APPENDIX A

Physical Description of the Shubenacadie River

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Physical Description of the Shubenacadie River

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1.0 Physical Description of the Shubenacadie River

The Shubenacadie River is a tidal bore river in Nova Scotia, Canada that experiences extreme changes in salinity, temperature, water elevation, suspended sediment and river bottom configuration over very short temporal periods (less than 1-hour). The river meander length is approximately 50 kilometers from its source at Shubenacadie Grand Lake to its mouth at Maitland on Cobequid Bay. The river system receives freshwater from a relatively large watershed area (2600 km^2) that includes the Stewiacke River, a tributary to the Shubenacadie River, where the confluence is located approximately 22 kilometers upriver of the mouth. Due to the extreme tidal forcing (> 10 m large tidal range) from Cobequid Bay, the lower 30 kilometers of the river (Figure 1.0) is tidal. Within this lower reach of the river, the brackish water has salinities that can vary from 0 to 25 ppt over a single tidal cycle.

The turbulence associated with the passage of the tidal bore in the Shubenacadie River plays an important role in the transport of sediment within the estuarine system and Cobequid Bay. Suspended sediment is continuously being reworked from bottom sediments and eroded from exposed banks to form the extensive spatial and temporal varying shoals within the river and salt marshes throughout Cobequid Bay.

In order to assess the trends and variability in physical oceanographic and hydrologic processes that influence the Shubenacadie River it was necessary to collect all existing data on bathymetry, currents, salinity, and flow discharge. However, only limited historical data has been documented. The Canadian Hydrographic Service (CHS) has no bathymetry or tidal data for the Shubenacadie River. Charts would be unreliable to mariners due to the rapid changes in river bottom (formation and erosion of large shoals) from year to year. Flow data along the tidal portion of the river is non-existent, but freshwater gauging stations (Water Survey of Canada) do exist upriver (non-tidal reach) of the Shubenacadie and Stewiacke Rivers. Due to the limited data, Martec Ltd. carried out an oceanographic field program in the summer and fall of 2006 to supplement the missing data and provide the necessary data for engineering design of the outfall, brine dispersion modeling and environmental studies. The 2006 program consisted of measuring tidal flows, water elevation, bathymetry at the proposed outfall, and salinity.

The 2006 field program provides a good understanding of the trends and variability of water elevation, flow and salinity in the Shubenacadie River but is limited in duration (latter part of summer season and full fall season). Because the Shubenacadie-Stewiacke River system is a very complicated tidally driven estuary, a detailed hydrodynamic model coupled with a water quality model (RMA 10-11) is currently being developed to aid in the numerical prediction of river flow and salt dispersion in the Shubenacadie River under normal and extreme conditions. The model will provide further details of the oceanographic variability and be utilized as a tool to further enhance the statistical significance of normal and extremal events that would otherwise not be measured during the ongoing oceanographic field studies.

A description of the trends and variability of water elevation, river flow, and salinity in the Shubenacadie River, based mainly on the data collected during the 2006 field surveys, are provided in the following sub-sections of this report.

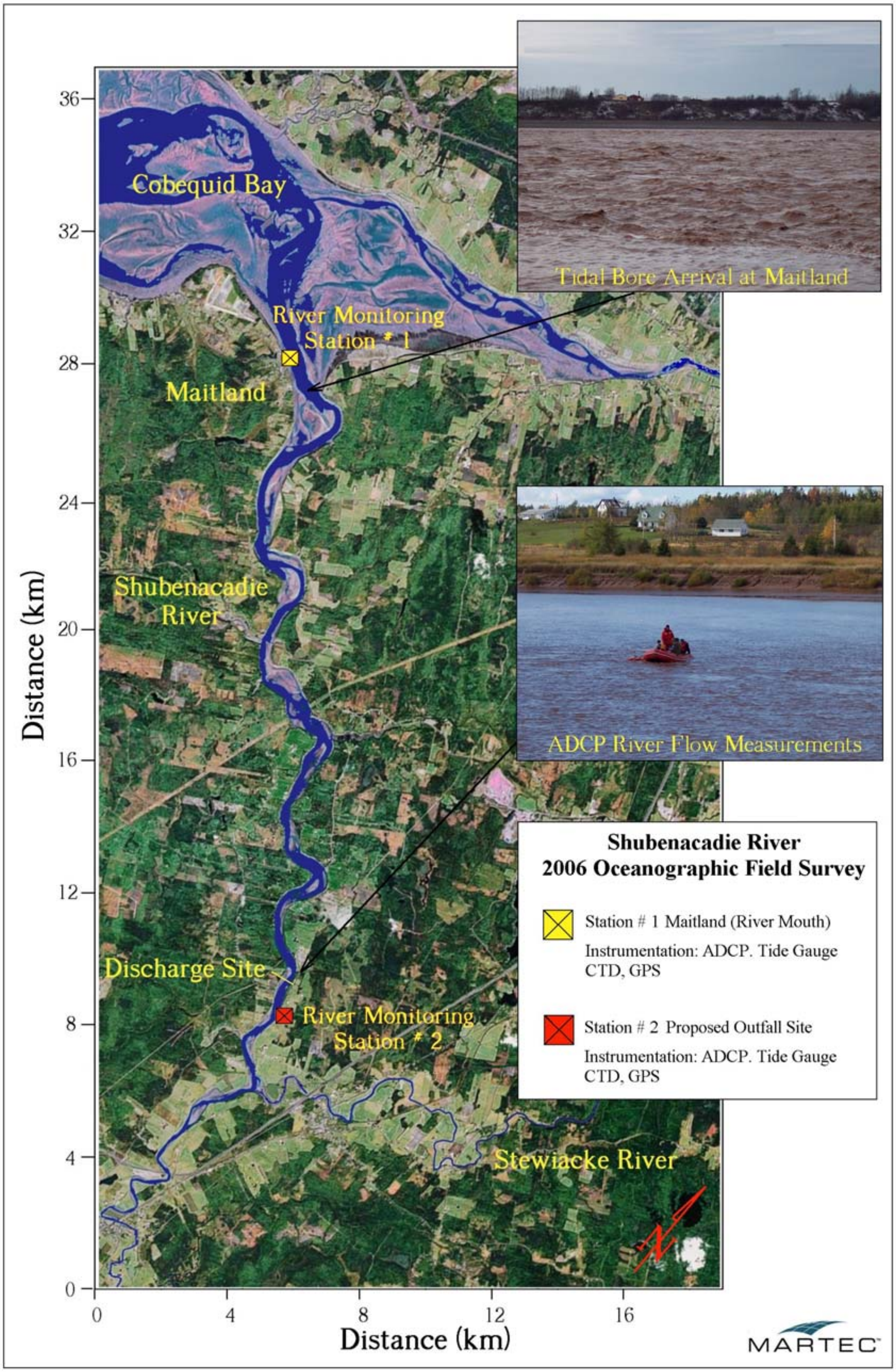


Figure 1.0 Oceanographic Study Area and Location of River Stations

1.1 Water Elevation Trends and Variability

Water elevation in the Shubenacadie River is driven mainly by the strong tidal forcing (> 10 meters) in Cobequid Bay and freshwater input from a relatively large watershed area and, secondary effects due to wind forcing, atmospheric pressure systems and frictional damping. Because the relatively shallow mudflats throughout the upper reaches of Cobequid Bay impedes the initial advance of the rising tide at the Shubenacadie River mouth, tidal bores are generated when the rapid rise in tidal elevation meets resistance from the ebb flowing water exiting the river. During the large tide, the tidal bore at the river mouth exceeds 1.0 meter in elevation and can advance significant distances upriver (>30 kilometers). Due to frictional damping and the gradual decrease of tidal flows upstream, the tidal bore loses energy with heights reduced to less than 0.30 meters at the proposed outfall site. Tidal bores are very turbulent in nature and can cause large longitudinal variations of bottom stresses that result in significant sediment transport (bedload and suspended transport) along the river reach. Because tidal bores induce strong turbulent mixing, vertical and horizontal mixing coefficients associated with tidal bores are typically greater than in estuary flows (Chanson, 2003). Vertical measurements of salinity with depth at the Shubenacadie River mouth and proposed outfall site during the initial summer and fall field surveys show a well-mixed estuary with little stratification.

