Hydrodynamic Modeling of Effluent Plume Discharge for the Sewage Treatment Plant at the Norman Manley International Airport

Submitted to:

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GLOSSARY OF OUTFALL TERMS

Benthic organisms: Organisms that live on or in the bottom of seas or lakes for most of their adult life cycle, such as clams, lobsters, and crayfish.

Bioaccumulation: Bioaccumulation is the general term describing a process by which certain chemicals are taken up by a plant or animal either directly from exposure to a contaminated medium (soil, sediment, water) or by eating food containing the chemical. Compounds of a certain type can accumulate in living things when they are taken up and stored faster than they are broken down (metabolized) or excreted. Certain compounds are easily broken down and do not bioaccumulate.

Biochemical oxygen demand (BOD): The amount of oxygen used by microorganisms in the breakdown or decay of organic matter in a water body.

Water Quality Guidelines: Guidelines that apply across Jamaica and represent safe levels of substances for the protection of a given water use, including drinking water, aquatic life, recreation and agricultural uses.

Chemical parameters: Substances such as metals, dissolved nutrients, oils, and pesticides, as well as chemical properties of the aquatic system such as dissolved oxygen, chemical oxygen demand, and acid neutralizing capacity.

Compliance monitoring: Monitoring to ensure immediate statutory requirements are met.

Contaminant: A material added by humans or through natural activities that may, in sufficient concentrations, render the environment unacceptable for plants and animals in the region. The mere presence of these materials is not necessarily harmful.

Conventional parameters: These refer to general water quality parameters such as pH, biochemical oxygen demand, total suspended solids, nutrients and fecal coliform.

Diffuser (Multi-port): A specially designed pipe, with multiple ports or openings along its length, that permits the rapid dilution of discharged wastewater.

Diffusion: Movement of suspended or dissolved particles from a more concentrated to a less concentrated area. The process tends to distribute the particles more uniformly.

Disinfection: Any process that destroys or removes disease-causing organisms such as viruses, bacteria or protozoa from wastewater. Examples include ultraviolet irradiation and chlorination.

Effluent: Treated or untreated liquid waste material that is discharged into the environment from a point source, such as a wastewater treatment plant or an industrial facility.

Fecal coliform: A type of bacteria that comes from the intestines of warm-blooded animals, including humans and ducks, and can cause disease if ingested in sufficient amounts. Fecal coliforms are often used as indicators of potential risks to human health.

Flow rate: The rate, usually in cubic meters per day or liters per hour, at which wastewater passes through the treatment facility.

Metals: Include total and dissolved metals such as aluminum, mercury, silver and zinc. These may occur naturally or come from human sources such as mercury from dental uses.

Nutrients: Any inorganic or organic substance needed by plants and animals for nutrition and growth (e.g., nitrogen, phosphorus). In water resources, excessive amounts of nutrients can lead to degradation of water quality by promoting excessive growth, accumulation, and subsequent decay of plants, especially algae.

Oceanographic Model: A computer program that simulates how the water moves around the outfalls. The model is generated using location-specific current, tide and weather data and is used to predict the path of the effluent plumes.

Outfall: Pipe through which wastewater (sewage, storm water, industrial effluent, etc.) is discharged to a receiving body of water.

Parameter: Numerical information used as input to a water quality model or estimated by a water quality model. Also used as a synonym for compound or analyte (i.e., a substance for which chemical, physical or biological testing is conducted).

Physical parameters: General conditions such as temperature, flow, sediment characteristics and water colour.

Primary treatment: The first level of wastewater treatment. It uses settling and skimming to remove solids, floating materials, and pathogens.

Receiving waters: A river, lake, ocean, stream or other watercourse into which wastewater or treated effluent is discharged.

Reference stations: Stations situated well outside the areas of influence of the outfalls that have similar physical characteristics (e.g. depth, type of sea floor, sea life) to the outfall sampling stations and provide areas to compare observations and assess effects.

Sanitary sewers: Underground pipes that carry only domestic or industrial waste, not storm water.

Secondary treatment: A level of wastewater treatment beyond primary treatment. It typically involves biological reduction in concentrations of particulate and dissolved oxygen-demanding pollutants.

Sewage: The waste and wastewater produced by residential, commercial and industrial sources that is discharged into sewers.

Source control: A practice, method, or technology used to reduce pollution from a source before it enters the wastewater stream. Source control focuses on reducing or eliminating contaminants before they enter the sewer system rather than treating them after they have been mixed with other wastes.

Surface water: The layer of water at the surface of the ocean. In this case, surface water samples around the outfalls are collected to monitor if fecal coliforms are present and in what quantity.

Suspended solids: Organic and inorganic particles, such as solids from wastewater, sand, clay, and mud that are suspended and carried in water.

Tidal currents: Horizontal movement of water caused by gravitational interactions between the sun, moon and the earth.

Total dissolved solids (TDS): The amount of dissolved substances, such as salts or minerals, in water remaining after evaporating the water and weighing the residue.

Treated wastewater: Wastewater that has been subjected to one or more physical, chemical, or biological processes designed to reduce solids, nutrients or other substances and contaminants typically found in effluent.

Wastewater: Wastewater includes the water and wastes that are flushed down the toilet and that drains from bathtubs, sinks, washing machines and many other domestic sources (i.e. also known as sewage). Businesses and industries also produce wastewater. In heavy rainfall events, storm water may end up as part of the wastewater stream.

Water pollution: The presence in water of enough harmful or objectionable material to damage the water's quality.

Water column: The vertical section of water between the surface of the ocean and the ocean bottom

1 INTRODUCTION

1.1 PROJECT BACKGROUND

The Norman Manley International Airport (NMIA) is one of three international aerodromes in Jamaica that handles approximately 1.5 million passengers annually. Wastewater generated onsite is treated by a treatment plant on the property. At present, the plant is rated at 1,746 m^3/ day, with a current estimated flow rate of approximately 500 m^3/ day. The effluent is discharged into the Kingston harbour via a 200mm diameter HDPE pipe, 42 meters long with a multiport discharger at the end. The operators of the airport, NMIA Airports Limited (NMIAL), presently need to model the plume behavior of the effluent in the coastal and marine environment and submit the results to the National Environment and Planning Agency (NEPA) for approval.

1.2 DESCRIPTION OF THE ENVIRONMENT

The NMIA is located 20 minutes from downtown Kingston. It is bordered by the seventh largest natural harbour of the word, the Kingston Harbour. The harbour itself is bordered in the north, east and west by the city of Kingston, and in the south by the Palisadoes spit. Much of this water, even close to shore, is deep enough to accommodate large ships. Domestic waste enters the system via gullies and culverts on the northern shore from the nearby city, and threatens the biodiversity of the bay with pollution and alien species being brought there by shipping. See Figure 1-1 for the project location.

FIGURE 1-1. LOCATION MAP FOR THE NMIAL MARINE OUTFALL.

1.3 REGULATORY FRAMEWORK

The National Resources Conservation Authority (NRCA) Act Permit and Licensing Regulations (1996) gives the NEPA the power to take the necessary steps to ensure the effective management of marine parks and protected areas. The Act provides for the management, conservation and protection of the natural resources of Jamaica. In April 2013, the NRCA released 'The Natural Resources Conservation (Wastewater and Sludge) Regulations' which outline the *Use of Marine Outfalls and Outfall Pipelines* in Part VII. This reads as follows:

1. Where marine outfalls are proposed, a request may be made by an applicant to the Authority to have effluent limits relaxed.
2. Requests for the use of marine outfalls shall be accompanied by –
   a. A model of the plume behavior of the effluent in the coastal and marine environment;

b. The data, studies and calculations that show that the proposed outfall will allow for an effluent quality which is still acceptable and will not affect the marine environment beyond the levels already established for the ambient water quality;
c. The data and studies to show the effect of the effluent on the flora and fauna of the marine environment, within the sphere of influence of the plume as described in paragraph (a);
d. A drawing of the route of the marine outfall pipe and the construction material and bio-physical survey of the route of the pipe, including the method of laying the pipeline o the floor of sea and stabilization method; and
e. Bathymetry of the seafloor along the alignment of the pipeline.

Currently NMIAL has received approval for the marine outfall and the objective of this report is to address items 2 (a) and 2(b).

1.4 Purpose and Scope of Work

The primary objective of this project is to obtain the license for the use of the marine outfall for the sewage treatment plant. NMIAL requires the construction and validation of a plume discharge model to investigate the effect of variation in hydrodynamic conditions on the transport and dilution of the treated wastewater plume from its activated sludge waste water plant. The scope of work include:

1. Development of a 3D visualization model of the near field plume geometry incorporating buoyancy, momentum and any surface or bottom interactions. The model shall include plume trajectory, shape, concentration, and dilution, the model shall also predict behavior of the plume for steady, unsteady ambient currents/tides, or stagnant ambient conditions

2. Development of 3D visualization model of the boundary interactions for the plume discharge. The model shall include plume trajectory, shape, concentration, and dilution, the model shall also predict behavior of the plume for steady, unsteady ambient currents/tides, or stagnant ambient conditions

3. Development of 3D model of the far field for the plume discharge. This model shall be performed in MIKE 3 by DHI software or equivalent and will include advection and dispersal modelling

4. The measurement of plume dilution by conducting bathymetry and velocimetry characterization for the area surrounding the plume discharge. This should be performed with the aid of boat mounted acoustic Doppler sonar along with Differential GPS points with 50 cm accuracy or better. It is recommended that the Jamaica VRS (Virtual Reference Station) be used as the base station for this exercise for highest accuracy.

5. The verification of the far field plume predictions by field dye studies.

6. The output generated from the DHI software (or its equivalent) shall be exported into an ESRI shapefile and submitted to the NMIA in electronic format or on an USB drive. The hard copy data from the MIKE and CORMIX software (or their equivalents) along with the standard written reports, graphs,

bar charts etc. shall be submitted in hard copy and Adobe pdf and/or Microsoft Word electronic format.

It should be noted that item number 5 pertains to a dye tracer study that will be conducted, and the results submitted to NEPA, in August 2014.

1.5 Literature review

A number of reports and articles have been written concerning the water quality of the Kingston Harbour. In this section a few relevant studies are highlighted and the information provided used to inform our assessment.

1.5.1 Institutional Strengthening & Preparation of Zoning & Physical Development Master Plan for Kingston Harbour (2005)

This report was submitted to NEPA as the *Institutional and Legal Framework for the Kingston Harbour Rehabilitation,* which sought to specifically address the environmental management framework for the Harbour. The report noted that the water quality in the harbour is badly degraded and contaminated, and that serious studies of the deterioration began in the 1970's. This deterioration has led to the "progressive reduction of fishing use to practically zero levels and [to the disappearance of] primary contact tourist use from the beaches of the interior of the harbour." It also mentioned that over the past few decades there have been several attempts to address the environmental health of the harbour, but to date, none have been successful.

The primary physical contributors to the degradation of the harbour's water and interdependent ecosystems were identified as the following:

- Untreated or inadequately treated sewage;
- Solid waste;
- Ship-generated waste;
- Sediment;
- Industrial effluents and oil spills or contamination; and
- Agricultural runoff (nutrients and other chemicals).

1.5.2 A Marine & Shoreline Environmental Impact Assessment Report for Proposed National Works Agency Shoreline Stabilization Works – Palisadoes, Kingston (2007)

This Environmental Impact Assessment evaluated the impact of the proposed shoreline stabilization works for the Palisadoes. The works included: elevating the roadway to about 2.0m, constructing boulder revetments along the shoreline and pumping sand onshore for re-nourishment and the recreation of sand dunes. As a component of this assessment, a water quality analysis was conducted. The analysis revealed that within the Kingston Harbour the total suspended solids and turbidity values far exceeded the limits prescribed by NEPA, which supports the information gleaned from other sources about the harbour.

1.5.3 Proposed Extension of Runway at Norman Manley International Airport, A Rapid Ecological Assessment (2011)

The rapid ecological assessment was completed in order to satisfy NEPA's permitting requirements for the extension of the runway by up to 500m using land-filling methods. A water quality analysis was completed in the area proposed for the extension and it revealed that there is no significant freshwater influence in the harbour. Particularly high Fecal Coliform counts and turbidity values were obtained for 2 of the 3 sample locations. It was however mentioned that turbidity values were probably influenced by the recent flood events (Tropical Storm Nicole), with fallout of suspended materials in freshwater discharged from the Kingston gullies.

1.5.4 Environmental Monitoring Reports for the Palisadoes Shoreline Protection and Rehabilitation Works (2010 – 2012)

Between September 2010 and December 2012 the Government of Jamaica in partnership with the Government of China, effected repairs and protection of the extensively and degraded Palisadoes shoreline. The scope of works included:

- Constructing rock revetment walls along the Caribbean Sea side of the Palisadoes (2.65 km in length), and along the Harbour side from the Harbour View round-a-bout to Gunboat Beach.
- Raising the road from its existing level to between 2.4 and 3.2 meters above sea level.
- Constructing additional drainage facilities along the Caribbean Sea side of the Palisadoes, and a 10m wide boardwalk along the Harbour side.

During the construction process CL Environmental carried out environmental monitoring activities on a monthly basis, which included water quality tests. These results provided background information on the water quality of the Kingston Harbour. Table 3-2 summarises these results and compares them to the NEPA standard for the marine environment. It should be noted that 1) all the values exceed those stipulated by NEPA, and 2) because of this the treatment plant's outfall will be unable to meet the NEPA standard, it will be limited by the condition of the harbour. The background condition of the harbour will be used in the modeling analysis to be completed.

Table 1-1. Background water quality for the Kingston Harbour obtained from a monthly environmental monitoring program carried out between September 2010 and December 2012.

	Phosphate (mg/L)	Nitrates (mg/L)	Faecal Coliform (MPN/ 100ml)	BOD (mg/L)
Average	0.066	0.963	88.84	8.30
NEPA	0.003	0.014	13	1.16

2 Oceanographic Data Collection Programme

2.1 General Approach

The approved scope of work called for data collection to facilitate the modeling exercise and define the background condition. The key elements of this programme were:

1. Bathymetric data in the outfall and dispersion area.
2. Currents in the outfall area and drogue tracking in the dispersion area to verify the ADCP programme
3. CTD surveys to define the background conditions for the outfall dilution model and to provide a secondary means of verification of the outfall dilution

2.2 Bathymetric Survey

Bathymetric data is required in order to facilitate the hydrodynamic modeling of the effluent plume discharge. The survey was carried out on June 19 and 20, 2014 using a single beam sonar with autonomous GPS, and it was bench marked to a tide station set up on the shoreline. Survey lines were set parallel and perpendicular to the shoreline on grid lines with a minimum spacing of 30m, see Figure 2-1 for the survey plan lines.

Figure 2-1. Survey lines for the bathymetric survey conducted on June 19 and 20, 2014.

2.2.1 Methodology

An Odom single beam sonar with real time kinematic (RTK) GPS correction was used for this exercise. The General Specification of the survey was to National standards. The following were the specifications:

- Survey on 30 metre grid with tie lines at 30 metre intervals for checking main survey lines in the area of the outfall. For the other survey lines in the harbour 90 meters grids with tie lines at 60 metre intervals were used.
- Single beam 200 KHz sounder, at 1 second intervals at a maximum speed of 6 knots. No surveys were carried out in heave or swell conditions exceeding 0.5 meters in wave height or in water depths less than 1.5 meters.
- Chart datum (CD) determination from National Land Agency (Survey Department) Bench Mark to tide station was set up on shoreline.
- Automatic tide correction by dynamic real time ellipsoid height GPS measurements. Statistic Ellipsoid height from pre-survey field checks in the area and correlation to Chart Datum.
- Accuracy to 0.2 meters for depth and +/- 0.5 meters horizontal accuracy (plus latency), using real-time Trimble DSM 232 DGPS system and ODOM sounder. Maximum PDOP of 3 for quality control of fix. Display and logging by HYPACK software for plan lines of surveys and for during surveys to ensure complete capture
- Shallow (<3.0 meters) and deep water (<15.0 meters) bar check before survey with reporting to verify accuracy. These will be reported on the final drawings

2.2.2 Results and Discussion

The overall bathymetric survey is presented in Figure 2-2 with the outfall area (highlighted). A more detailed drawing of the outfall is presented in Figure 2-3 showing the configuration of the pipe and diffusers.

The bathymetric chart indicates depths ranging from 2 to 14 m across the project area. The contours also indicated an area extending to the north-west of the new runway having a (dredged) trench with bottom elevations of -4to -12m. The outfall pipe extends 42 meters from the shoreline where the diffusers (discharge area) are located within approximately 10 to12 meters of water.

