle limit for a survey will result in lower overall survey costs (particularly data collection costs), but will result in a greater average depth uncertainty for each sounding.

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