Water elevation measurements in the Shubenacadie River were an important component of the oceanographic program. Previous water elevation measurements in the river were limited, and as such, fixed bottom-mounted tide gauges were deployed at the mouth of the river and proposed outfall site. Due to the relatively harsh environment, back-up tide gauges were also installed at each site to ensure data recovery. Sampling at both sites were synchronized and set to record pressure at a sampling frequency of 5-minutes. Pressure data was converted to water depth data from instrument guidelines relating water temperature and salinity (measured concurrently). Atmospheric pressure data was obtained from Environment Canada's Halifax International Airport Weather Station. The main objectives of the water elevation measurement surveys were the following:

1. Provide measured data of water elevation for a coupled 1-D/2-D hydrodynamic and water quality model (RMA10-11). The model development currently being carried out will be able to provide greater detail into the hydrodynamics of the Shubenacadie River System. Measured water elevation data at the river mouth (Maitland) provides the necessary tidal forcing data at the model outer boundary. Water elevation data collected at the proposed outfall site is used for calibration, to ensure the model is accurately predicting the rise and fall of the tide at this upriver station for a range of river conditions.
2. Provide the necessary data for engineering design, operational criteria of the outfall and brine dispersion modeling.
3. Assess the asymmetrical profile of water elevation and the relationship between water elevation and currents at the two sites. Particular attention was given to tidal phase and height differences between the two sites.
4. Determine the frequency of occurrence that water elevations exceed a particular threshold elevation.
5. Assess the relationship between freshwater/tidal flows and water elevation at the proposed outfall site.

Measured differences in water elevation between Maitland and the proposed outfall site are significant as depicted in Figure 2.0. The 11.0-meter large tide at Maitland on Nov 06, 2006 reduces to a tidal range of just over 4.0 meters at the proposed outfall site.

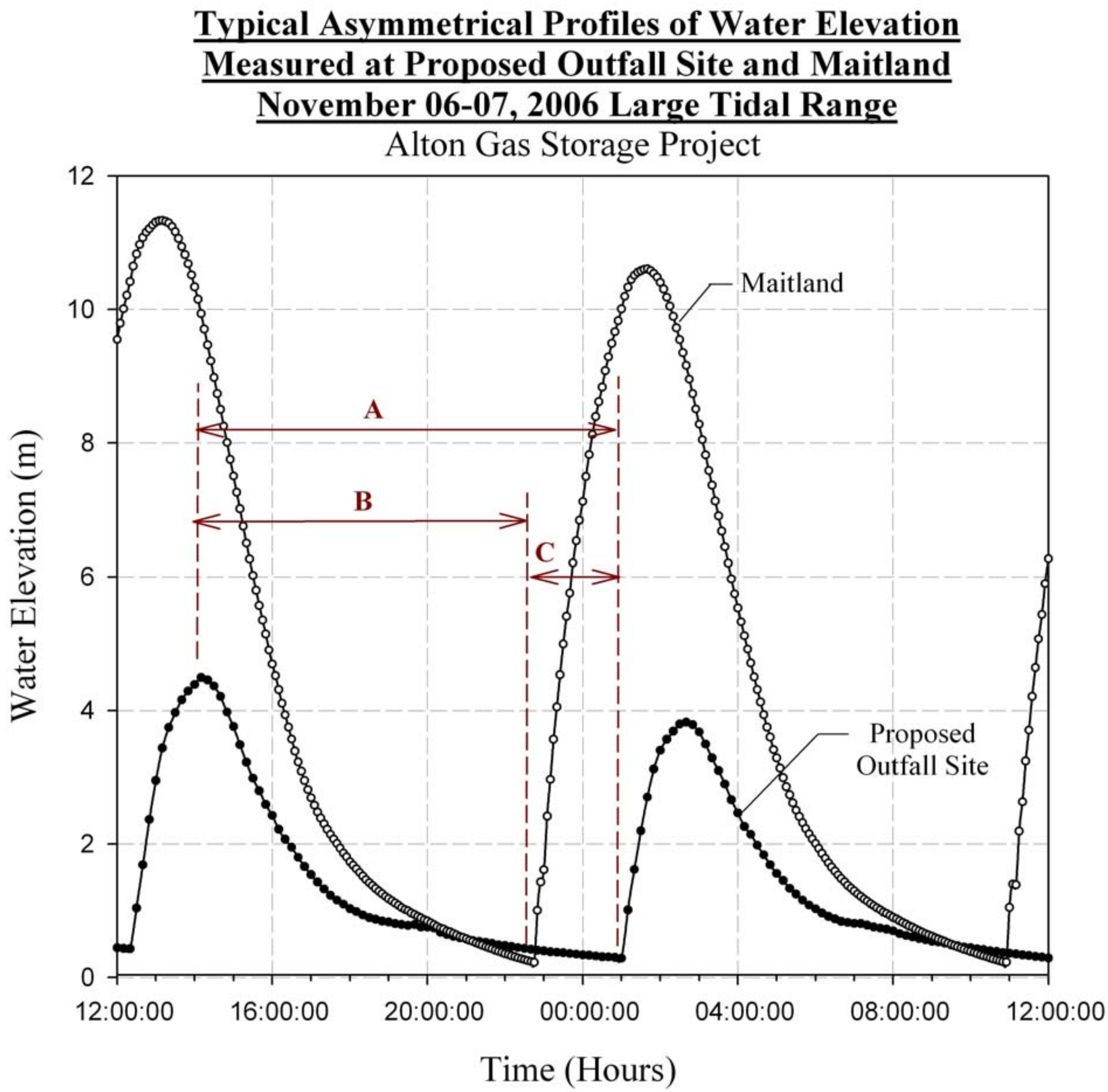


Figure 2.0 Water Elevation Profiles Measured at Maitland and Proposed Outfall Site

The difference in tidal range between the two sites is primarily due to the increase of river bottom elevation from Maitland to the proposed outfall site. This increase in river bottom elevation is not a gradual one, but highly variable along this 20 km section of river. Various river sections have abrupt changes in elevation that can cause rapids during large ebb flow events. The largest vertical drop in river bottom occur midway between the Kennetcook Bridge and the proposed outfall site.