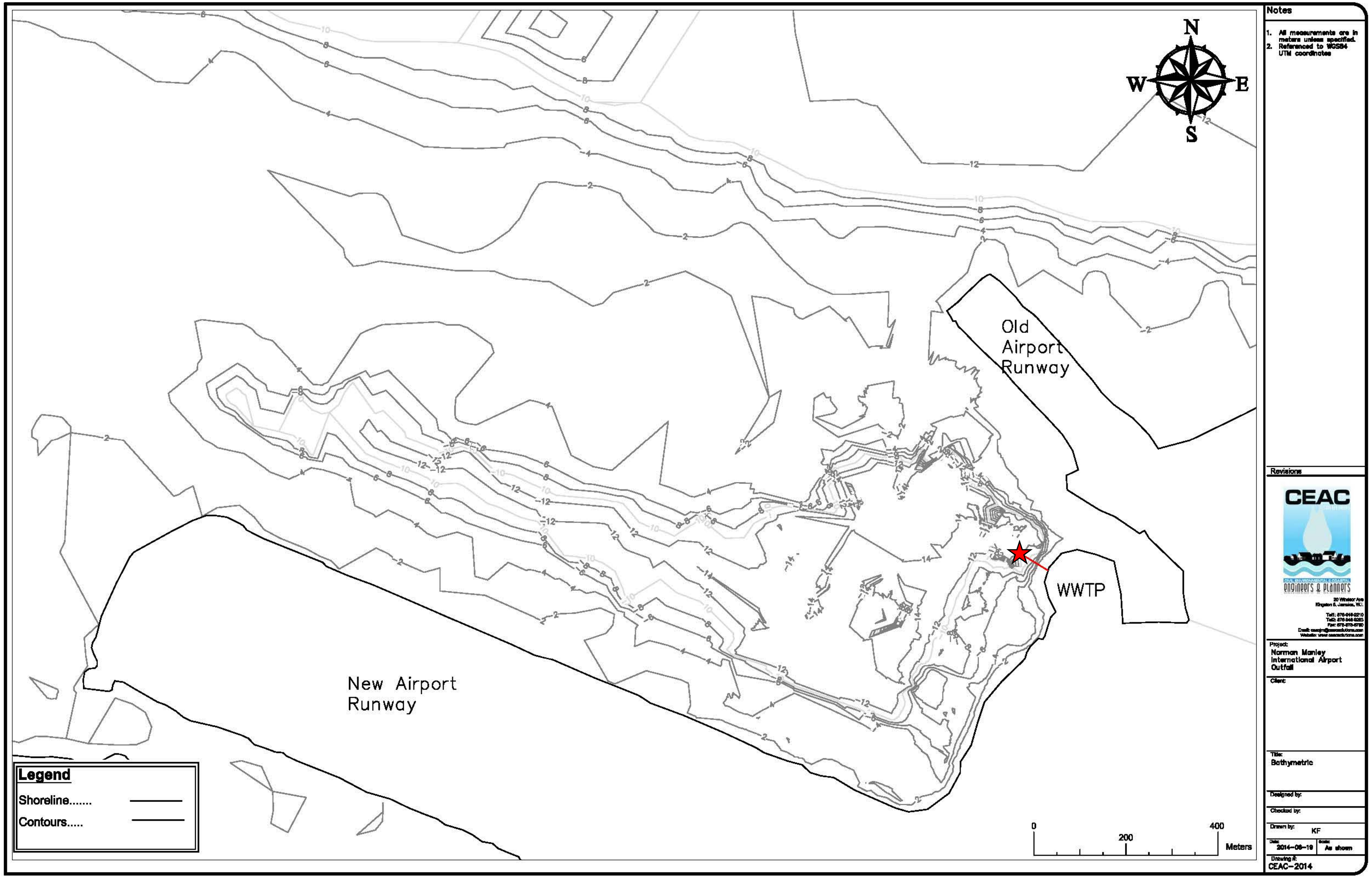


FIGURE 2-2. BATHYMETRIC SURVEY CONDUCTED ON JUNE 20TH, 2014 IN RELATION TO WWTP OUTFALL (HIGHLIGHTED WITH RED MARKER).

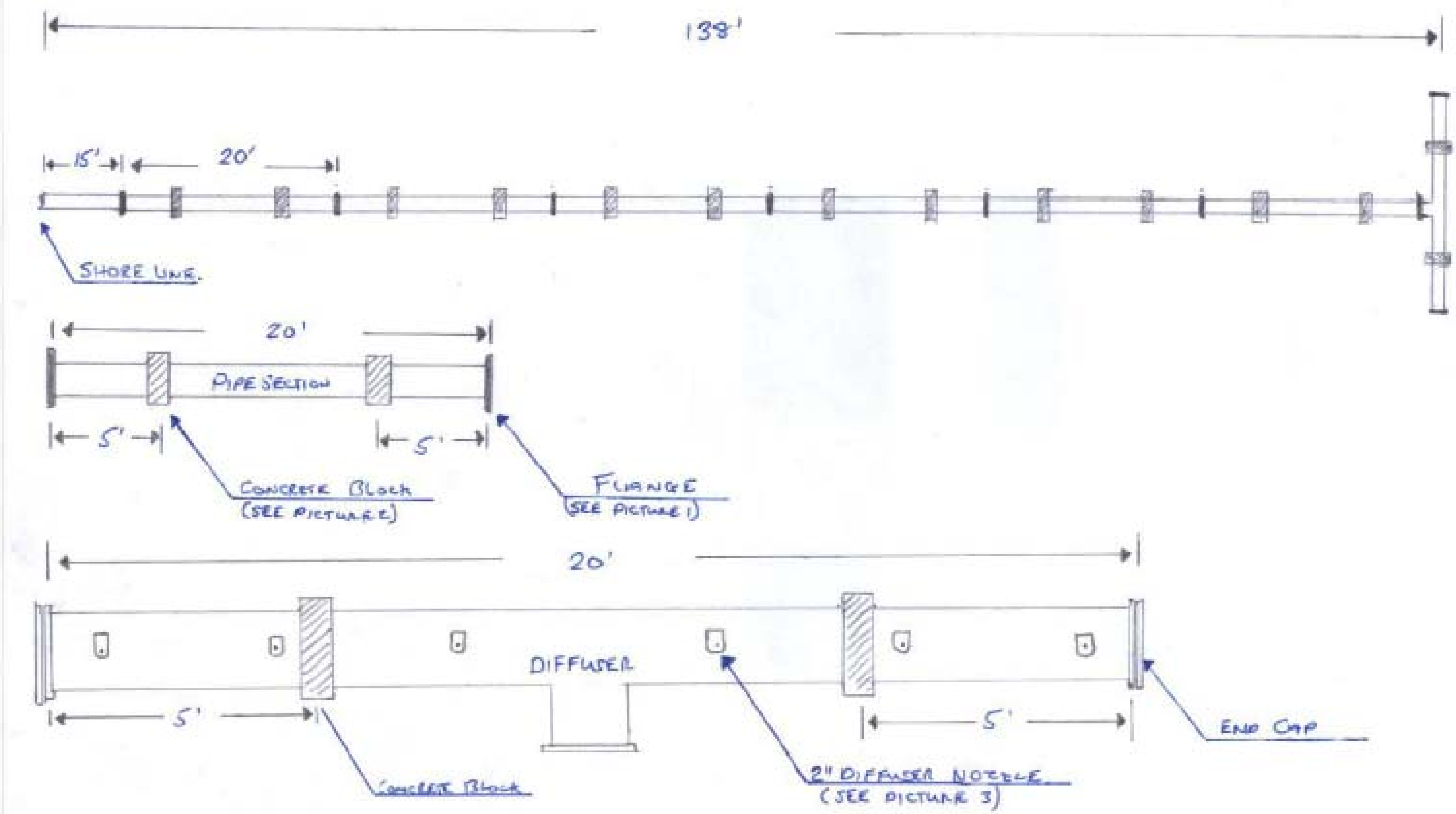


FIGURE 2-3. DETAILED SKETCH OF THE MARINE OUTFALL FOR THE NMIA WASTEWATER TREATMENT PLANT.

2.3 Currents

In order to facilitate the development of the hydrodynamic model for the area it was necessary to collect information on tides, winds and currents. This information will be acquired by carrying out four (4) drogue tracking missions and deploying an Acoustic Doppler Current Profiler (ADCP) on the sea floor for approximately one month. At this stage in the project two of the drogue tracking missions are complete, the remainder will be conducted during the dye tracer study, during the deployment of the ADCP, so as to verify the results from that analysis.

2.3.1 Drogue tracking

Drogue tracking information provides information on the water circulation pattern throughout the project area. Two sets of drogue tracking missions were executed on June 19 and 20, 2014, at the marine outfall and four (4) offshore locations (with depths ranging from 2 to 5 meters).

The GPS and drogue log sheet results from the drogue tracking missions were reduced and incorporated into a database. The data was then analyzed in order to determine current speed and directions, and current speed vectors were produced for the rising and falling tides below. This information is presented in the Appendices.

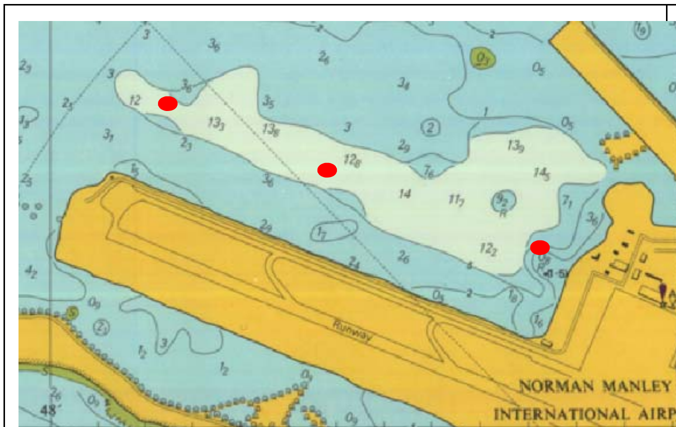


Plate 2.1. Drogues in the vicinity of the outfall and between the old and new NMIA runways (in red).

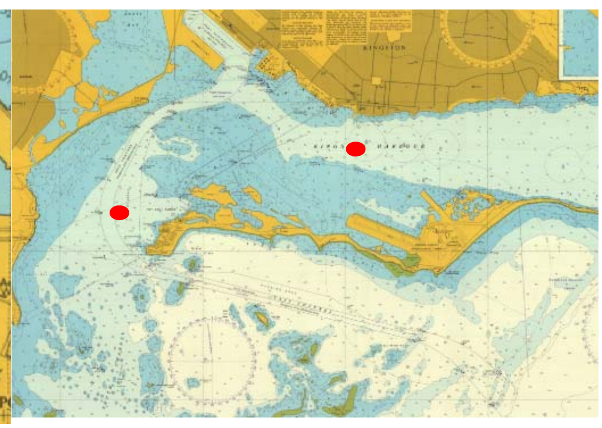


Plate 2.2. Drogues in the Kingston Harbour (in red).

2.3.2 Results and Discussion

2.3.2.1 Session 1 – Falling Tide

This morning session had five (5) sets of drogues located over the outfall area, between the new and old runway, in the middle of the Kingston Harbour and the mouth of the Caribbean Sea. During this session, the outfall surface and subsurface drogues were both observed to be moving in a north-westerly direction with average speeds of 4.67 cm/s and 4.71 cm/s respectively. The two (2) sets of drogues deployed between the new and old runways were both observed to be moving in a generally western direction with average surface and subsurface speeds of 7.27 cm/s and 6.49 cm/s respectively. The surface and subsurface drogues being tracked within the Kingston Harbour was documented to be moving in a western direction with speeds of 2.45 cm/s and 1.41 cm/s respectively. The surface drogue deployed at the mouth of the Caribbean Sea was observed to be moving in a westerly direction with a speed of 11.86 cm/s while the subsurface drogue moved in a north-westerly direction with a speed of 5.99 cm/s.

All surface and subsurface drogues were observed to travel in the direction of the wind, with the exception of one location within the old and new runway which was observed to be travelling perpendicular to the wind. Overall, the surface and subsurface currents appeared to be wind driven even though the wind speeds were of faster. One set of drogues deployed between the runways were determined to be tidally driven. Figure 6-1 (Appendix) shows a plot of the drogue tracking session.

2.3.2.2 Session 2 – Rising Tide

This evening session had five (5) sets of drogues located over the outfall area, between the new and old runway, in the middle of the Kingston Harbour and the mouth of the Caribbean Sea. During this session, the outfall surface and subsurface drogues were both observed to be moving in a north-westerly direction with average speeds of 4.93 cm/s and 3.85 cm/s respectively. The two (2) sets of drogues deployed between the new and old runways were both observed to be moving in a generally western and north-western direction with average surface and subsurface speeds of 11.47 cm/s and 5.27 cm/s respectively. The surface and subsurface drogues being tracked within the Kingston Harbour was documented to be moving in a western and north-western direction with speeds of 7.83 cm/s and 0.26 cm/s respectively. The surface drogue deployed at the mouth of the Caribbean Sea was observed to be moving in a southern direction with a speed of 8.25 cm/s while the subsurface drogue moved in a north-easterly direction with a speed of 13.08 cm/s.

All surface and subsurface drogues were observed to travel in the direction of the wind, with the exception of those deployed within the mouth of the Caribbean Sea, which was observed to be travelling perpendicular to the wind. Overall, most of the surface and subsurface drogues appeared to be wind driven even though the wind speeds were of faster. The drogues deployed at the mouth of the Caribbean Sea were determined to be tidally driven. Figure 6-2 (Appendix) shows a plot of the drogue tracking session.

2.3.2.3 Session 3 – Falling Tide

This morning session had four (4) sets of drogues located over the outfall area, between the new and old runway, in the middle of the Kingston Harbour and the mouth of the Caribbean Sea. During this session, the outfall surface and subsurface drogues were both observed to be moving in a north-westerly direction with average speeds of 9.24 cm/s and 8.64 cm/s respectively. The drogues deployed between the new and old runways were observed to be moving in a generally north-western direction with average surface and subsurface speeds of 17.01 cm/s and 19.08 cm/s respectively. The surface and subsurface drogues being tracked within the Kingston Harbour was documented to be moving in a north-western direction with speeds of 11.08 cm/s and 9.32 cm/s respectively. The surface drogue deployed at the mouth of the Caribbean Sea was observed to be moving in a south-western direction with a speed of 16.57 cm/s while the subsurface drogue moved in a westerly direction with a speed of 7.21 cm/s.

All surface and subsurface drogues were observed to travel in the direction of the wind, with the exception of those deployed within the mouth of the Caribbean Sea, which was observed to be travelling perpendicular to the wind. Overall, most of the surface and subsurface drogues appeared to be wind driven. The drogues deployed at the mouth of the Caribbean Sea were determined to be tidally driven. Figure 6-3 (Appendix) shows a plot of the drogue tracking session.

2.3.2.4 Session 4 – Rising Tide

This evening session had three (3) sets of drogues located over the outfall area, between the new and old runway and the mouth of the Caribbean Sea. During this session, the outfall surface drogue was observed to be moving in a north-westerly direction with average speeds of 5.67 cm/s while the sub-surface drogue was moving north with a speed of 4.70 cm/s. The surface and sub-surface drogues deployed between the new and old runways were both observed to be moving in a generally north-western and eastern direction with speeds of 10.43 cm/s and 7.05 cm/s respectively. The surface and sub-surface drogues deployed at the mouth of the Caribbean Sea were both observed to be moving in a north-western direction with speeds of 22.61 cm/s and 22.60 cm/s.

All surface and subsurface drogues were observed to travel in the direction of the wind, with the exception of the sub-surface drogue deployed between the runways, which was observed to be travelling perpendicular to the wind. Overall, most of the surface and subsurface drogues appeared to be wind driven. Figure 6-4 (Appendix) shows a plot of the drogue tracking session.

2.4 Water Quality Survey (CTD)

2.4.1 Survey Method

CTD profiling was used to measure salinity, temperature, and dissolved oxygen at different water depths. This survey was done during the two drogue tracking missions by presetting station locations and collecting data at the locations. The water quality data were collected in – situ by using a Hydro Lab (multi – probe system). Temperature reading was taken at the surface, 1m, 2m and 4m below the surface. The readings were taken with the rising and falling session of each day. The data was then analyzed and the temperatures plotted. See the appendices for a graphical comparison of both surface and sub-surface plots within falling and rising tides.

2.4.2 Results and Discussions

2.4.2.1 Temperature

Temperature plots from the survey revealed that cooler water is coming from the diffusers. This occurs during both the rising and falling tides with the temperatures being higher at the surface. The temperatures for the surface and sub-surface waters varied between 28 and 29°C and between 25 and 27°C respectively. These temperatures were recorded near the outfall.

2.4.2.2 Salinity

As expected, the salinity plots revealed that freshwater is coming from the treatment plant. This water moves in a south westerly direction during the falling tide sessions, while during the rising tide it is concentrated around the outfall. Salinity concentrations at the surface varied between 36 and 37ppt, while at the sub-surface it varied between 33 and 35ppt.

2.4.2.3 Dissolved Oxygen (DO)

Lower concentrations of DO were observed in the vicinity of the outfall. The reason for this is that the effluent from the treatment plant contains BOD (which are organisms), that consume oxygen from the surrounding water in the form of DO. As you move further offshore the concentration of DO within the water increases. Surface concentrations were 5 mg/L, while sub-surface concentrations were between 4.8 – 5.1 mg/L.

3 Outfall Diffuser Modeling

3.1 Approach and Basis

A diffuser is the most seaward end of an outfall consisting of relatively small holes in various configurations. The purpose of a diffuser is to increase the dilution by increasing entrainment into the ambient fluid (seawater in this case). The NMIAL treatment plant comprises of a 200mm diameter HDPE pipe, 42 meters long, discharging via a multiport diffuser with six (6) 2" openings, into the Kingston Harbour. This system will be modeled to see how well it performs. The approach will entail both near-field and far-field dilution modeling. Near-field dilution will be done with an initial and entrainment dilution model and far-field with a 3-dimensional hydrodynamic model. The approach will take into consideration:

- Expected effluent flows
- Ambient current speeds and direction
- Effluent temperature
- Effluent dilution

The performance of the outfall is characterized by its ability to meet NEPA guidelines for trade effluent discharge. The guideline for thermal discharge states that temperature increases of up to 2^{o}C above ambient is allowed within a 100m radius from the point of discharge. The efficiency of the effluent dilution is essential in ensuring that the NEPA guidelines are met.

3.2 Model and Data

3.2.1 Effluent Fluid Parameters

These parameters were determined from historical data received from the NMIAL. The parameters included the concentration of the effluent, temperature and daily flow, and they are summarized in Table 3-1.

Table 3-1. Effluent water quality parameters.

Parameter	Value
Existing Flow Rate (m^3/ d)	500
Temperature (^{o}C)	26
Phosphate concentration (mg/L)	5.74
Salinity (ppt)	0

3.2.2 Ambient Fluid Properties

3.2.2.1 Water Quality

Background information on the water quality of the Kingston Harbour was provided by CL Environmental and used to determine the performance of the outfall. See Table 3-2 for a comparison of the results with the NEPA standards for marine outfalls. The background condition of the harbour will be used as the ambient water quality in the modeling analysis to be completed.

Table 3-2. Background water quality for the Kingston Harbour obtained from a monthly environmental monitoring program carried out between September 2010 and December 2012.

	Phosphate (mg/L)	Nitrates (mg/L)	Fecal Coliform (MPN/ 100ml)	BOD (mg/L)
Average	0.066	0.963	88.84	8.30
NEPA	0.003	0.014	13	1.16

The CTD study conducted also revealed other important parameters for the ambient water; namely a:

- Temperature of 28 °C, and
- Salinity of 37ppt.

3.2.2.2 Vertical Current Structure

The vertical current structure was deduced by analyzing the current and wind climate obtained from the drogue tracking missions. The currents were analyzed, and the prevailing current speeds and directions determined. The results were then separated into 3 conditions: slow, average and fast. A summary of these results are presented in Table 3-3.

Table 3-3. Current profiles used in the outfall modeling exercise.

Condition	Slow		Average		Fast	
	Average current speed (cm/s)	Average current direction (n-degrees)	Average current speed (cm/s)	Average current direction (n-degrees)	Average current speed (cm/s)	Average current direction (n-degrees)
Surface (0.1m)	4	291	10	304	17	300
Sub-surface (2m)	4	296	8	318	19	297
Sea floor (7m)	0.001	296	0.001	318	0.001	297

3.2.3 Description of CORMIX

CORMIX is a US Environmental Protection Agency (USEPA) supported mixing zone model and decision making support system for environmental impact assessment of regulatory mixing zones resulting from continuous point source discharges. The system emphasizes the role of boundary interaction to predict steady-state mixing behavior and plume geometry.

The CORMIX methodology contains systems to model single-port, multiport diffuser discharges and surface discharge sources. Effluents considered may be conservative, non-conservative, heated, brine discharges or contain suspended sediments.

3.2.3.1 INPUT SPECIFICATIONS FOR SCENARIOS

The model we explored was the UM3 model within CORMIX. The model required data input to define the diffuser configuration as well as the ambient and effluent fluid properties. The diffuser configuration includes port size, direction of port, number of ports and port spacing. The ambient fluid properties required include current speed and direction as well as ambient water temperature.

3.3 RESULTS OF THE NEAR-FIELD SCENARIO MODELING

3.3.1 EXISTING OPERATIONAL CONDITIONS

The model was run for the slow, average and fast operational conditions as presented in Section 26 Vertical Current Structure for the existing treatment plant flow of 500 m^3/d. It was also fun for the worst case oceanographic condition, that is, when there is a slack tide (no currents). This occurs at the turn of the tide when there is relatively still water.

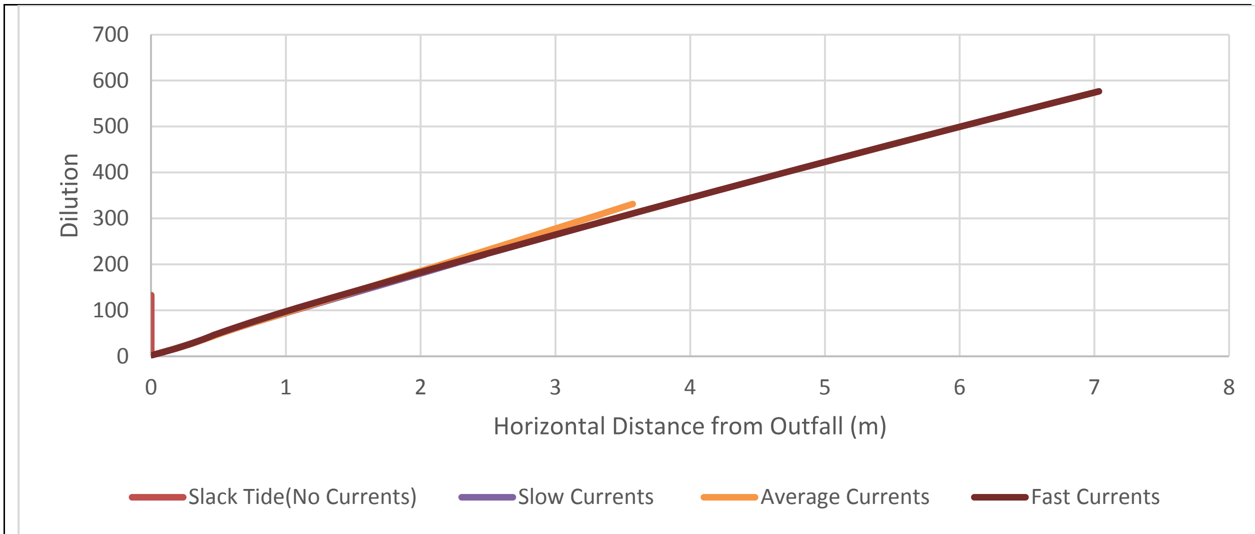
It was revealed that during the operational conditions the effluent plume reaches the surface between 2.5 and 7 meters from the outfall (horizontal distance). The effluent concentration is also diluted by between 222 and 577 during these conditions. See Table 3-4 and Table 3-5. The horizontal distance at which the effluent concentration blends into the ambient background and is undetectable is between 2.8 and 20 meters from the outfall; the corresponding effluent concentration ranges from 236 and 250.

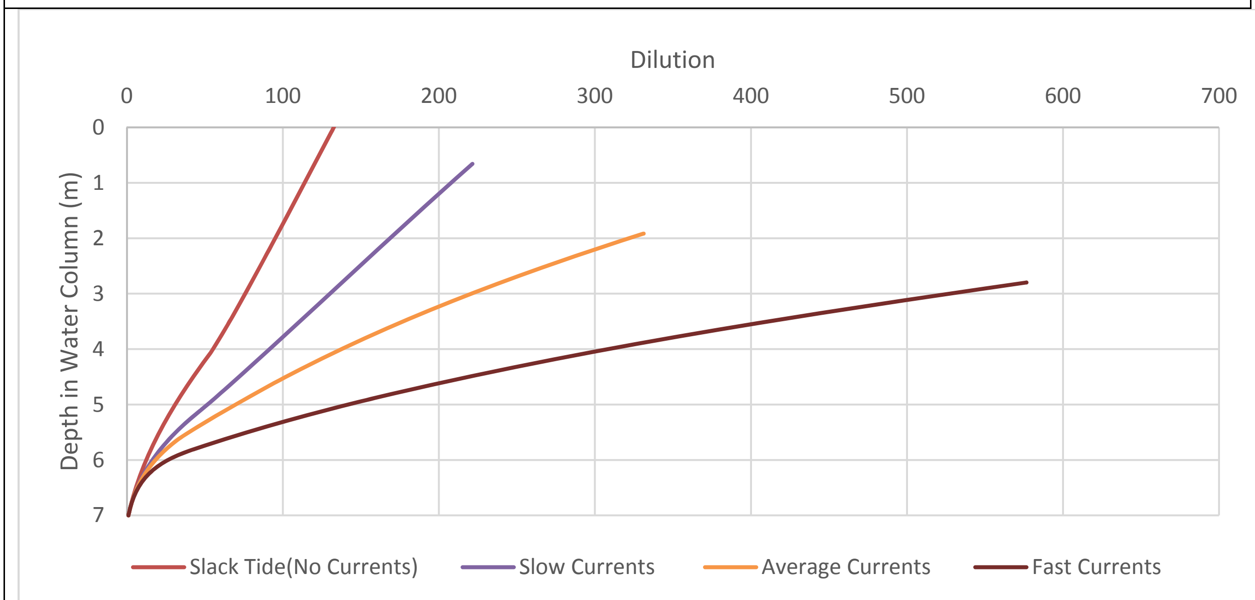
The worst case scenario of no current conditions was modeled and referred to as the Slack Tide condition. The results show a dilution of 133 at the surface at the outfall. It was also revealed that the effluent concentration is undetectable 100 meters from the outfall with a dilution of 252. See Table 3-4 and Table 3-5.

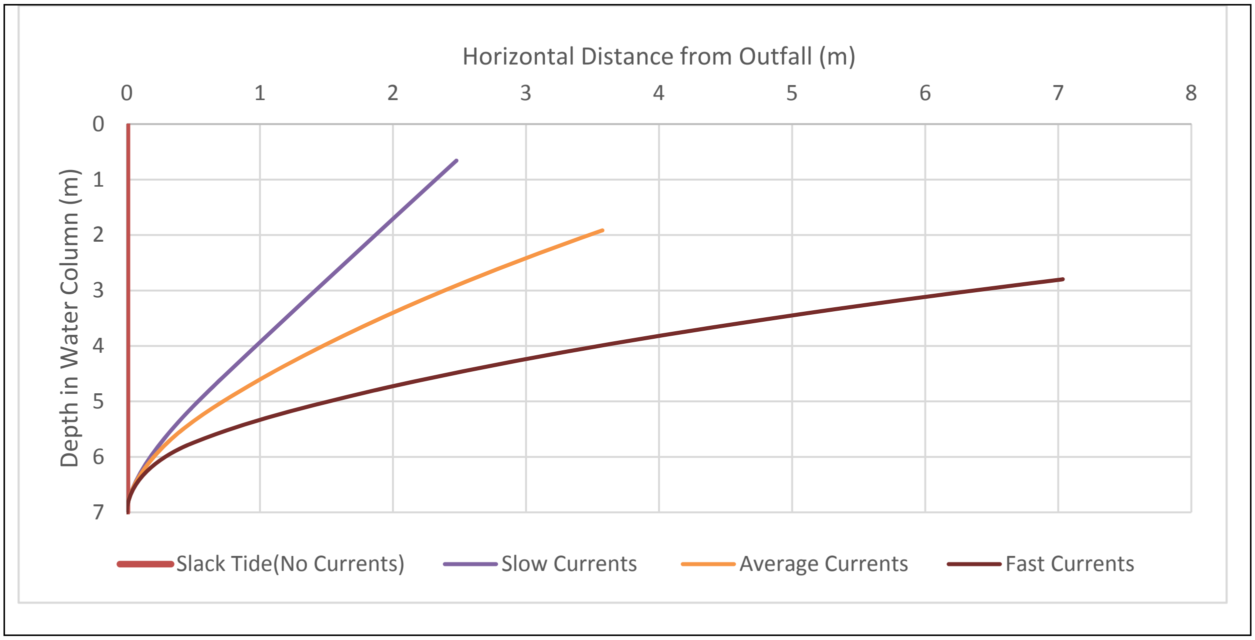
TABLE 3-4. PLUME MODEL RESULTS FOR THE AVERAGE OPERATIONAL CONDITIONS (SLOW, AVERAGE AND FAST CURRENTS) AND FOR THE WORST CASE OCEANOGRAPHIC CONDITIONS (DURING SLACK TIDE).

	Operational Conditions	Dilution	Horizontal dist. From source (m)
At Surface	Slack Tide (No currents)	133	0
	Slow Current	222	2.5
	Average Current	331	3.6
	Fast Current	577	7
At which the effluent concentration is undetectable	Slack Tide (No currents)	252	100
	Slow Current	236	20
	Average Current	217	2.4
	Fast Current	250	2.8

Table 3-5. Summary of UM3 model output for the multiport diffuser system at the NMIAL WWTP, comprising of dilution, horizontal distance from the outfall and depth in the water column 500 m^3/d flow conditions.







3.3.2 Future Operational Conditions

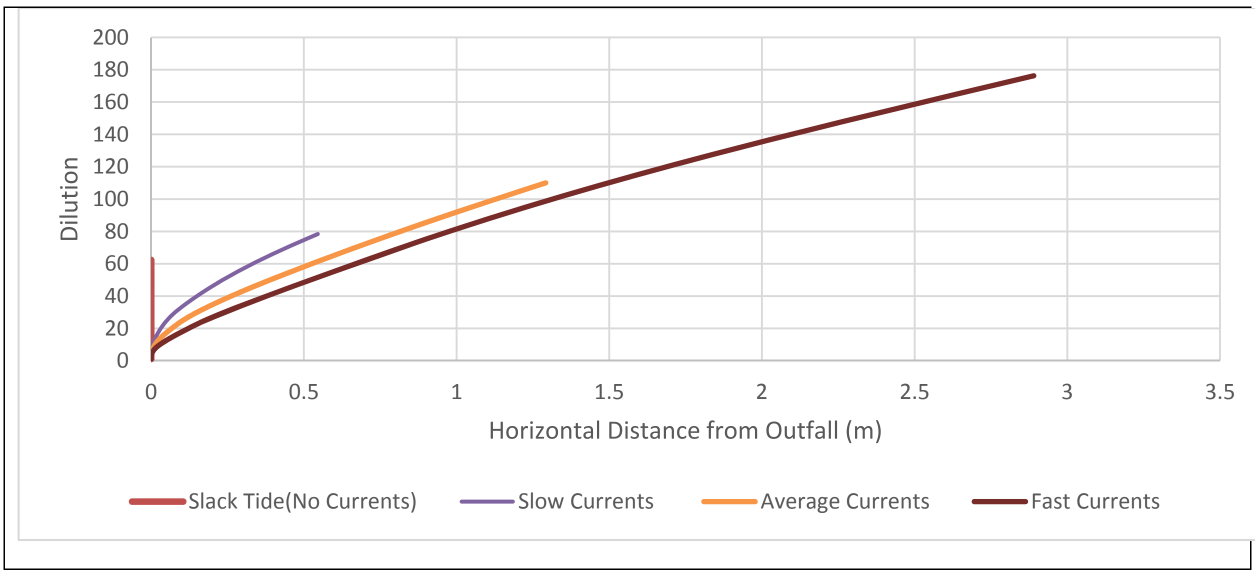
The operational conditions associated with the treatment plant's rated flow of 1746 m^3/ d were also modeled. It was revealed that during the operational conditions the effluent plume reaches the surface between 0.5 and 2.9 meters from the outfall (horizontal distance). The effluent concentration is also diluted by between 78 and 176 during these conditions. See Table 3-6 and Table 3-7. The horizontal distance at which the effluent concentration blends into the ambient background and is undetectable is between 80 and 480 meters from the outfall; the corresponding effluent concentration ranges from 248 and 260.

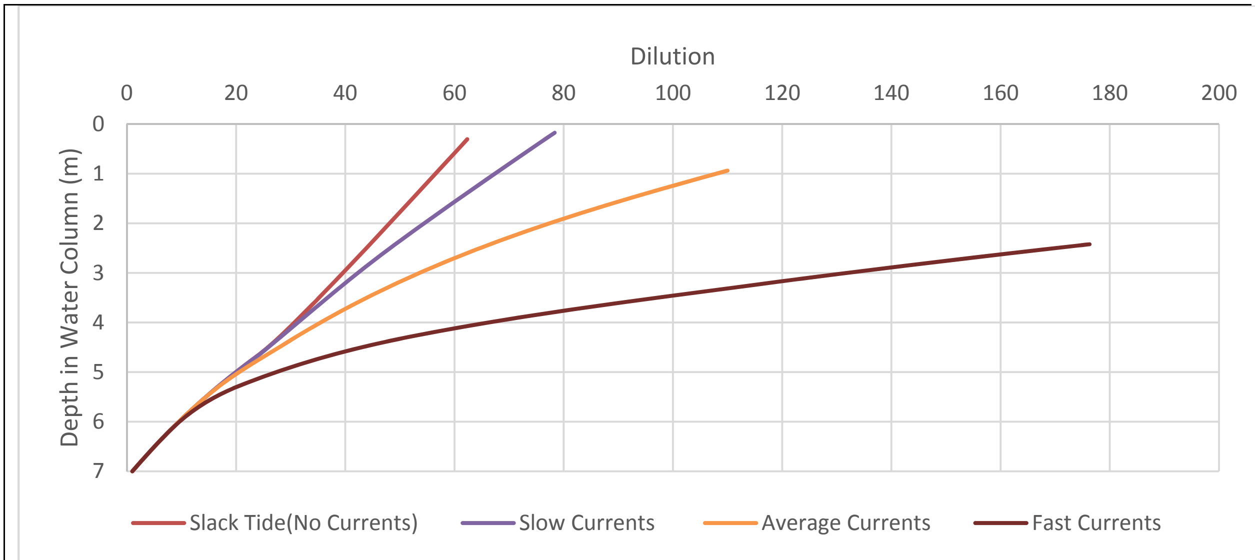
The worst case scenario of no current conditions was modeled and the results show a dilution of 62 at the surface at the outfall. It was also revealed that the effluent concentration is undetectable 480 meters from the outfall with a dilution of 251. See Table 3-6 and Table 3-7.

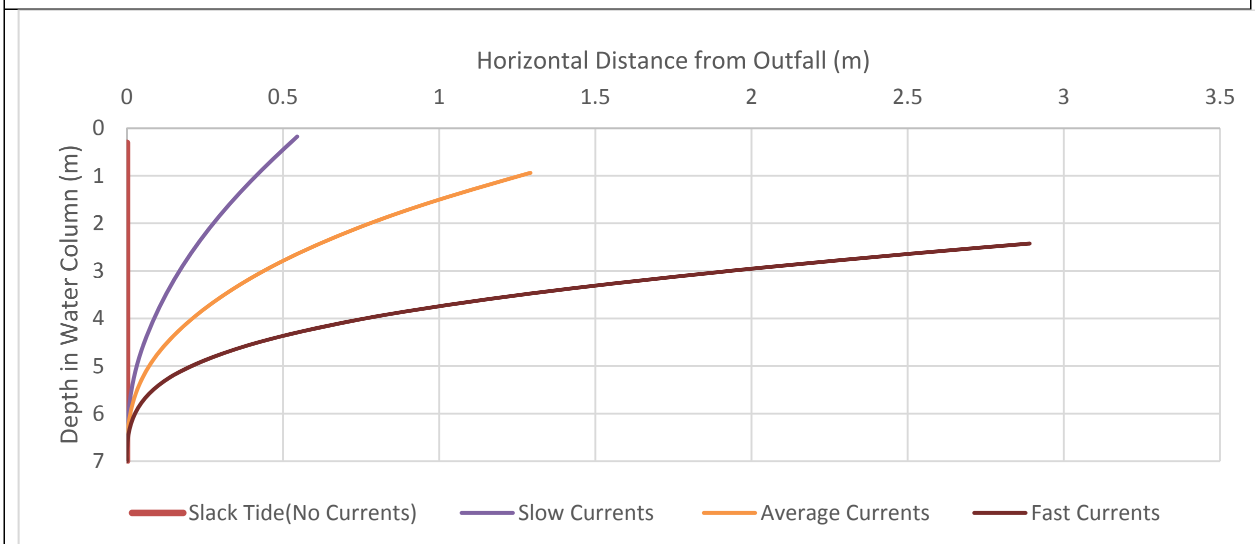
TABLE 3-6. PLUME MODEL RESULTS FOR THE AVERAGE OPERATIONAL CONDITIONS (SLOW, AVERAGE AND FAST CURRENTS) AND FOR THE WORST CASE OCEANOGRAPHIC CONDITIONS (DURING SLACK TIDE).