The variables A, B, and C depicted in Figure 2.0 represent the phase difference of tidal heights between Maitland and the proposed outfall site. In particular, the tidal records for the period November 03-24, 2006 were analyzed to determine the average time for the following:

A = Average duration of falling tide at proposed outfall site (10 hr 56 m)

B = Average time between high tide at outfall site and next tidal reversal at Maitland (8 hr 19 m)

C = Average time for tidal bore to propagate from Maitland to the outfall site (2 hr 37 m)

A, B, and C show considerable variability (approximately +/- 1 hr) for the tidal period analyzed. Examination of the water elevation and salinity records show that large freshwater flows from the Shubenacadie-Stewiacke Watershed can slow the speed of the tidal bore and increase the duration of ebb flow at the proposed outfall site. Similarly, low freshwater flows into the river tend to increase the speed of the bore and reduce the duration of ebb flow.

The asymmetrical profile of water elevation at the proposed outfall site is more similar to an "impulse" of positively surged water that gradually retreats during ebb flow than the more common sinusoidal tidal signal associated with an open sea. Typically, the water elevation rises from low to high water in less than 2-hours and then falls for a period of 10 to 11 hours. It is important to note that during the falling tide, water elevation falls most rapidly for a period of approximately 3-hours after high tide and then gradually decreases in elevation until the arrival of the next tidal bore.

Figure 3.0 presents time-series plots of water elevation and precipitation at Maitland and proposed outfall site for the period November 03 to December 07, 2006. Daily precipitation data in the plots was obtained from Environment Canada Halifax International Airport Weather Station. The period includes a significant rainfall event (> 60 mm) on November 09, 2006. The water elevation at Maitland is predominantly tidal with only small variations of the signal during periods of heavy rainfall. A slight increase in water level is apparent during low water after the rainfall events. Although the water elevation signal at the proposed outfall site is also predominantly tidal, rainfall events have a significant effect on the level of low water. The signal clearly shows a rapid increase in low water levels after rain events. Low water level increased by approximately 1.0 meter after the November 09 rainfall event.

Based on the measured water elevation data, the large tidal range at Maitland and proposed outfall site were 11.2 and 4.1 meters, respectively. During the small tide, the range is reduced to 8.0 and 1.6 meters, respectively. Flooding of the riverbank occurred at the proposed outfall site when water levels exceed 8.1 m (Geodetic Datum). This event occurred during the large tide on November 06, 2006. The protective dike further inland (Figure 4.0) is at higher elevation (9.9 m Geodetic) and was not flooded during the survey.

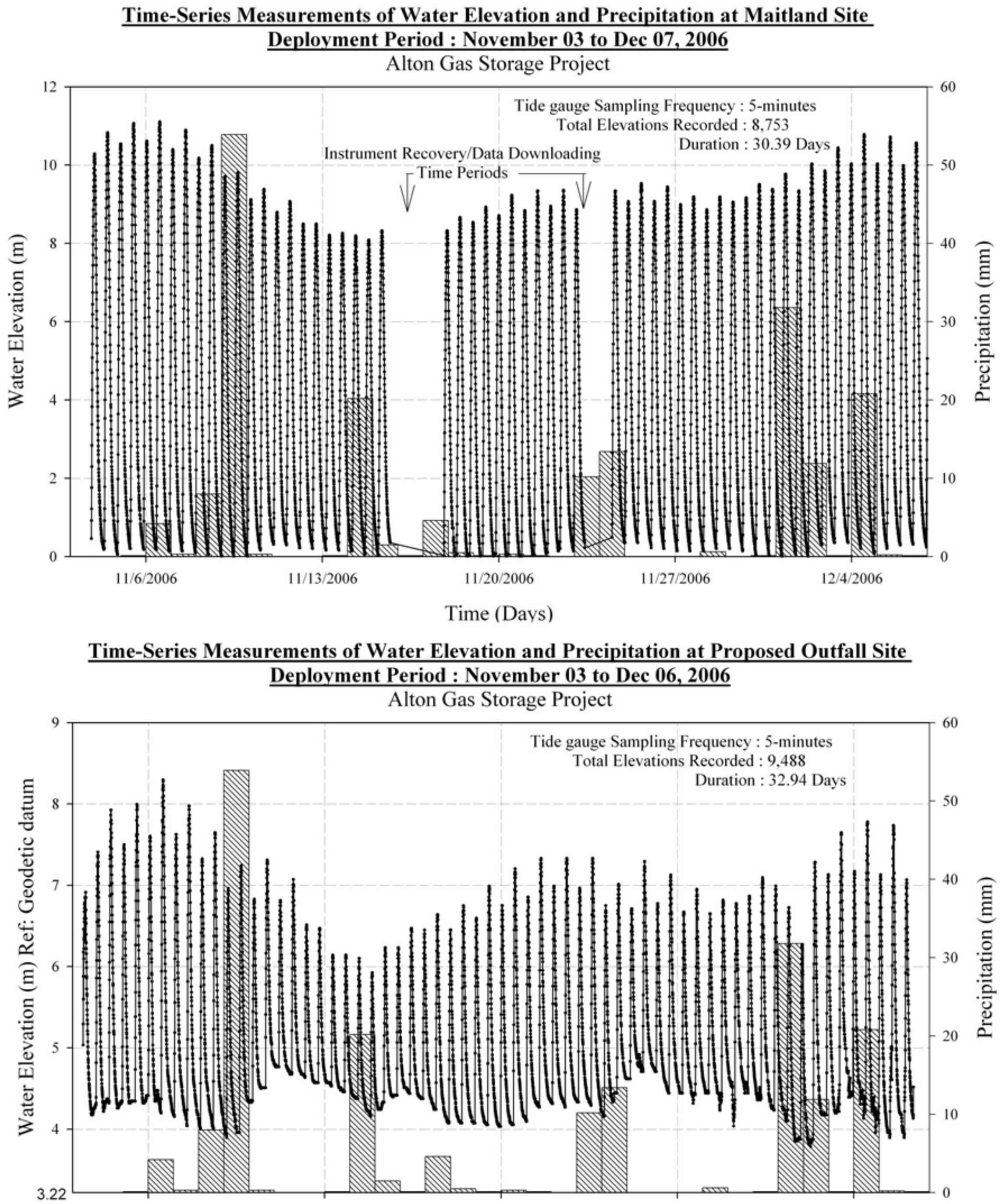


Figure 3.0 Time –Series Measurements of Water Elevation and Precipitation at Maitland (upper figure) and Proposed Outfall Site (lower figure)