	Operational Conditions	Dilution	Horizontal dist. From source (m)
At Surface	Slack Tide (No currents)	62	0
	Slow Current	78	0.5
	Average Current	110	1.3
	Fast Current	176	2.8
At which the effluent concentration is undetectable	Slack Tide (No currents)	251	480
	Slow Current	248	340
	Average Current	241	180
	Fast Current	260	80

TABLE 3-7. SUMMARY OF UM3 MODEL OUTPUT FOR THE MULTIPORT DIFFUSER SYSTEM AT THE NMIAL WWTP, COMPRISING OF DILUTION, HORIZONTAL DISTANCE FROM THE OUTFALL AND DEPTH IN THE WATER COLUMN UNDER 1746 M^3/D FLOW CONDITIONS.




Dilution
0
20
40
60
80
100
120
140
160
180
200
Depth in Water Column (m)
0
1
2
3
4
5
6
7
Slack Tide(No Currents)
Slow Currents
Average Currents
Fast Currents


Horizontal Distance from Outfall (m)
0
0.5
1
1.5
2
2.5
3
3.5
Depth in Water Column (m)
0
1
2
3
4
5
6
7
Slack Tide(No Currents)
Slow Currents
Average Currents
Fast Currents

4 HYDRODYNAMIC MODELING (FAR FIELD)

4.1 INTRODUCTION

The current regime (i.e. patterns and speeds) in the coastal setting determines the ability of an area to flush and maintain sufficiently good water quality. Currents are generated by winds, tides and waves:

- **Tides** – Rising tides will cause water to enter the harbour and a portion will leave on the falling tide that follows. This will result in some exchange of water between the outside and inside of our project area. This result is dependent on the ratio of the water entering to the water leaving; this ratio is dependent on the tide, range, hydraulic efficiency of the entrance, and the water internal depths.
- **Wind** – Wind action over the water surface will generate a surface current that will essentially be in the direction of the wind. This wind generated current will be a few degrees to the right of the wind, (in the northern hemisphere), owing to the Coriolis effect, (Bowden, 1983). If the fetch and duration are sufficient, the surface current speeds may approach 2 – 3% of the wind speeds.

Circulation patterns can be predicted by numerical, physical models or field studies. Numerical models are most often used as it simply requires the collection of field data to calibrate and verify the model for use in a predictive mode. The models are also robust enough to include prediction of sediments and nutrients dispersion in the Bay.

4.1.1 OBJECTIVES AND APPROACH

The objective of this analysis is to characterize the existing hydrodynamic regime in the area so as to describe the surface current patterns on which the surfaced buoyant plume moves. The hydrodynamic model facilitates the detailed far-field dilution modeling. The model used for this purpose was RMA10.

4.2 DESCRIPTION OF MODELS

Investigation of currents was undertaken using RMA10. It utilizes bathymetric information on the project area and driving forces from tides and winds to solve the 3-dimensional flow equations. This model is calibrated on the observations of currents through the project area from drogues and the moored ADCP. The sediment plume models were generated using RMA11. RMA11 is a finite element water quality model for simulation of three-dimensional estuaries, bays, lakes and rivers. It is also capable of simulating one and two dimensional approximations to systems either separately or in combined form. It is designed to accept input of velocities and depths, either from an ASCII data file or from binary results files produced by the two-dimensional hydrodynamic model, RMA2, or the three-dimensional stratified flow model, RMA10. Results in the form of velocities and depth from the hydrodynamic models are used in the solution of the advection diffusion constituent transport equations

4.2.1 RMA 10

RMA-10 is a three-dimensional finite element model for stratified flow by King (1993). The primary features of RMA-10 are:

- The solution of the Navier-Stokes equations in three-dimensions;
- The use of the shallow-water and hydrostatic assumptions;
- Coupling of advection and diffusion of temperature, salinity and sediment to the hydrodynamics;
- The inclusion of turbulence in Reynolds stress form;
- Horizontal components of the non-linear terms are included;
- A capacity to include one-dimensional, depth-averaged, laterally-averaged and three-dimensional elements within a single mesh as appropriate;
- No-, partial- and full-slip conditions can be applied at both lateral boundaries;
- Partial or no-slip conditions can be applied at the bed;
- Depth-averaged elements can be made wet and dry during a simulation; and
- Vertical turbulence quantities are estimated by either a quadratic parameterization of turbulent exchange or a Mellor-Yamada Level 2 turbulence sub-model.

4.2.2 RMA 11

The RMA 11 sediment transport model by (King & Rachiele, Multi-dimensional modeling of hydrodynamics and salinity in San Francisco Bay, 1989) (King & DeGeorge, Multi Dimensional Modeling of Water Quality Using the Finite Element Method, 1995) is a three dimensional finite element model that can also function as a two dimensional depth averaged model. The primary features of RMA11 are as follows.

- RMA11 shares many of the same capabilities of the RMA2/RMA10 hydrodynamics models including irregular boundary configurations, variable element size, one-dimensional elements, and the wetting and drying of shallow portions of the modeled region.
- RMA11 may be executed in steady-state or dynamic mode. The velocities supplied may be constant or interpolated from an input file (This may be RMA2 or RMA10 output).
- Source pollutants loads may be input to the system either at discrete points, over elements, or as fixed boundary values.
- In formulating the element equations, the element coordinate system is realigned with the local flow direction. This permits the longitudinal and transverse diffusion terms to be separated, with the net effect being to limit excessive constituent dispersion in the direction transverse to flow.
- For increased computational efficiency, up to fifteen constituents may be modeled at one time, each with separately defined loading, decay and initial conditions.
- The model may be used to simulate temperature with full heat exchange with the atmosphere, nitrogen and phosphorous nutrient cycles, BOD-DO, algae, cohesive or non-cohesive suspended sediments and other non-conservative constituents.

- A multi-layer bed model for the cohesive sediment transport constituent keeps track of thickness and consolidation of each layer.

4.3 Finite Element Mesh Development

The process of mesh development entails the following steps:

- Input of bathymetric data for the wider area and in detail for the project area;
- Specifying of nodes in the mesh;
- Element construction in the mesh;
- Interpolation for depths at nodes;
- Specifying open boundaries.

The mesh constructed for the calibration and existing configuration extended some 9.3 km westerly and 6.2 km in an easterly direction (see Figure 4-1). The outer deep waters were gridded with large mesh sizes that gradually decreases (greater detail) as you approach the project area. The western boundary was used as the only open boundary on which tides were applied.

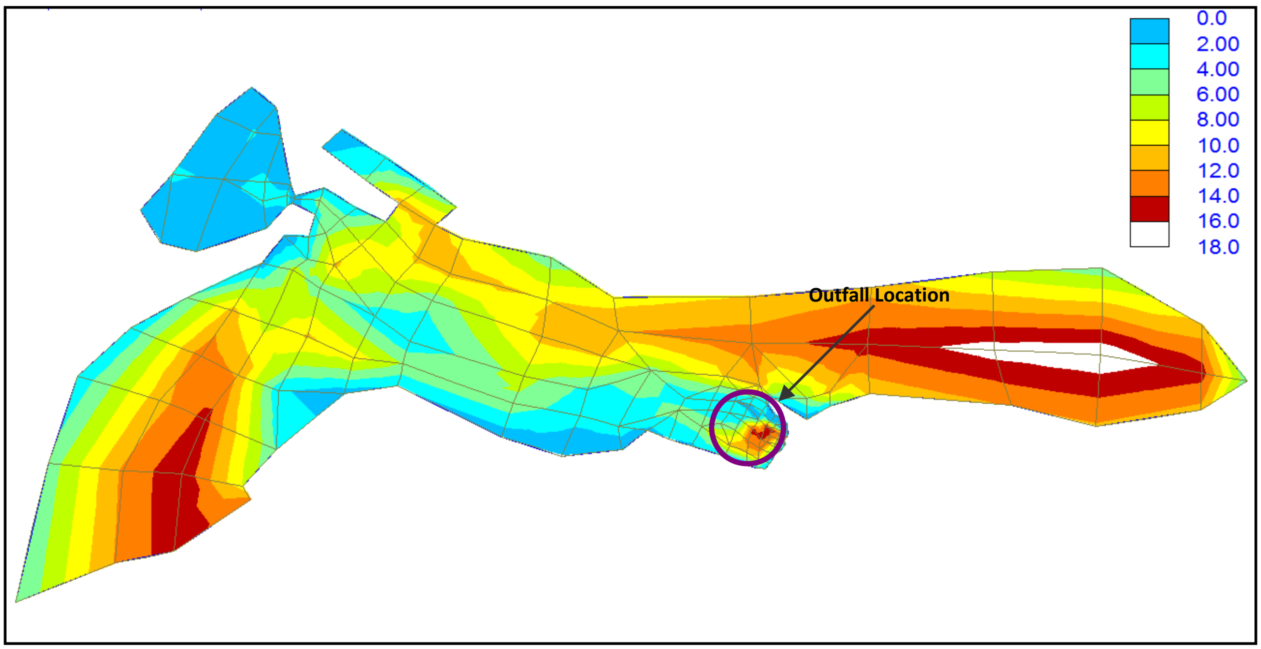


Figure 4-1 Overview of entire Finite Element Mesh (FEM) used for the project showing the depth in meters

4.4 Calibration

The model was calibrated by adjusting the tide elevation signal on the model boundaries, turbulence and viscosity parameters, until there was reasonable agreement between the observed currents and model predictions. Predicted current speeds and directions and drogue tracking sessions' data are summarized in Table 4-1. The model predictions were within the data ranges for the observed occurrences in most instances. Of the four (4) calibration sessions, all showed a positive correlation ranging between 89 to 100%. This indicates that there exists a direct positive relationship between the variations of the values at different points during those sessions with the predicted currents generally similar in direction and magnitude to the drogues.

The calibration data essentially indicates that there is reasonable agreement between the model and the data (observations).

TABLE 4-1 CALIBRATION DATA FOR FEM FOR THE EXISTING BATHYMETRIC CONFIGURATION BASED ON DROGUE AND WIND DATA FOR THE DROGUE TRACKING MISSIONS CARRIED OUT IN JUNE 2014.

Date	Session	Location	Observations		Model Predictions		Correlation
			Speed (m/s)	Direction	Speed (m/s)	Direction	Speed (m/s)
June 19th, 2014	1 - Falling	Nearshore	0.047	W	0.03	SW	1.00
		Offshore	0.025	W	0.02	W	
		Deepwater	0.119	W	0.09	NW	
June 19th, 2014	2 - Rising	Nearshore	0.049	NW	0.04	NW	0.93
		Offshore	0.078	W	0.06	NW	
		Deepwater	0.083	S	0.08	NE	
June 20th, 2014	3 - Falling	Nearshore	0.092	NW	0.06	NW	0.89
		Offshore	0.111	NW	0.1	NW	
		Deepwater	0.166	SW	0.12	NE	
June 20th, 2014	4 - Rising	Nearshore	0.057	NW	0.06	NW	1.00
		Offshore	0.104	NE	0.08	NW	
		Deepwater	0.226	NW	0.13	NW	

The model was considered suitable for analyzing the design conditions that would be experienced in the bay. The calibration parameters were kept constant and carried forward for extensive hydrodynamic model runs and then far-field dispersion modeling.

4.5 RESULTS OF CURRENT PREDICTIONS

4.5.1 APPROACH

The current speeds were investigated for different wind speeds and directions given their impacts on currents in the Kingston Harbour. The wind directions and speeds investigated were from the more predominant south-eastern direction. The speeds and directions used are summarized in Table 4-2.

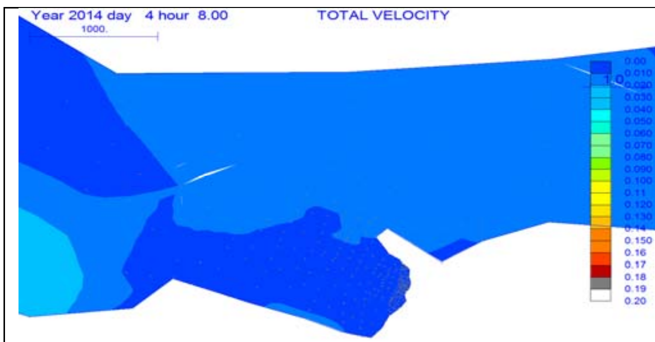
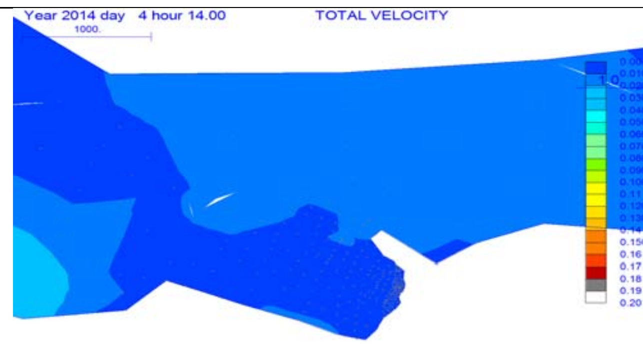
TABLE 4-2 SUMMARY OF WIND SPEEDS AND DIRECTIONS INVESTIGATED

Conditions	Speed (m/s)	Direction
Slow	3.0	South-Easterly
Average	9.5	South-Easterly
Fast	12	South-Easterly

4.5.2 SLOW WIND CONDITIONS

Surface current predictions for the slow wind speed meteorological conditions for the existing shoreline configuration indicated that current velocities below 2 cm/s can be expected within the bay (between old and new runway). The current directions are predominantly westerly during the falling tide which indicates the surface currents are wind driven during periods when the tidal currents are not very active.

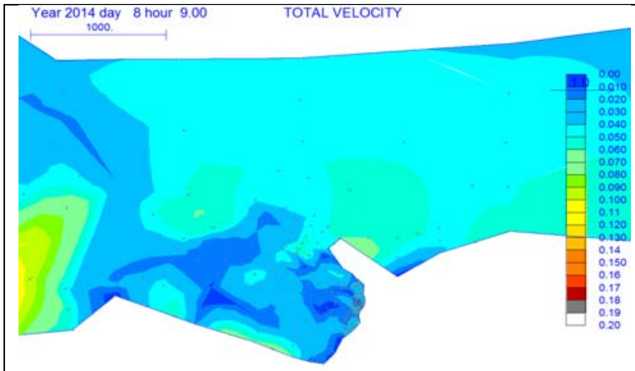
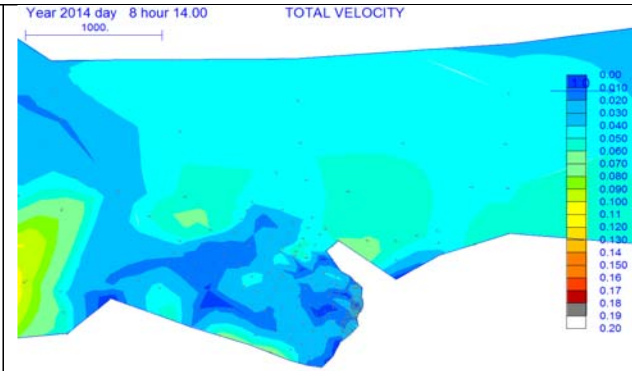
TABLE 4-3 PREDICTIONS FOR CURRENT SPEEDS IN RISING AND FALLING TIDE UNDER SLOW WIND CONDITIONS (CURRENT SPEEDS LESS THAN 2 CM/S)

 FALLING TIDE	 RISING TIDE

4.5.3 AVERAGE WIND CONDITIONS

Surface current predictions for the average wind speed meteorological conditions for the existing shoreline configuration indicate that current velocities of up to 8 cm/s for rising and falling tides within the bay (see Table 4-4). The current directions are predominantly towards the north-west indicating that the surface currents are predominantly wind driven.

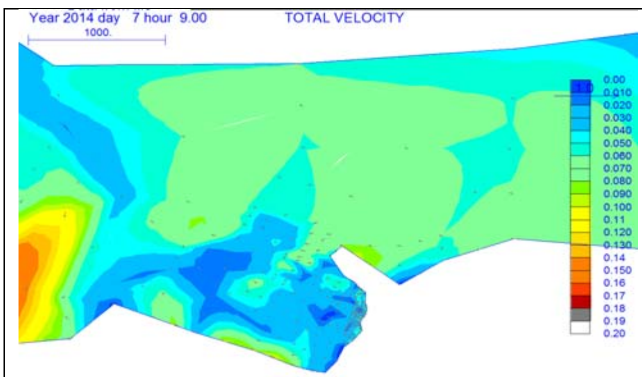
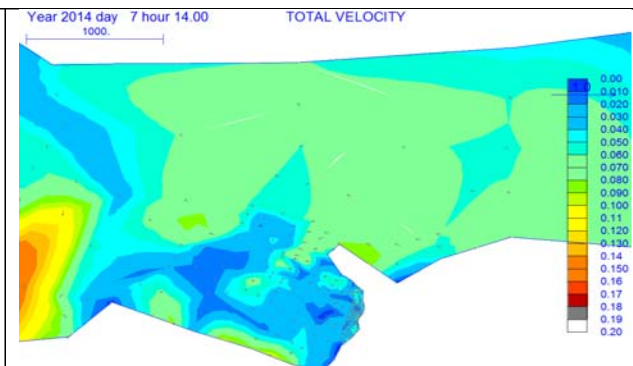
TABLE 4-4 PREDICTIONS FOR CURRENT SPEEDS IN RISING AND FALLING TIDE UNDER AVERAGE WIND CONDITIONS (CURRENT SPEEDS LESS THAN 8 CM/S)

 FALLING TIDE	 RISING TIDE

4.5.4 FAST WIND CONDITIONS

Surface current predictions for the average wind speed meteorological conditions for the existing shoreline configuration indicate that current velocities up to 10cm/s for falling and rising tides could occur in sections of the bay (see Table 4-5). Current speeds close to the project site (outfall) are, however, expected to remain below 5 cm/s with a general north-westerly direction. The currents during these periods are driven primarily by the fast winds. It should be noted that these conditions are expected to occur less than five (5) to ten (10) percent of the time.