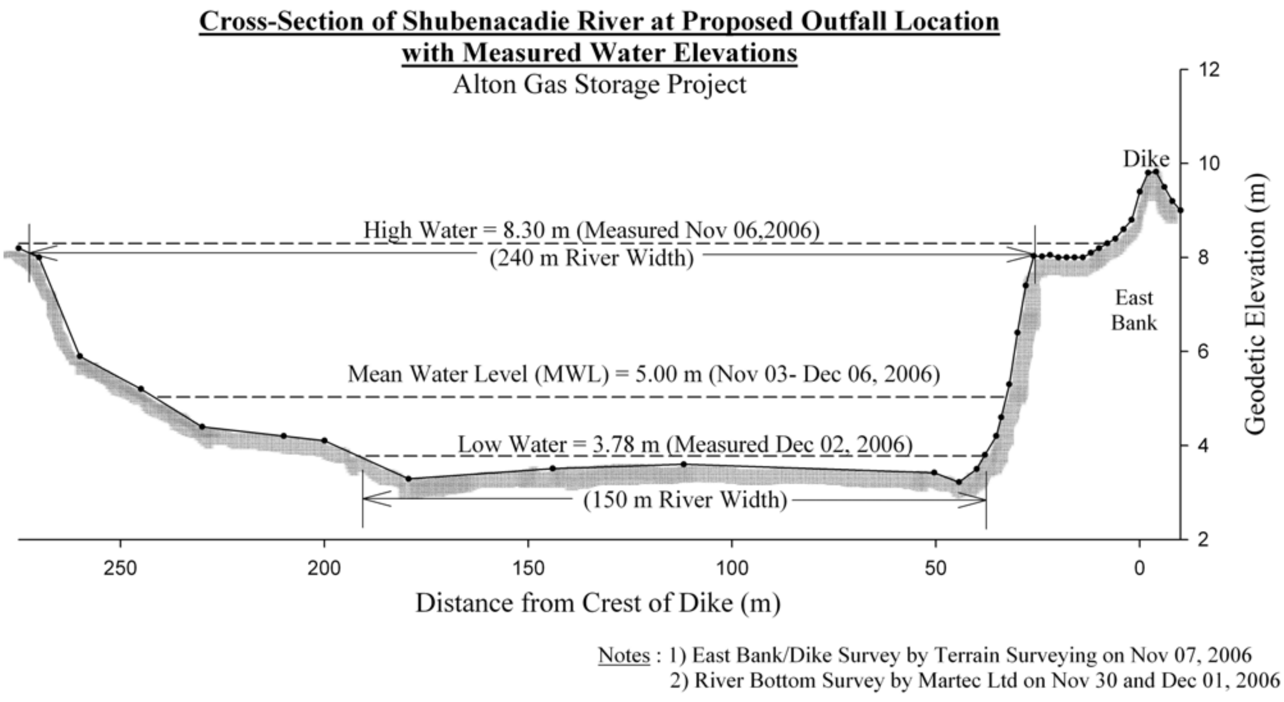


Figure 4.0 Water Elevation Data Superimposed on River Cross-Section (Outfall Location)

Further investigations were carried out to determine the frequency of time water levels at the proposed outfall site were above or below particular threshold values (i.e. MWL). Cumulative frequency distributions for the period Nov 03 – Dec 01, 2006 are depicted in Figure 5.0 for the following:

1. Cumulative distribution (A) of all water levels during the rising and falling tide (upper plots)

2. Cumulative distribution (B) of water levels during the falling tide only (lower plots)

Data presented in the plots provide the following information:

1. The most frequent water elevation that occurs during this period is 0.4 m (4.2 m Geodetic).

2. Water levels greater than MWL occurred for a time period of approximately 7.5 days (cumulative time) of the 28-day period. For the falling tide only, this reduces to approximately 5 days.

3. Probability distributions are clearly skewed towards the lower water elevations, which implies an asymmetrical profile of water elevation. Although high water levels occur at the site, the duration or frequency of time that these levels occur is quite small. The rapid rise and fall of the tide ("pulse") at the proposed outfall site is a common occurrence for both the small and large tidal range.

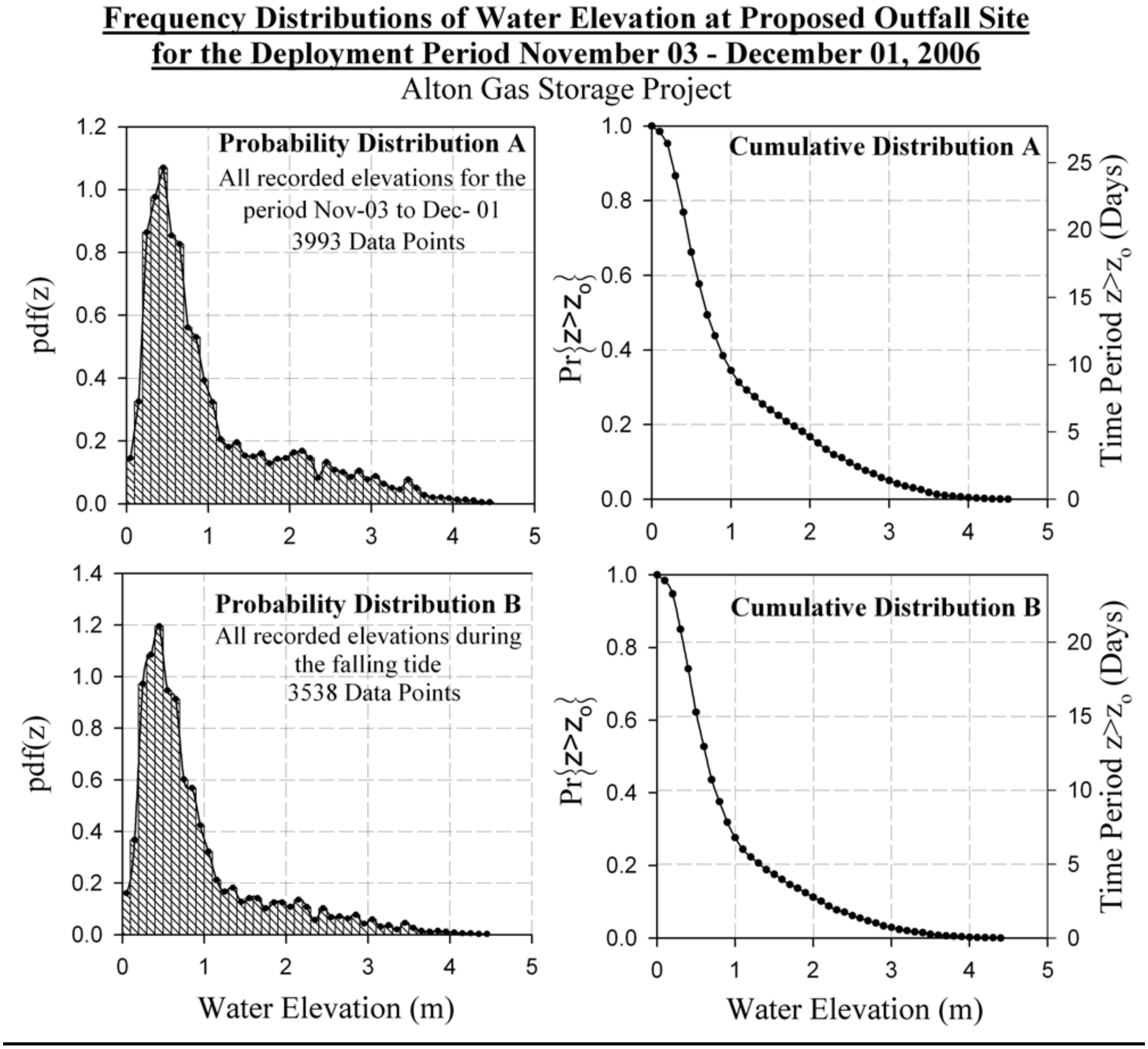


Figure 5.0 Frequency Distributions of Water Elevation at Proposed Outfall Site
(Note: Geodetic Elevation (m) = Water Elevation (m) + 3.8)

Dilution of brine with receiving waters will depend largely on the available depth and river flow rate during the period of discharge. The greatest dilution during the falling tide will occur within 3 to 4 hours after high tide. Water depths during this period are generally greater than 2.0 m and flows are quite large. Beyond this time, the water level typically becomes very shallow and is not conducive to efficient mixing conditions in the near field.