TABLE 4-5 PREDICTIONS FOR CURRENT SPEEDS IN RISING AND FALLING TIDE UNDER FAST WIND CONDITIONS (CURRENT SPEEDS GREATER THAN 10 CM/S)

 FALLING TIDE	 RISING TIDE

4.6 RESULTS OF FAR-FIELD EFFLUENT DISPERSION MODELING

The results obtained from the outfall diffuser modeling (near-field) was used as a basis for input within the RMA-11 (far-field) dispersion model. This entailed determining the dilution factor of the sewage effluent (plume) at the water surface, where the diluted concentration of the effluent parameters can then be calculated and compared to the ambient as well as the national concentration standards (NEPA).

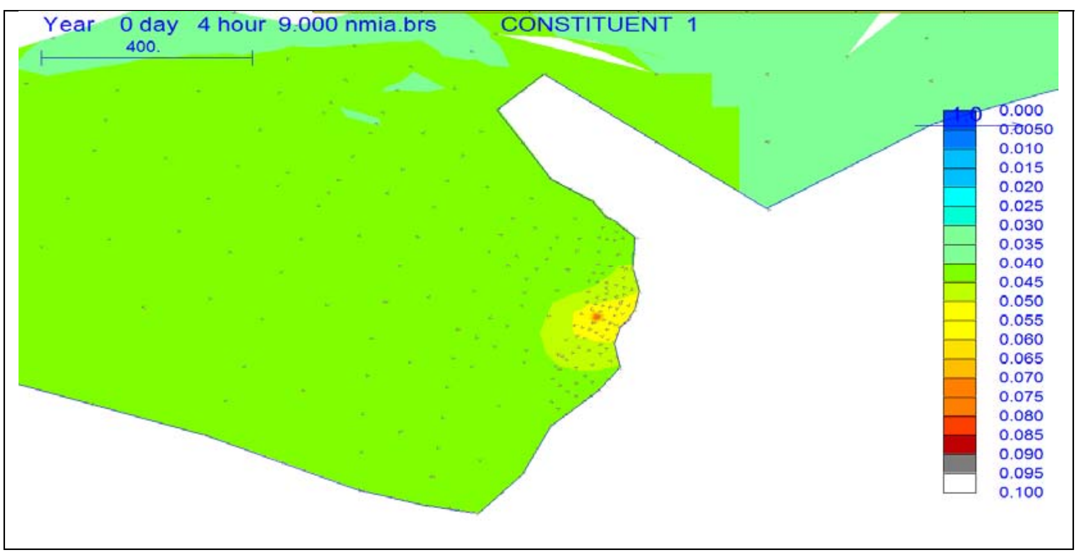
The scenarios simulated within RMA-11 were modelled based on slow, average and fast wind conditions. An initial concentration of 0.668 mg/L was implemented within the model which represented the parameter Phosphate (PO_3). Phosphate was selected due to it requiring the most dilution based on the water quality sampled within the harbour. The results are discussed in the following sections.

4.6.1 SLOW WIND CONDITIONS

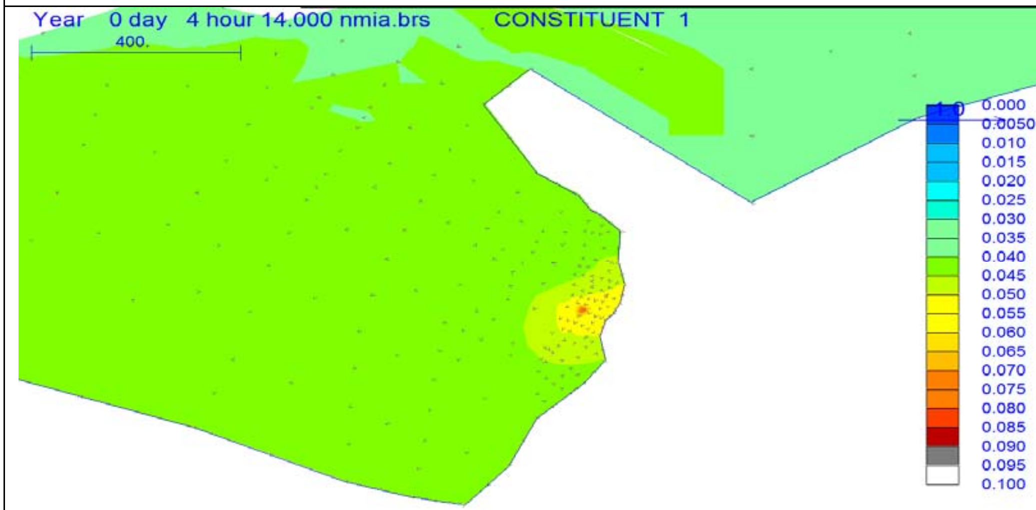
During slow wind conditions the temperature of the water in the mixing zone (or 100m radius) will rise to 27.6 °C in comparison to the ambient temperature of 28°C. The heating of the effluent discharge will take longer as the movement of currents driven by wind are slower and facilitates less mixing (effluent concentration is 26°C). This will cause a fairly small area of slightly decreased temperature (less than 0.5 °C below ambient).

It was determined that under slow wind conditions a dilution factor of 78.3 can be expected based on the results of the near-field outfall modeling. A conservative dilution factor of 20 (includes a safety factor of 3) was input in the RMA-11 model. The resulting far-field dispersion resulted in a plume extending approximately 250 meters in a north-south direction and 175 meters in an east-west direction for both falling and rising tide (see Table 4-6). The resulting concentration of the plume ranged between 0.045 – 0.080 mg/L.

TABLE 4-6 GRAPHICAL REPRESENTATION OF FAR-FIELD DISPERSION AT NMIA WWTP OUTFALL UNDER SLOW WIND CONDITIONS



FALLING TIDE



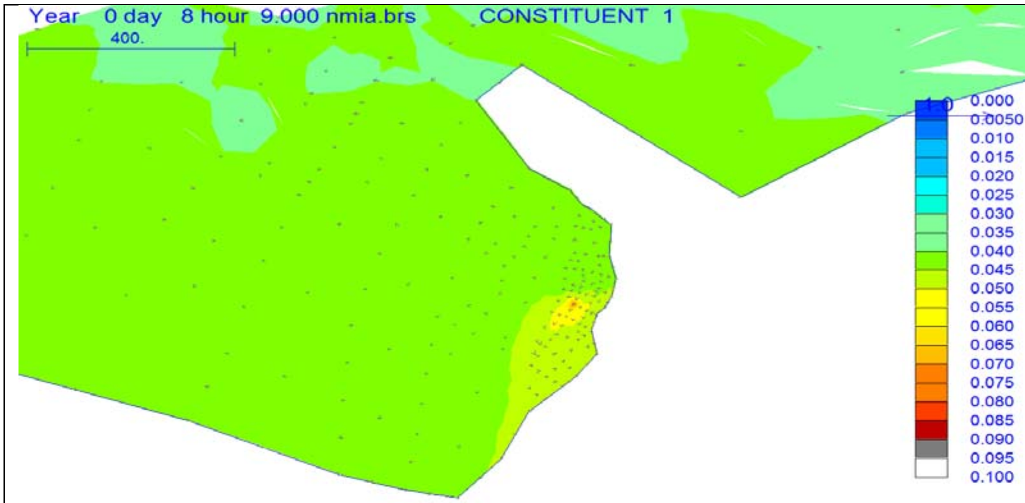
RISING TIDE

4.6.2 Average Conditions

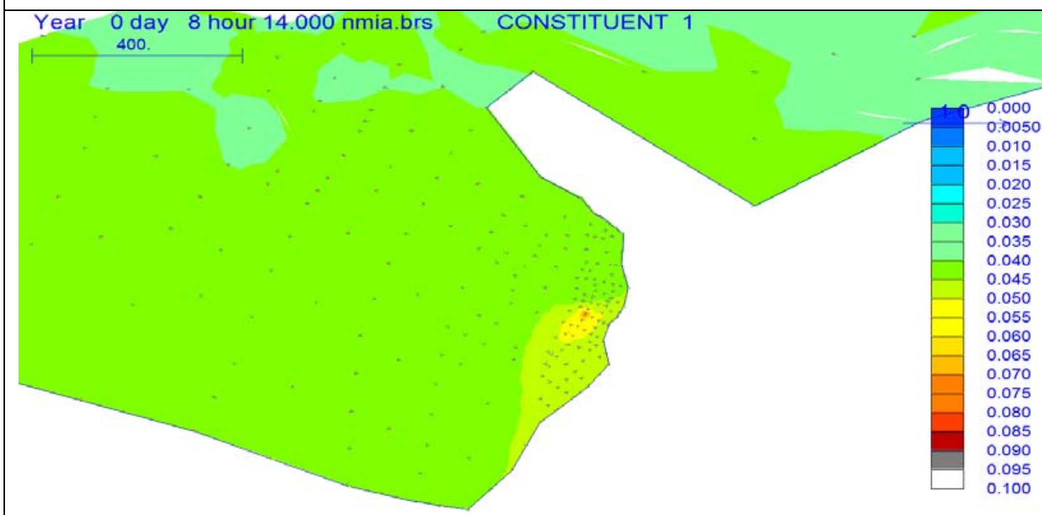
During average wind conditions the temperature of the water in the mixing zone (or 100m radius) will rise to 27.9 °C in comparison to the ambient temperature of 28°C. The heating of the effluent discharge will occur relatively short as the movement of currents driven by wind are fairly fast and facilitates good mixing. This will cause a fairly small area of slightly decreased temperature (less than 0.5 °C below ambient).

It was determined that under average wind conditions a dilution factor of 78.3 can be expected based on the results of the near-field outfall modeling. A conservative dilution factor of 20 (includes a safety factor of 3) was input in the RMA-11 model. The resulting far-field dispersion resulted in a plume extending approximately 400 meters in a north-south direction and 175 meters in an east-west direction for both falling and rising tide (see Table 4-7). The concentration of the plume ranged between 0.045 – 0.075 mg/L.

TABLE 4-7 GRAPHICAL REPRESENTATION OF FAR-FIELD DISPERSION AT NMIA WWTP OUTFALL UNDER AVERAGE WIND CONDITIONS



FALLING TIDE



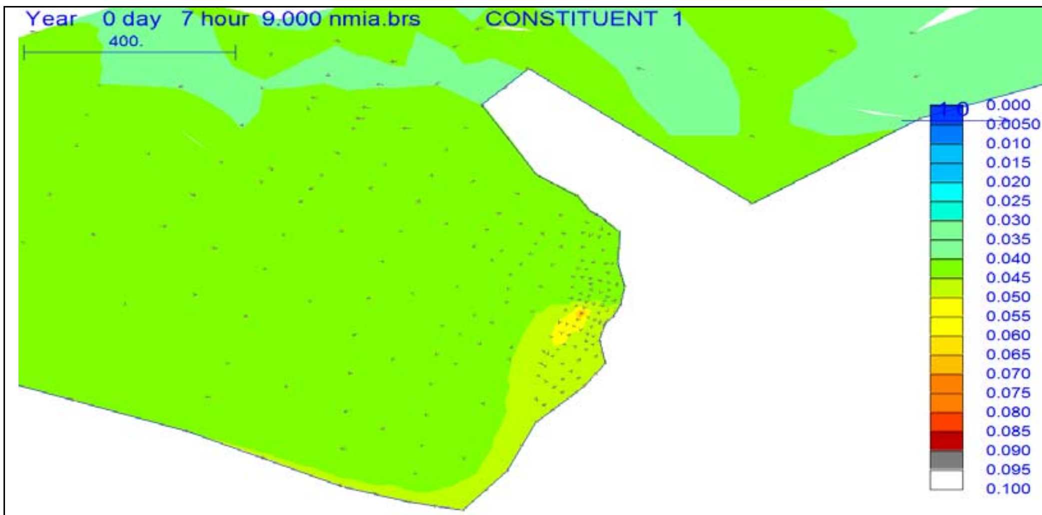
RISING TIDE

4.6.3 Fast Wind Conditions

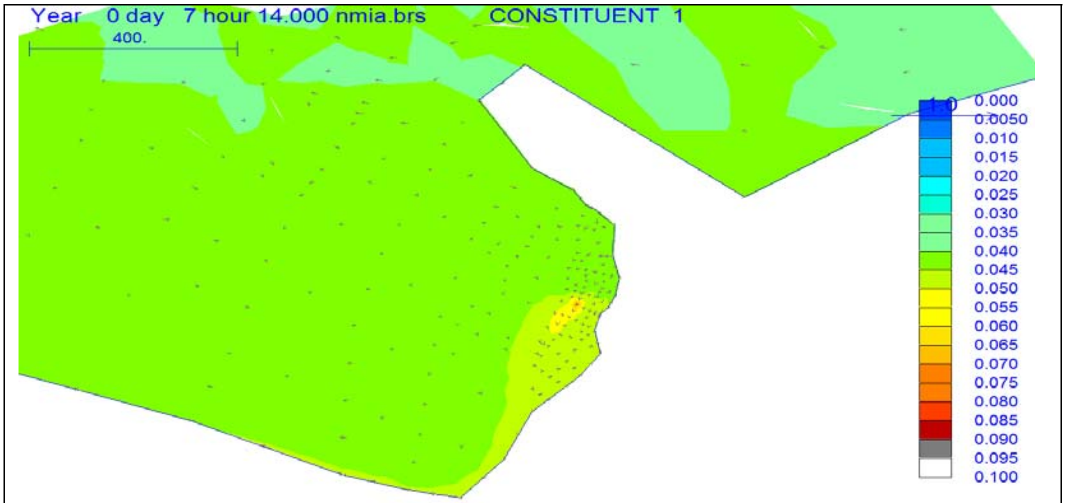
During fast wind conditions the temperature of the water in the mixing zone (or 100m radius) will rise to 27.9 °C in comparison to the ambient temperature of 28°C. The heating of the effluent discharge will be very short as the movement of currents driven by wind are very fast and facilitates good mixing. This will cause a fairly large area of slightly decreased temperature (less than 0.5 °C below ambient).

It was determined that under fast wind conditions a dilution factor of 78.3 can be expected based on the results of the near-field outfall modeling. A conservative dilution factor of 20 (includes a safety factor of 3) was input in the RMA-11 model. The resulting far-field dispersion resulted in a plume extending approximately 500 meters in a north-south direction and 175 meters in an east-west direction for both falling and rising tide (see Table 4-8). The concentration of the plume ranged between 0.045 – 0.070 mg/L.

Table 4-8 Graphical representation of far-field dispersion at NMIA WWTP Outfall under fast wind conditions



FALLING TIDE


Year 0 day 7 hour 14.000 nmia.brs
CONSTITUENT 1
400.
0.000
0.0050
0.010
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0.060
0.065
0.070
0.075
0.080
0.085
0.090
0.095
0.100

RISING TIDE

5 Conclusions and Recommendations

5.1 Conclusions

The following could be concluded from the analysis conducted to date:

1. The review of literature documenting the condition of the Kingston Harbour revealed that the water quality of the harbour is degraded. Background information on the water quality of the Kingston Harbour was provided based on water quality samples collected in the area over the 2010 to 2012 period. These results were compared to the NEPA standard for the marine environment. It should be noted that 1) all the values exceed those stipulated by NEPA, and 2) the background condition of the harbour will be used as the ambient water quality in the modeling analysis to.

2. The marine outfall was modeled using CORMIX for the near-field conditions. The model was run for the slow, average and fast operational conditions for the existing treatment plant flow of 500 m^3/d. It was revealed that during the operational conditions the effluent plume reaches the surface between 2.5 and 7 meters from the outfall (horizontal distance). The effluent concentration is also diluted by between 222 and 577 during these conditions. The horizontal distance at which the effluent concentration blends into the ambient background and is undetectable is between 2.8 and 20 meters from the outfall; the corresponding effluent concentration ranges from 236 and 250.

3. The worst case oceanographic condition, that is, when there is a slack tide (no currents) was also modeled. The results show a dilution of 133 at the surface at the outfall. It was also revealed that the effluent concentration is undetectable 100 meters from the outfall with a dilution of 252.

4. CORMIX was also used to model the operational conditions under the treatment plant's rated flow of 1746 m^3/ d. It was revealed that during the operational conditions the effluent plume reaches the surface between 0.5 and 2.9 meters from the outfall (horizontal distance). The effluent concentration is also diluted by between 78 and 176 during these conditions. The horizontal distance at which the effluent concentration blends into the ambient background and is undetectable is between 80 and 480 meters from the outfall; the corresponding effluent concentration ranges from 248 and 260.

5. The worst case scenario of no current conditions was modeled under the rated flow conditions and the results show a dilution of 62 at the surface at the outfall. It was also revealed that the effluent concentration is undetectable 480 meters from the outfall with a dilution of 251.

6. Surface current predictions for the slow wind speed meteorological conditions for the existing shoreline configuration indicated that current velocities below 2 cm/s can be expected within the bay, while current velocities up to 8 cm/s was predicted under average wind conditions and current velocities up to 10 cm/s was predicted under average wind conditions. The current directions are predominantly towards the north-west indicating that the surface currents are predominantly wind driven.

7. The resulting far-field dispersion, under slow wind conditions, resulted in a plume extending approximately 250 meters in a north-south direction and 175 meters in an east-west direction with a resulting plume concentration of 0.045 – 0.080 mg/L. Under average wind conditions, the plume extends approximately 400 meters in a north-south direction and 175 meters in an east-west direction with a final plume concentration of 0.045 – 0.075 mg/L. Under fast wind conditions, the plume extends approximately 500 meters in a north-south direction and 175 meters in an east-west direction with a final plume concentration of 0.045 – 0.070 mg/L.

5.2 Recommendations

The following are our recommendations:

1. Our assessment revealed that the diffusers get blocked from time to time thus reducing the performance of the outfall. It is recommended that the regular cleaning of the diffusers be included in the plant's Operation and Maintenance Plan.

2. Also, as the flow through the treatment plant increases, the NMIA should reassess the performance of the outfall to ensure that it is performing satisfactorily.

3. As a part of the Scope of Works the far field plume predictions should be verified by field dye studies. This study will be completed shortly and the results submitted to NEPA in August 2014.

6 APPENDICES

6.1 DROGUE TRACKS

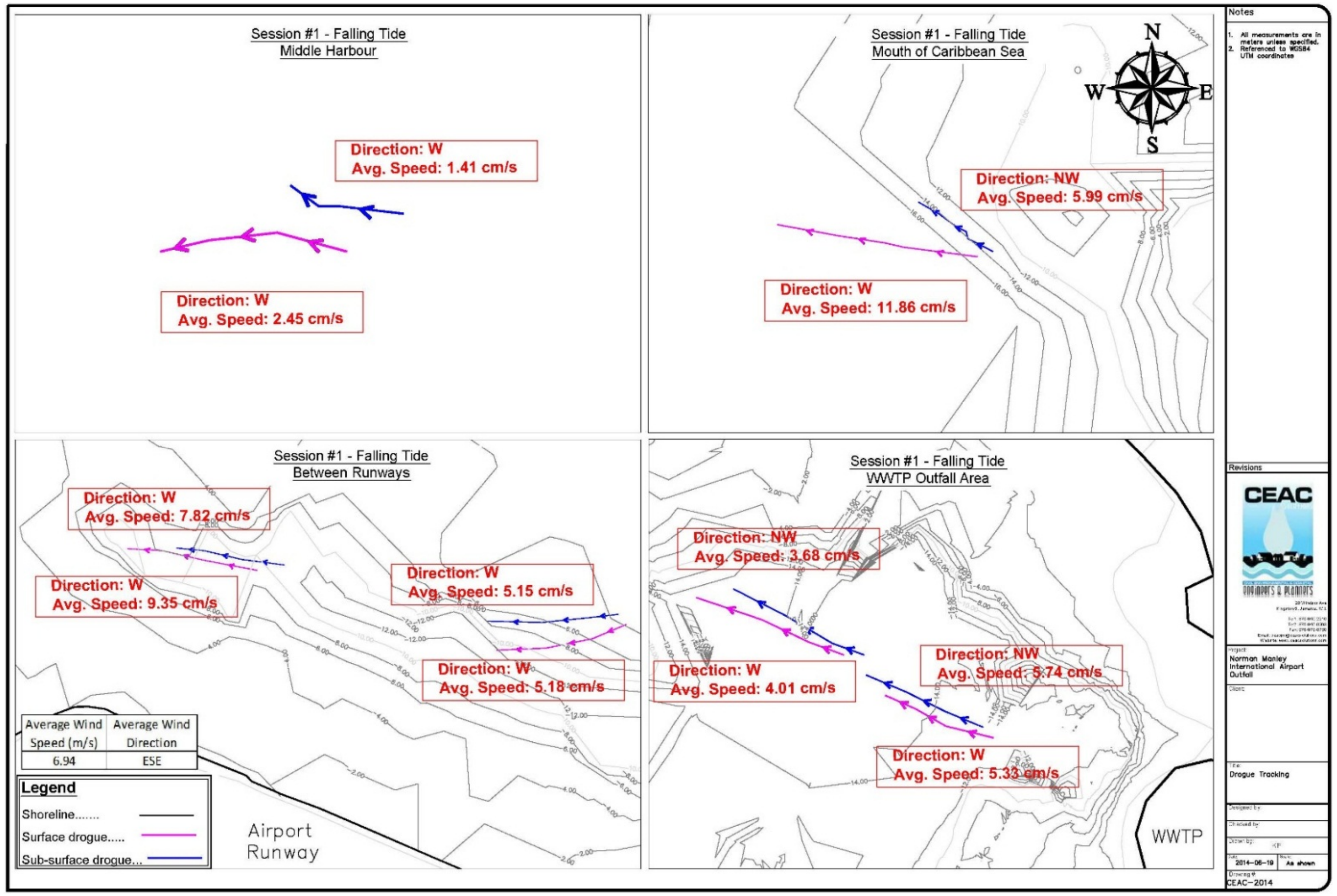


FIGURE 6-1. DROGUE TRACKING SESSION 1 (FALLING TIDE) CONDUCTED ON JUNE 19TH, 2014.

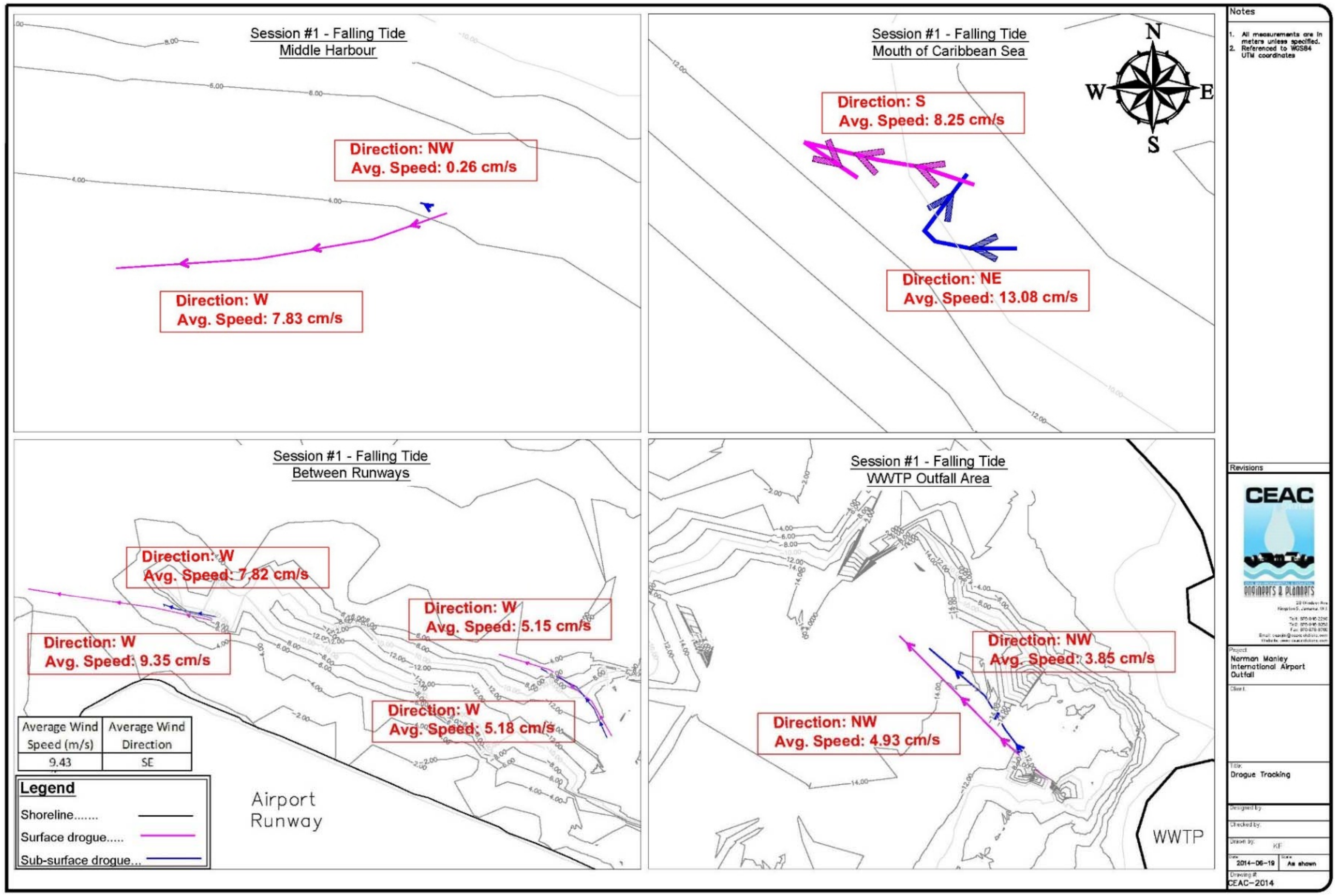


FIGURE 6-2. DROGUE TRACKING SESSION 2 (RISING TIDE) CONDUCTED ON JUNE 19TH, 2014.

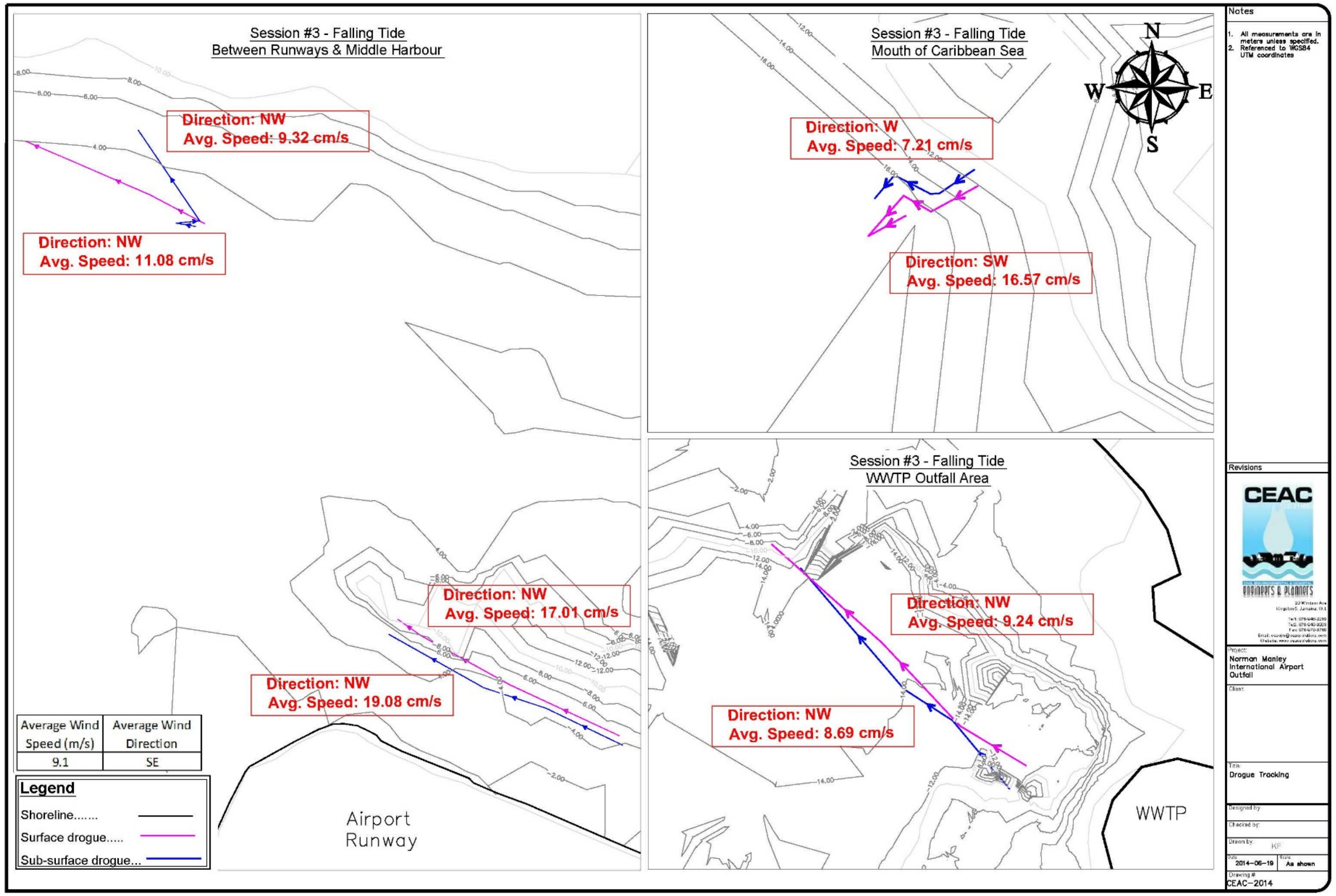


FIGURE 6-3. DROGUE TRACKING SESSION 3 (FALLING TIDE) CONDUCTED ON JUNE 20TH, 2014.

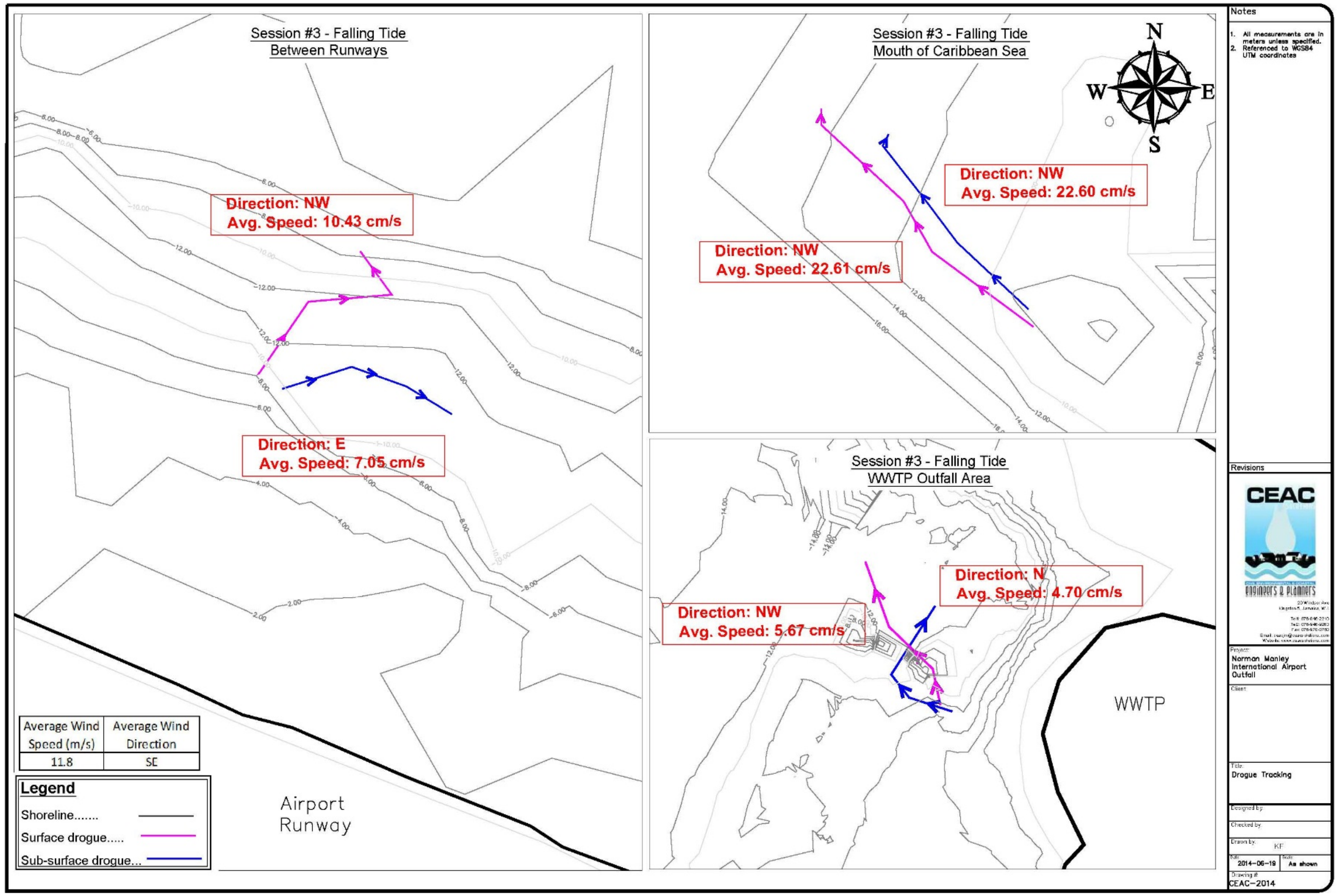
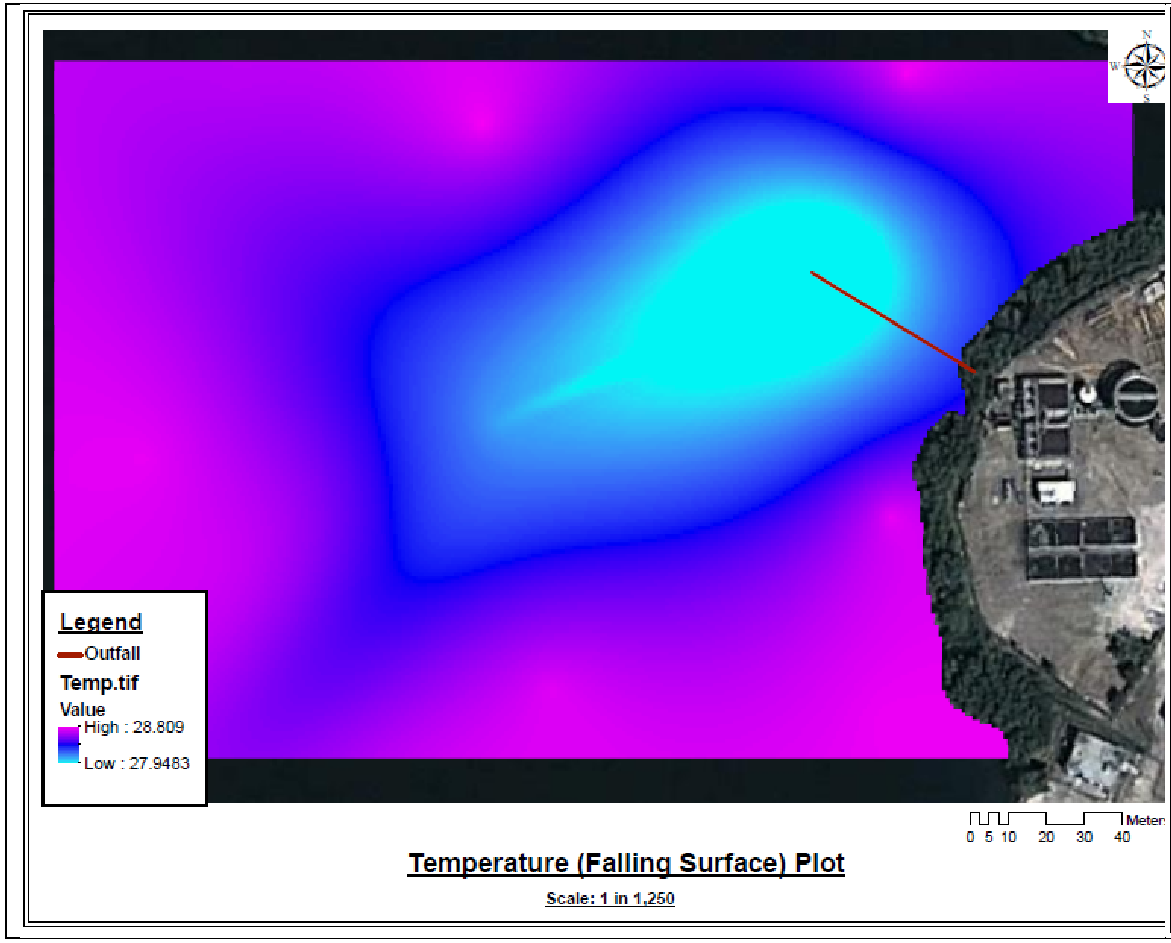
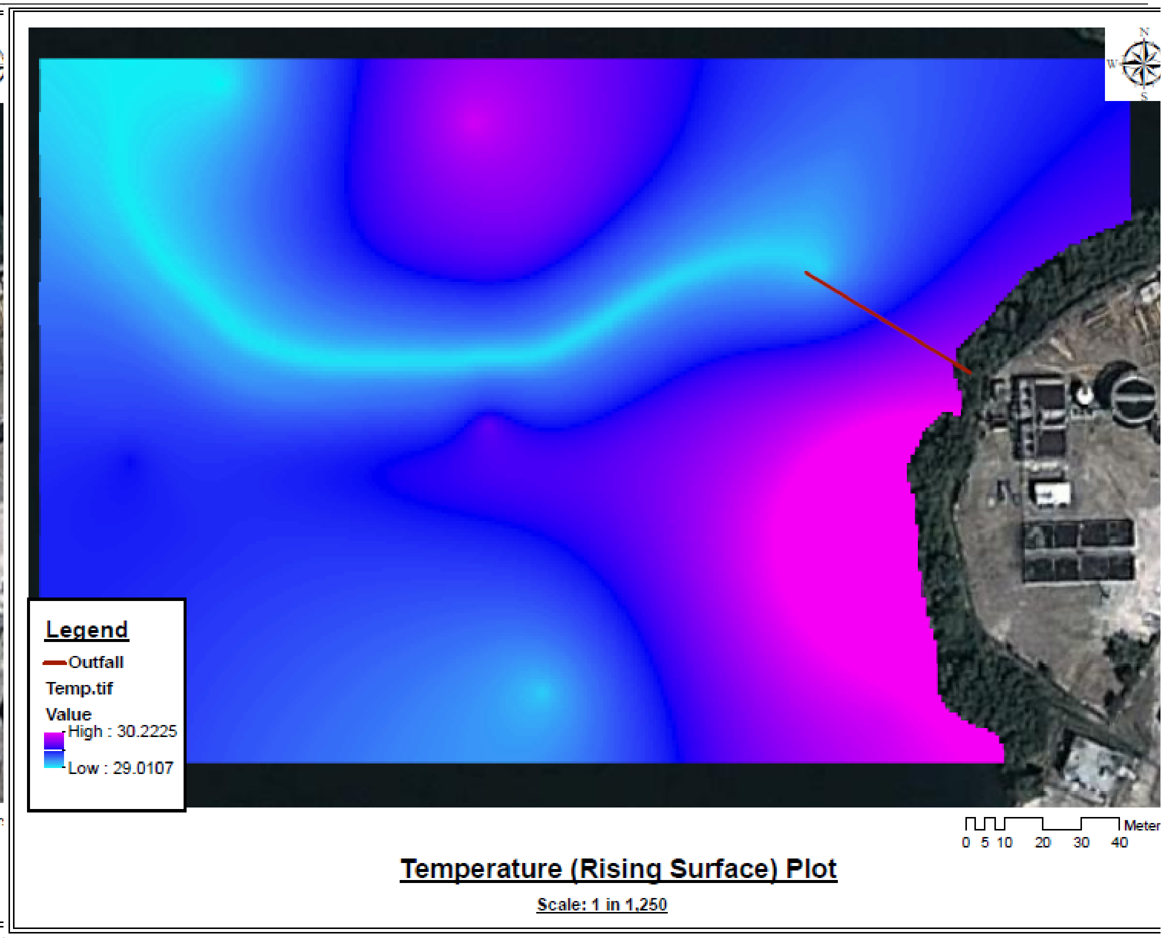