1.2 River Flow Trends and Variability

River flow rates in the Shubenacadie River are comprised of the predominant tidal flows and the secondary fresh water flows. River flows are highly variable and dependent on the particular reach within the river, the phase and amplitude of the tide, and amount of fresh water input from the relatively large watershed area. An important factor in the reliable prediction of natural salt-water intrusion to the upper reaches of the Shubenacadie River is an accurate knowledge of the proportion of freshwater flow. Obtaining reliable and accurate estimates of fresh water flows in the tidal reaches can however be problematic. In reversing tidal flow, conventional flow measuring techniques which depend upon routine measurement of water level alone and which deduce the river flow from this by the application of a rating curve, will not work. For measuring the river flow in the tidal reach itself, the most commonly employed method in large rivers is continuous gauging using boats equipped with current meters. For this reason, field surveys in the Shubenacadie River were carried out using a shallow-draft Zodiac boat equipped with a side-mounted ADCP mounted on a Catamaran type sled. This instrument can provide accurate estimates of currents (near-surface to bottom) and river flow rates (operating in transect mode).

Martec Ltd carried out four ADCP surveys in the Shubenacadie River during the fall of 2006. Three of those surveys were carried out at the proposed outfall site on Oct 16 (small tide), Nov 06 (large tide) and Nov 30 (moderate tidal range). The fourth ADCP survey was carried out near the river mouth (Maitland) on Dec 06 during a large tide. A typical ADCP transect of currents measured at the proposed outfall site is presented in Figure 6.0.

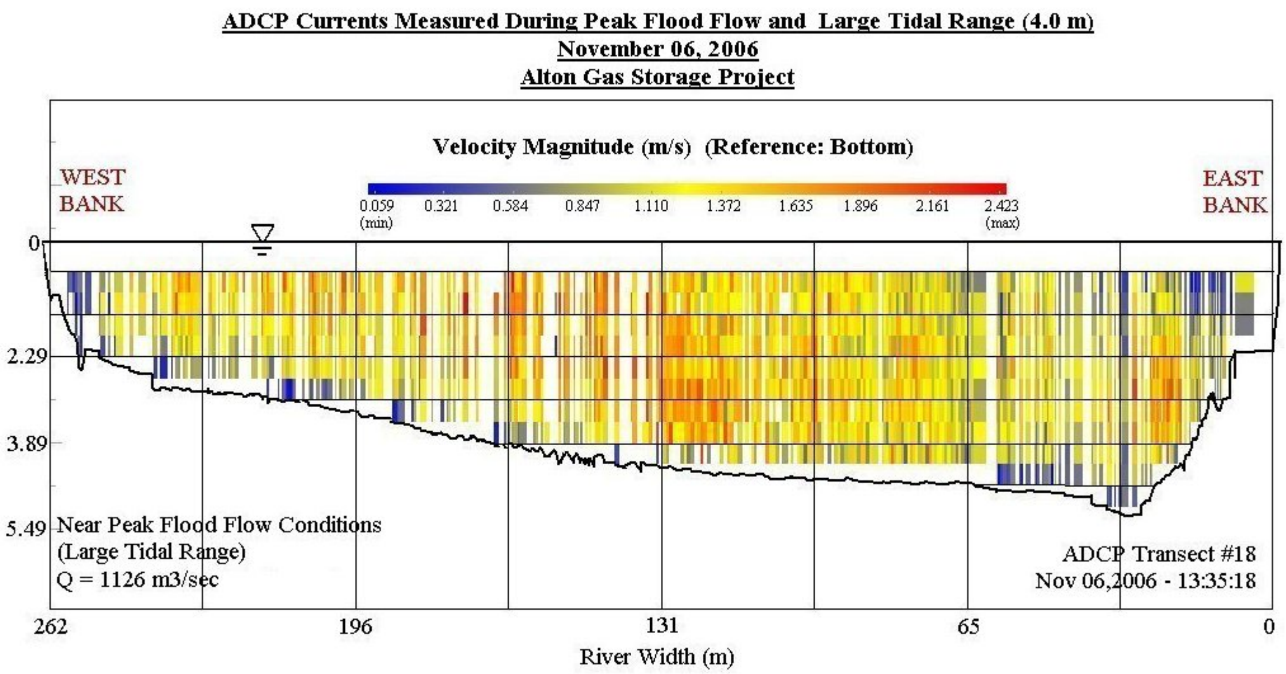


Figure 6.0 ADCP Currents Measured at Proposed Outfall Site During Peak Flood Flow

Figures 7.0 and 8.0 depict the ADCP surveys of measured river flow and corresponding water elevation for the proposed outfall site and Maitland. Based on the survey data, significant volumes of water is transported in and out of the Shubenacadie River over a tidal cycle. At Maitland on Dec 07, 2006, approximately 8000 m^3/sec of water entered the river during peak flood, large tidal conditions (10.4 m tidal range). At the proposed outfall site on Nov 06, 2006, approximately 1240 m^3/sec was flowing upriver during peak flood, large tidal conditions (4.1 m tidal range).

Measured river flow and water elevation data for the four surveys are summarized in Table 1.0. The peak ebb and flood flows, tidal range, and cumulative flood flow volumes are presented for each survey. The cumulative flood flow volume (tidal prism) was determined by computing the area under the flood flow curve (i.e. positive river flow values only).

Table 1.0 Summary of Measured River Flow and Water Elevation Data

ADCP Survey	**Date**	**Location**	**Tidal Range (m)**	**Peak Ebb Flow (m^3/sec)**	**Peak Flood Flow (m^3/sec)**	**Cumulative Flood Vol (m^3)**
# 1	Oct 16, 2006	Outfall Site	1.6 Small	-340	+380	+1,575,000
# 2	Nov 06, 2006	Outfall Site	4.1 Large	-805	+1240	+5,844,000
# 3	Nov 30, 2006	Outfall Site	2.7 Moderate	-440	+760	+3,240,000
# 4	Dec 07, 2006	Maitland	10.4 Large	-----(1)	+8000	+58,800,000

(1) Peak ebb flow too hazardous to measure transversely

For the large tidal range, approximately 10% of the cumulative flood volume that flows past Maitland flows upriver of the proposed outfall site. These measured values are useful for calibration of the detailed hydrodynamic model and to ensure the proper volume of water is numerically flowing across the boundaries. In addition, first-order estimates of salt mass transport can be determined for calibration of the water quality model (salinity as a conservative tracer). For example, water entering the Shubenacadie River at Maitland with an average salinity of 25 ppt (25,000 mg/l) is equivalent to 1.47 million metric tons of total salt mass entering the river per large tidal cycle, or, approximately 2.9 million metric tons of salt per day. A daily brine discharge of 9000 m^3 at 260 ppt (260,000 mg/l) is equivalent to 2,340 metric tons of salt per day. Comparison of the two gives a salt mass ratio of 1:1239.