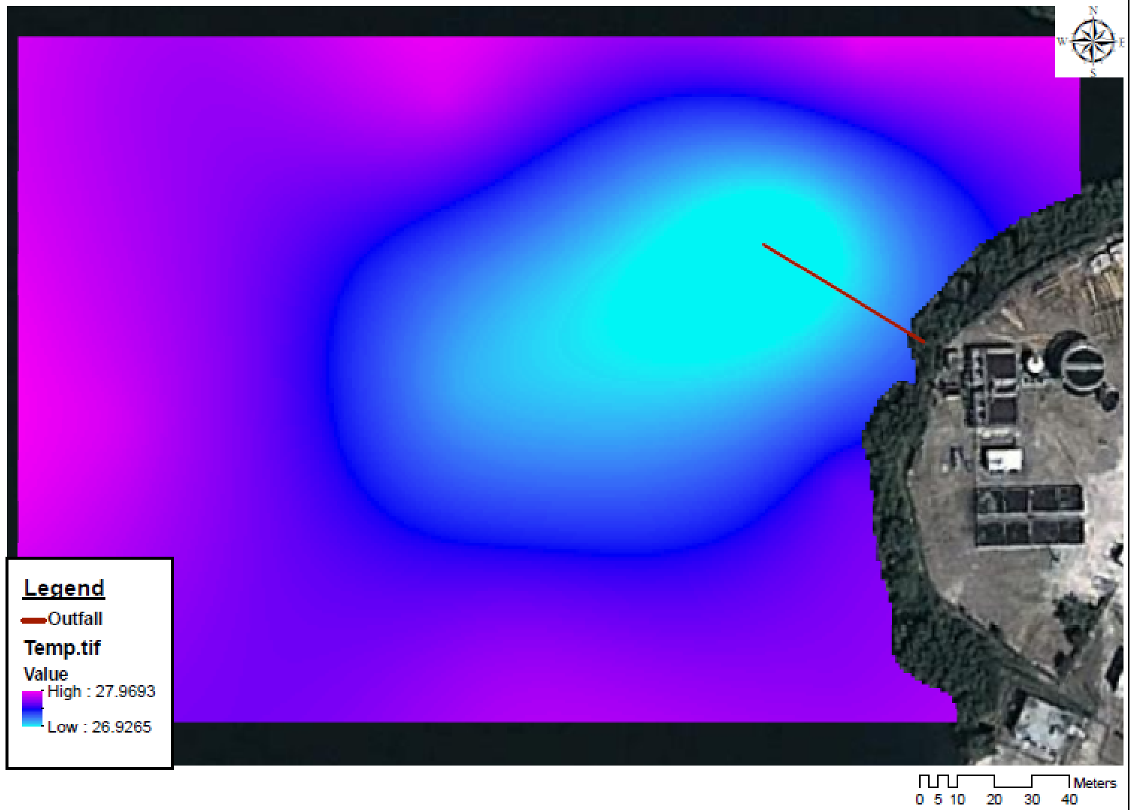
FIGURE 6-4. DROGUE TRACKING SESSION 4 (RISING TIDE) CONDUCTED ON JUNE 20TH, 2014.

6.2 Water Quality Plots

Table 6-1. Map showing temperature readings collected in the Kingston Harbour during the rising and falling tide on June 19,2014.

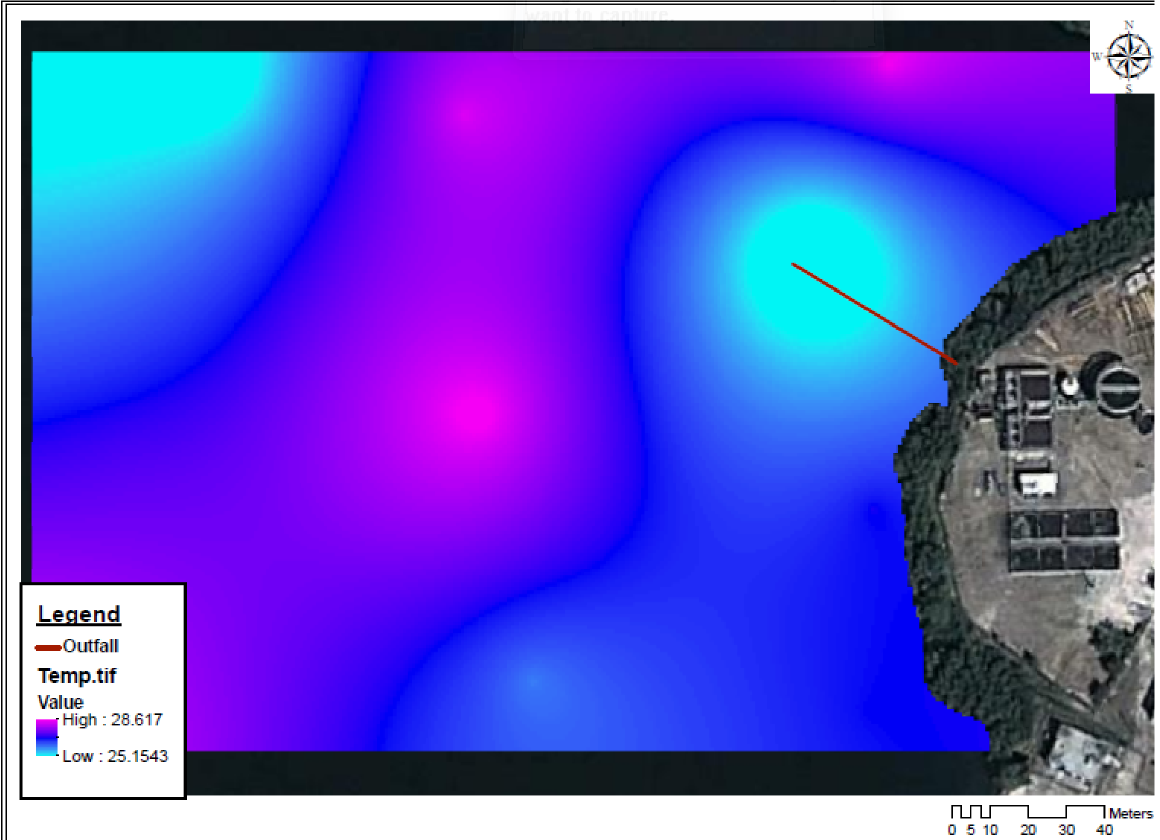






Temperature (Falling Sub-Surface) Plot

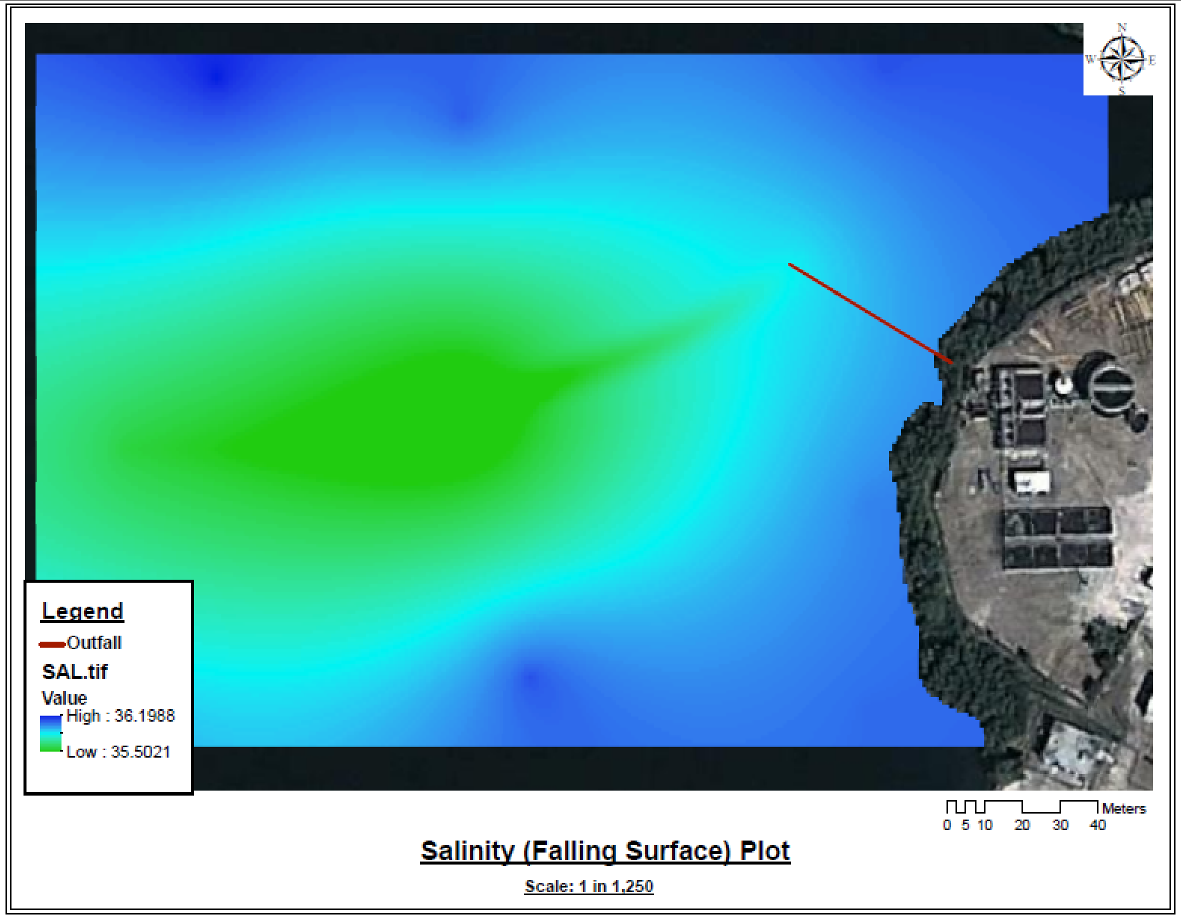
Scale: 1 in 1,250

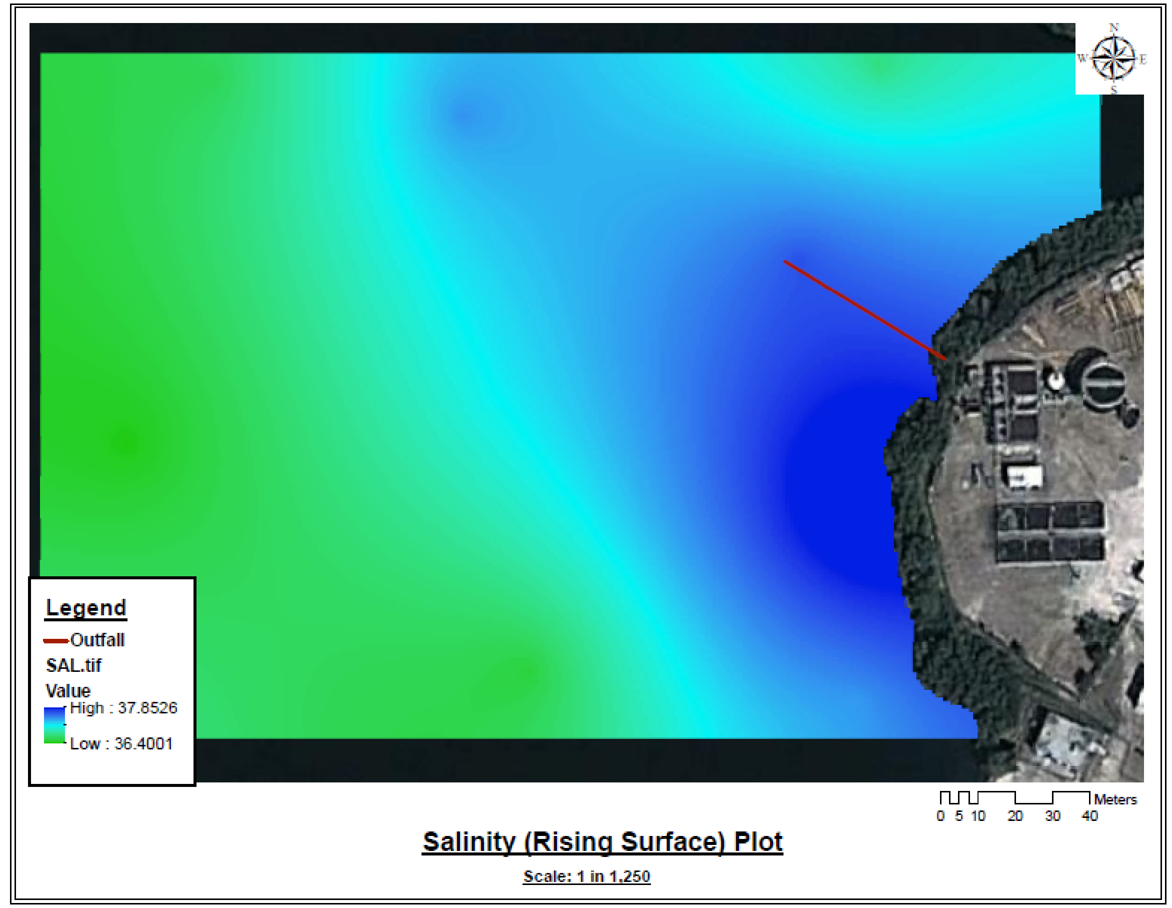


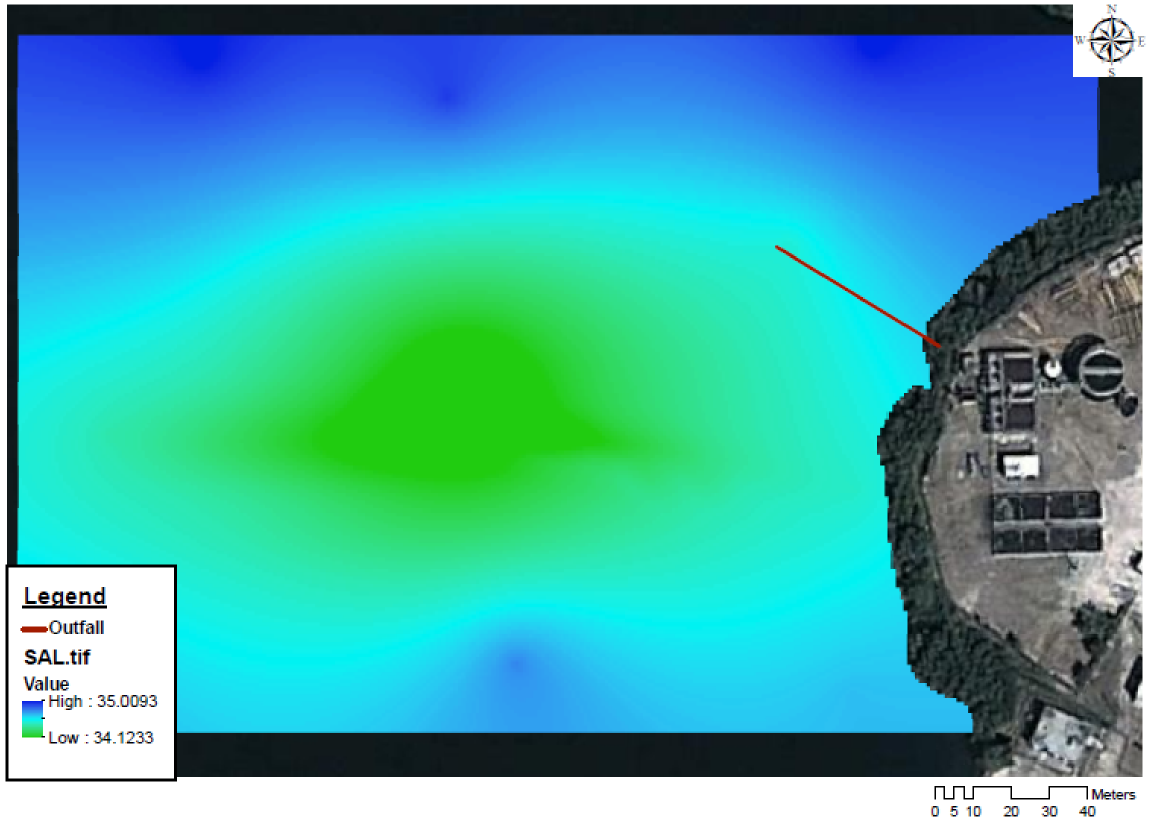
Temperature (Rising Sub-Surface) Plot

Scale: 1 in 1,250

Table 6-2. Map showing salinity readings collected in the Kingston Harbour during the rising and falling tide on June 19,2014.