Measured river flow and water elevation at the proposed outfall site (Figures 7.0 and 8.0) show that peak flood flow occurs approximately 30 to 60 minutes before high tide. Measured currents at peak flood flow are in excess of 2.0 m/s for the large tide (1.4 m/s for the small tide) at mid-channel. Once high tide is reached, the water continues to flow upriver and does so for a time period of approximately 30 minutes until slack water. Soon after the flow reversal, peak ebb flow is typically reached within 30 to 60 minutes. Currents measured during peak ebb flow are generally less than peak flood currents. After peak ebb flow, the flow gradually reduces for the remainder of the ebb flow period.

Shubenacadie River Flow and Water Elevation Measurements
at Proposed Outfall Site on Oct 16 and Nov 06, 2006
Alton Gas Storage Project

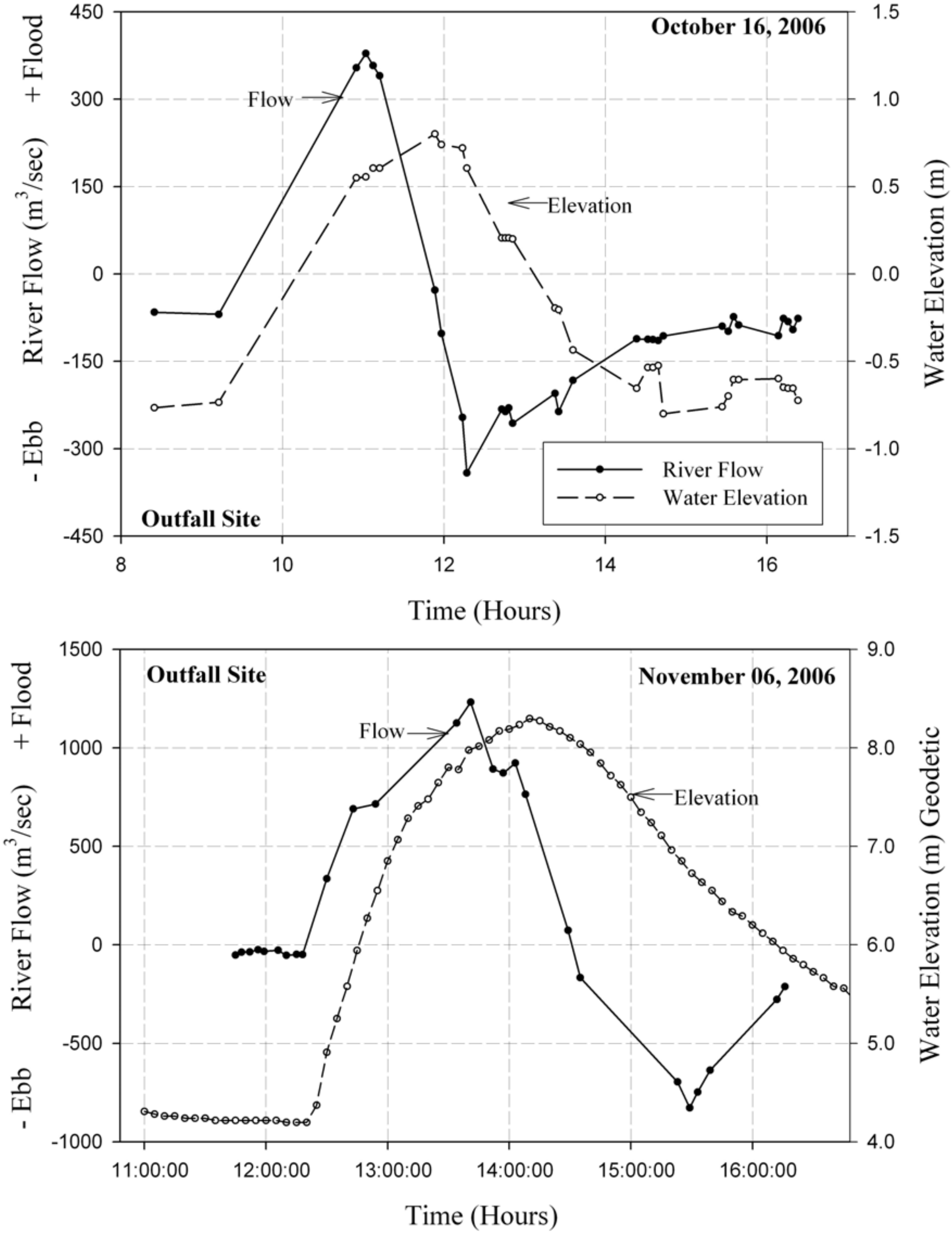


Figure 7.0 Flow Discharge and Water Elevation at Proposed Outfall Site
On Oct 16 (Upper Plot) and Nov 06, 2006 (Lower Plot)

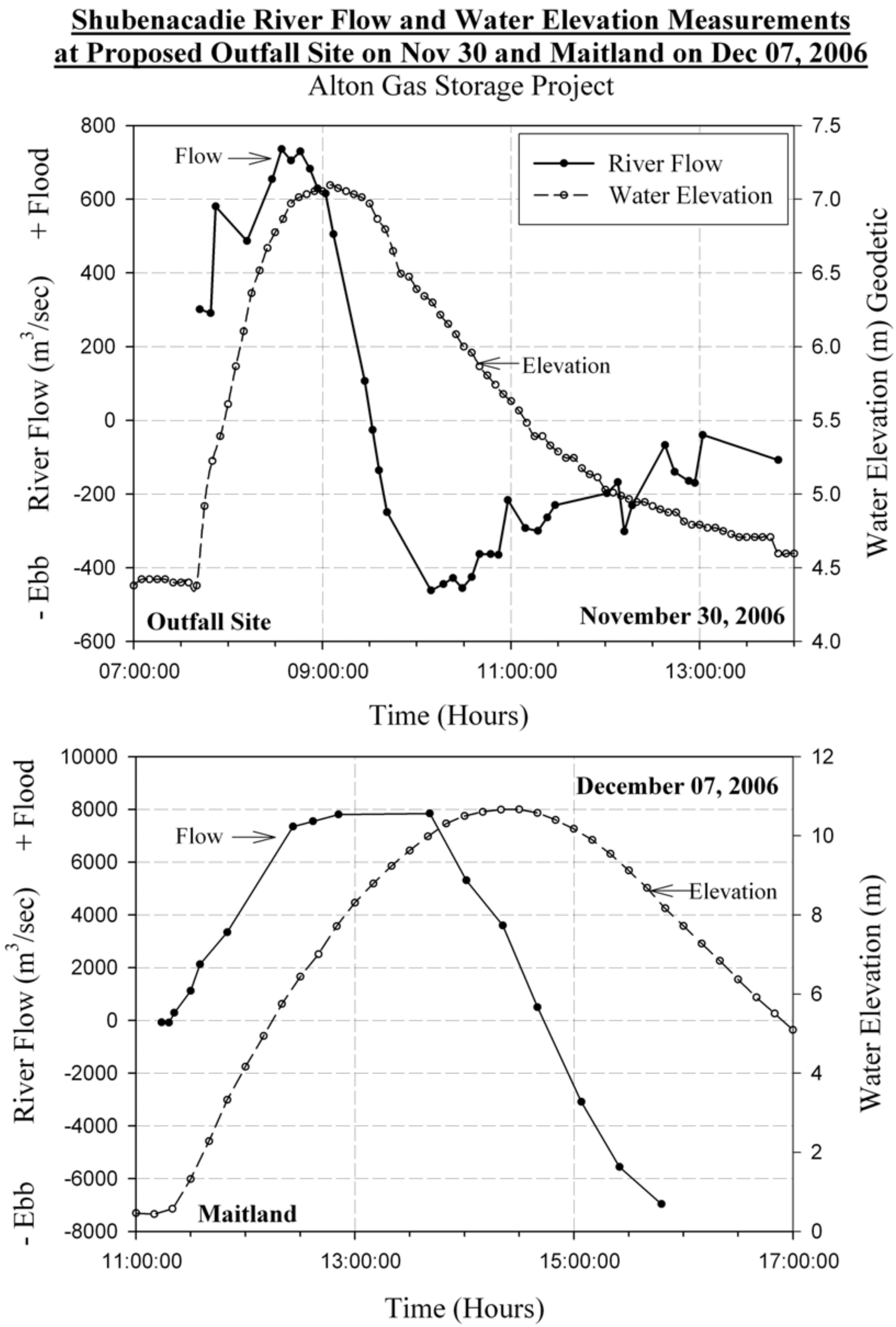


Figure 8.0 Flow Discharge and Water Elevation at Proposed Outfall (Nov 30 Upper Plot) And Maitland (Dec 06 Lower Plot)

The distribution of currents and flow across the river at the proposed outfall site are highly irregular but do show a consistent pattern where currents and flow near mid-channel are approximately 20-40 % larger than currents near the riverbanks. The river thalweg does vary with time and can shift away from the channel centerline during different stages of the tide.

Freshwater flow in the Shubenacadie River is highly variable and dependent on the amount of precipitation over the watershed area. The component of freshwater flow in the river was quantified by assessing salinity measurements at the mouth and the proposed outfall over a tidal cycle. Approximately 1-month of continuous salinity data (5-minute sampling) has been measured at both sites. The flow discharge curves also provide some insight into freshwater flow by measuring river flow just prior (within 30-minutes) to the arrival of the tidal bore. During this period of ebb flow the salinity is usually quite low and the water level remains fairly constant. As an example at the proposed outfall site, freshwater flows on Oct 16 and Nov 06, 2006 are estimated to be no more than 60 and 40 m^3/sec respectively.

Statistical long-term freshwater flow at the proposed outfall site can be estimated from the Water Survey of Canada (WSC) flow gauging stations upstream of the tidal limit in the Stewiacke River (Station # 01DG001 near Upper Stewiacke) and Shubenacadie River (Station # 01DG006 at Enfield). Computed flows for the entire river or at the proposed outfall site can be estimated by utilizing this long-term freshwater data and weighting the appropriate watershed area for the site of interest. Monthly freshwater flows computed for the river (Matrix Solutions Inc.) based on this procedure show that very low freshwater flows, less than 3.0 m^3/sec, can occur during the summer months. The largest freshwater flow in the river occur during the spring run-off (April) with mean and maximum monthly flows of 140 m^3/sec and 188 m^3/sec, respectively.

1.3 Salinity Trends and Variability

Measurements of salinity in the Shubenacadie River were carried out at the river mouth (Maitland) and the proposed outfall site (Figure 1.0) shows an estuary that is strongly influenced by freshwater flow and relatively large tidal forcing. Though the proposed outfall site is located approximately 20 kilometers upriver of the mouth at Cobequid Bay, a significant mass of salt from the Bay is transported upriver, albeit at lower salinity (generally less than 25 ppt) than the river mouth. Salinity measurements generally show predictable variations over the tidal cycle, such that salinities increase with the rising tide and decrease with the falling tide. Time-series measurements of salinity at the river mouth (Maitland) for the period November 03 to December 07, 2006 are presented in Figure 9.0.

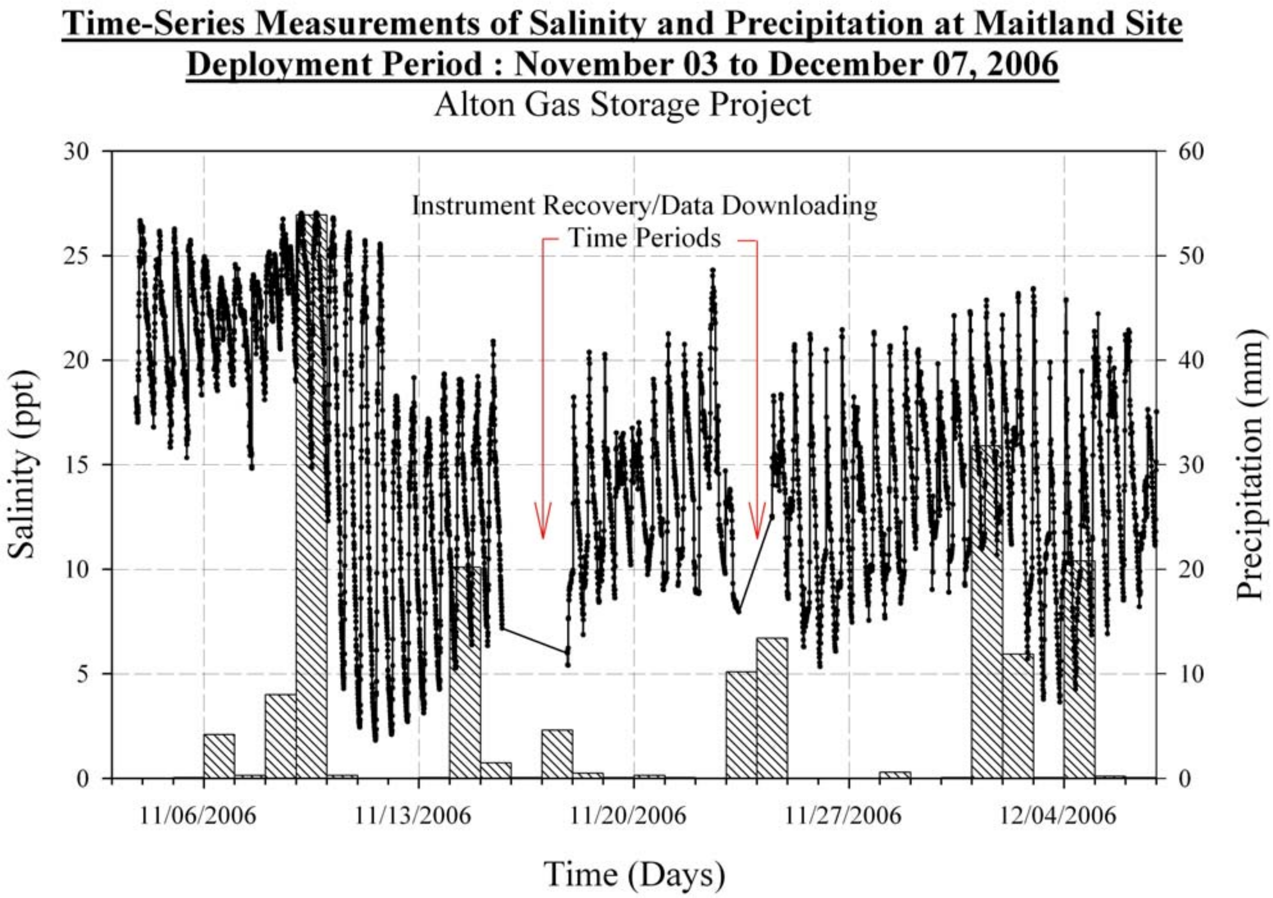


Figure 9.0 Time-Series Measurements of Salinity at River Mouth (Maitland)

The salinity signal clearly shows a sudden reduction in salinity after the Nov 11, 2006 rainfall event (54 mm). Prior to this event salinity during this 6-day period was as high as 27 ppt during flood flow and as low as 15 ppt during ebb flow. However, the large rain event significantly reduced the peak salinity during flood flow by approximately 9 ppt to 18 ppt (mean value of the peaks) for a period of 7-days. Salinity peaks gradually increased after this period towards the end of the time-series record. In addition to this reduction in peak salinity during flood flow, ebb flowing water from the river had a greater component of freshwater with minimum salinities as low as 2 ppt.