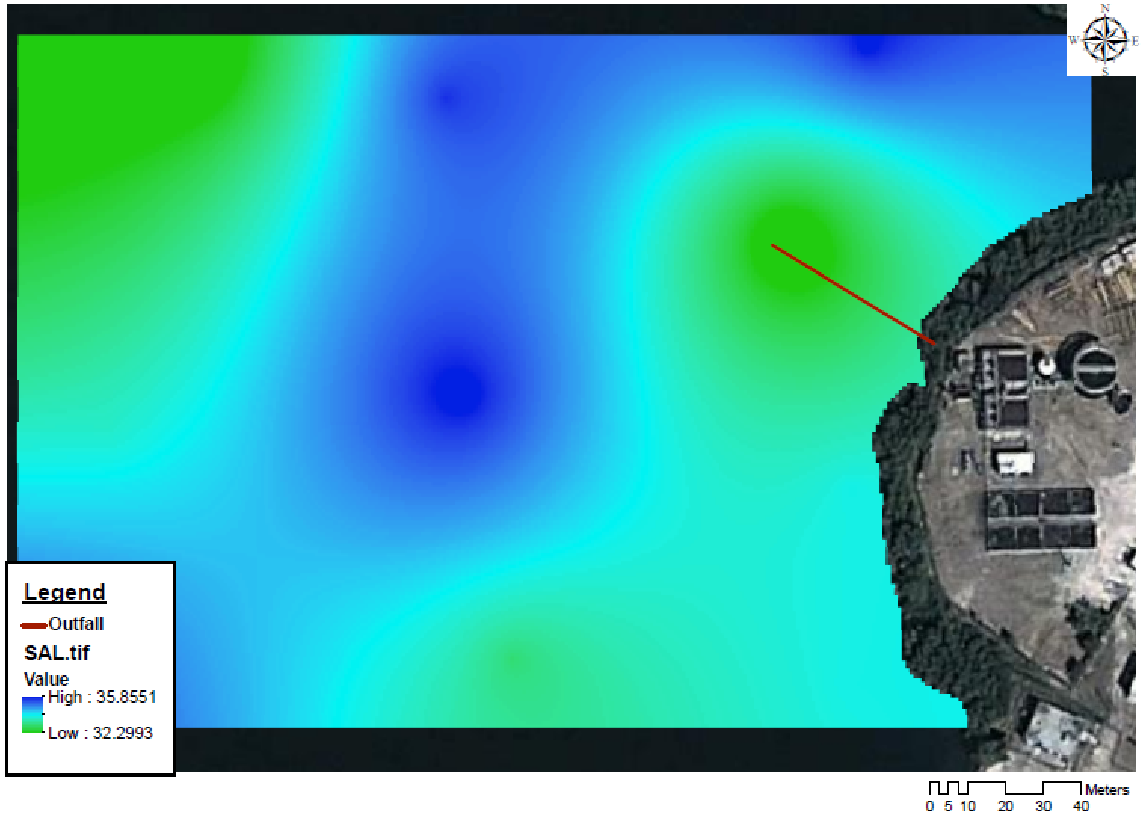






Salinity (Falling Sub-Surface) Plot

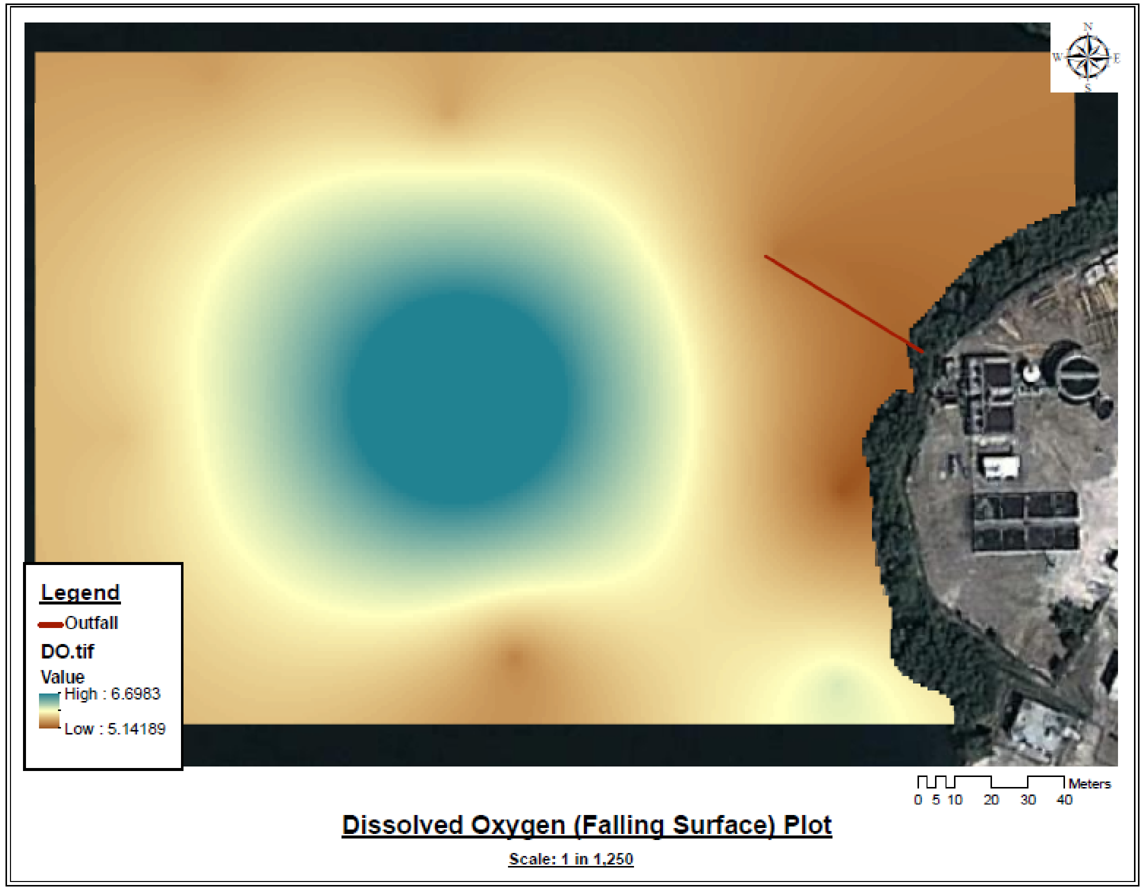
Scale: 1 in 1,250

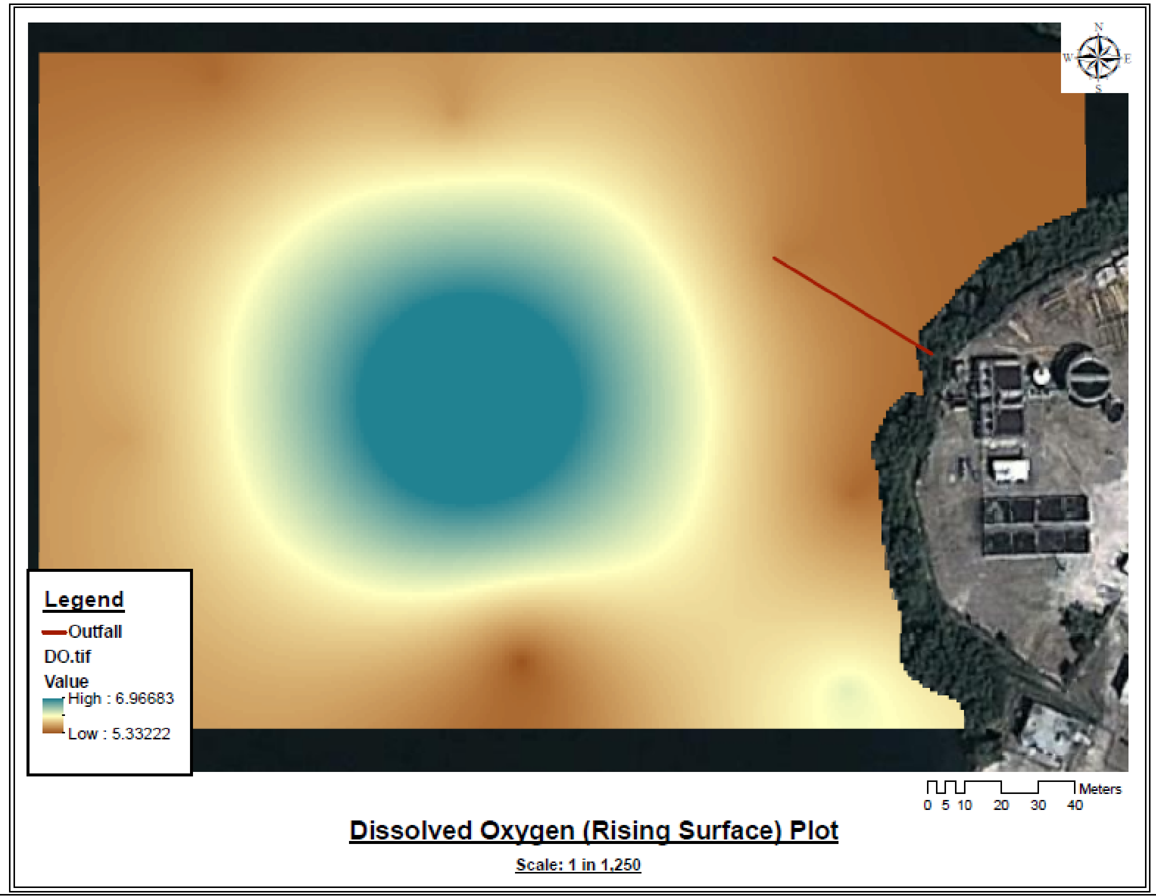


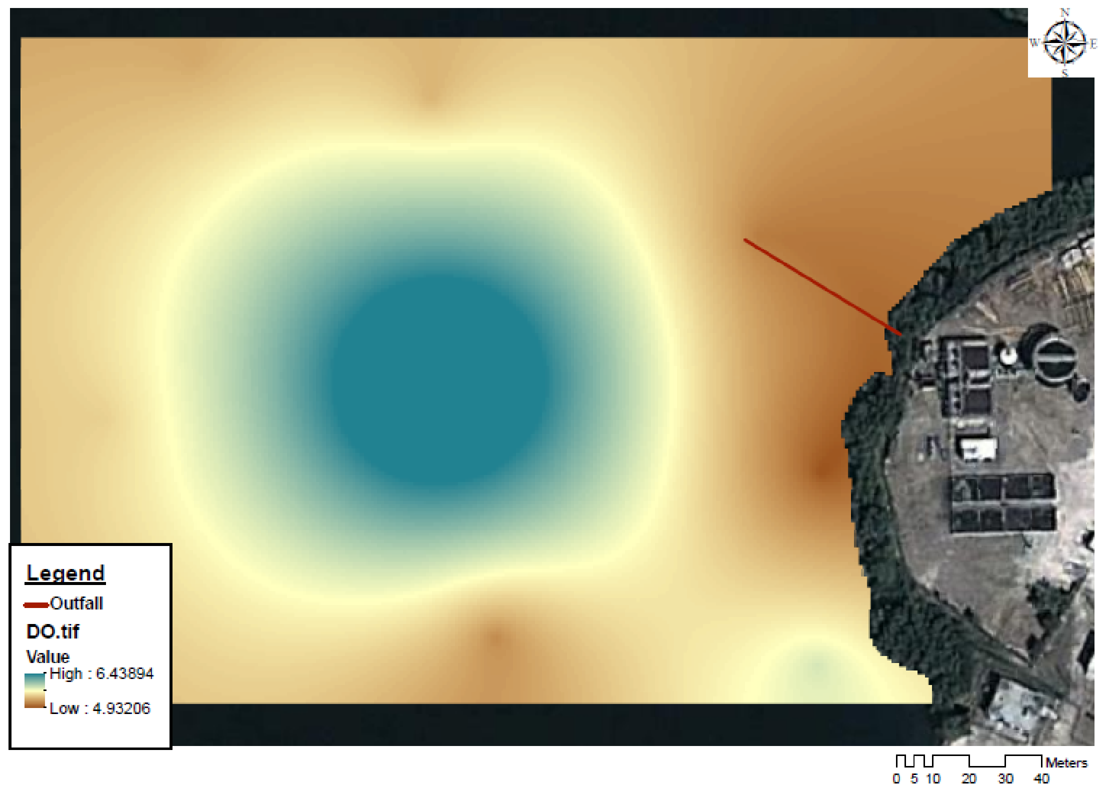
Salinity (Rising Sub-Surface) Plot

Scale: 1 in 1,250

Table 6-3. Map showing dissolved oxygen (DO) readings collected in the Kingston Harbour during the rising and falling tide on June 19,2014.

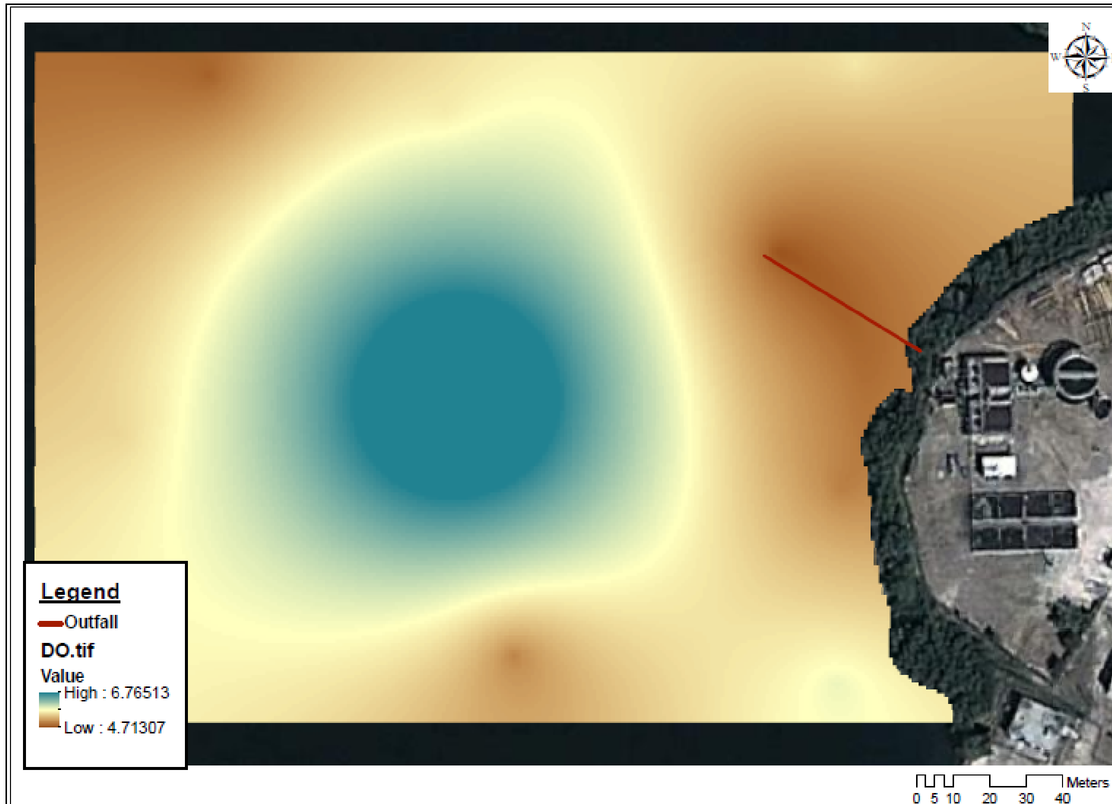






Dissolved Oxygen (Falling Sub-Surface) Plot

Scale: 1 in 1,250



Dissolved Oxygen (Rising Sub-Surface) Plot

Scale: 1 in 1,250