Salinity and water elevation measurements at the proposed outfall site for the deployment period of November 03 to December 30, 2006 (fall/winter season) show considerable variability with salinity varying between 0 to 18 ppt and water elevation between 3.88 to 8.30 m (referenced to geodetic datum). Some interesting trends are apparent in the time-series measurements, particularly when the data is plotted as a scatter diagram of salinity and corresponding water elevation (Figure 10). For comparative purposes, two additional surveys of salinity and corresponding water elevation measurements on August 22, 2006 and November 04, 2006 are plotted on the scatter diagram to demonstrate the salinity variability between summer conditions with low freshwater flow and fall conditions with relatively high freshwater flow. Both surveys had a similar tidal range of approximately 3.20 meters. The data presented in the scatter diagram show the following:

1. Data points of salinity and corresponding water elevation represent measurements at 5-minute intervals. The data has been divided for either ebb flow periods (black dot) or flood flow periods (red dot). By dividing the data set, trends in salinity and water elevation can be more clearly identified. Firstly, at the instant the tide begins to rise (Point A), measured salinity show a relatively freshwater environment.

2. Point A is referred to as the point of “salinity minima” and occurs consistently at the time of low tide flow reversal.

3. Salinity remains fairly low until the water rises to the 6.0-meter elevation (Point B). Data points in the scatter diagram clearly show this elevation as a “threshold boundary” between the relatively fresh river water and higher salinity water sourced from Cobequid Bay.

4. This is a very interesting trend because the visual appearance of the tidal bore arriving at the outfall site is actually relatively fresh “river water” that is being pushed back upriver by the rapidly rising tide in Cobequid Bay. Higher salinity ocean water does not appear to flow past the site until the water increases to elevations greater than 6.0 meters.

5. Salinity continues to increase rapidly from Point B to Point C where high tide is encountered. Although high tide is reached at Point C, river water continues to flow upriver even though the tide is dropping. Salinity continues to increase after high tide until slack water occurs (Point D).

6. Point D is referred to as the point of “salinity maxima” and occurs consistently at the time of high tide flow reversal.

7. During ebb flow (between Points D to A), salinity and water elevation continue to decrease to a minimum at Point A.

8. The summer survey shows similar trends in salinity/water elevation as the fall and winter surveys. However, because the freshwater flow during the August Survey was relatively low, a greater volume of salty water from Cobequid Bay can extend to the upper reaches of the Shubenacadie and Stewiacke Rivers. The salinity maxima recorded during the summer (Aug 22, 2006) survey was approximately 9 ppt higher than the fall (Nov 04, 2006) survey.

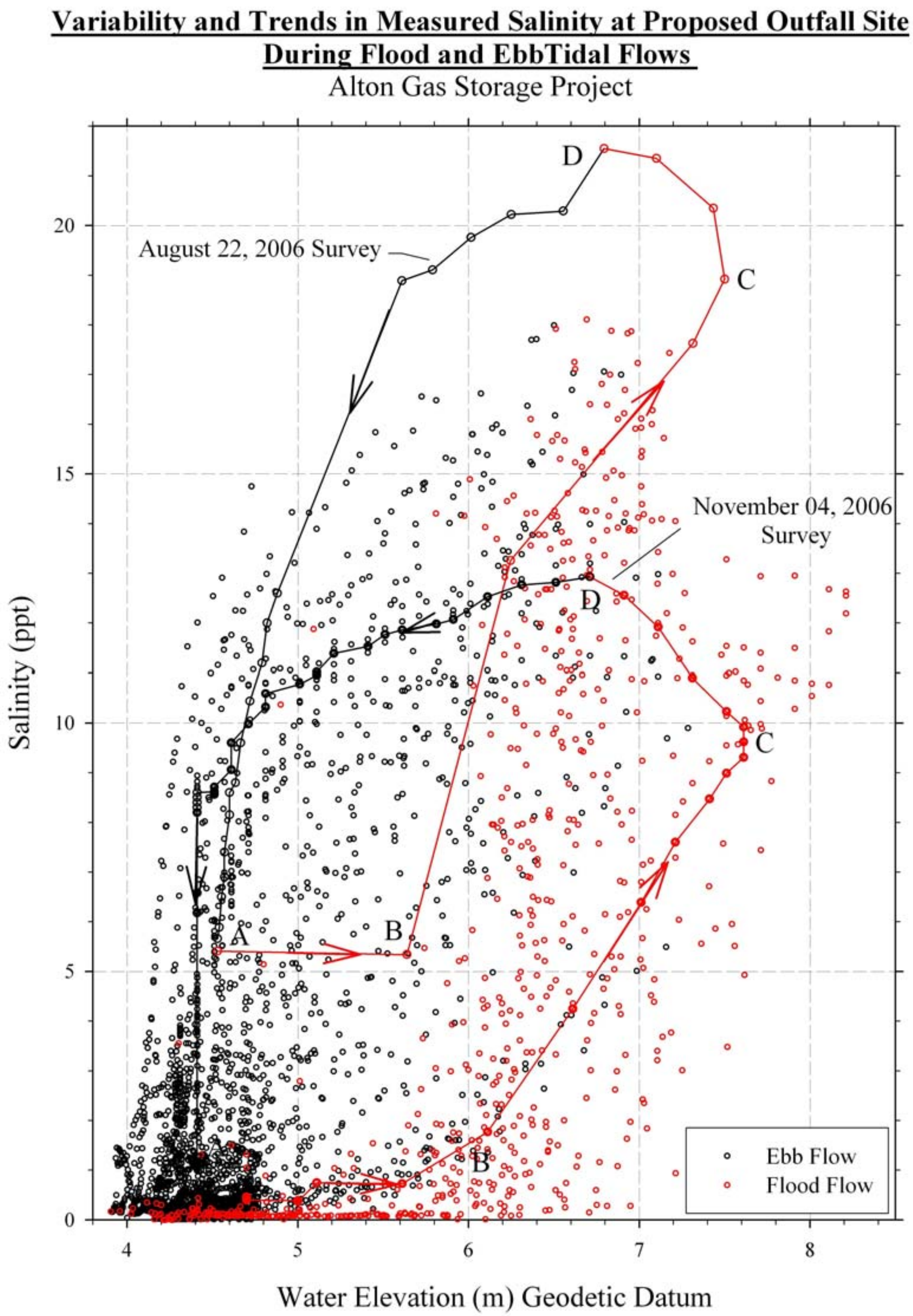
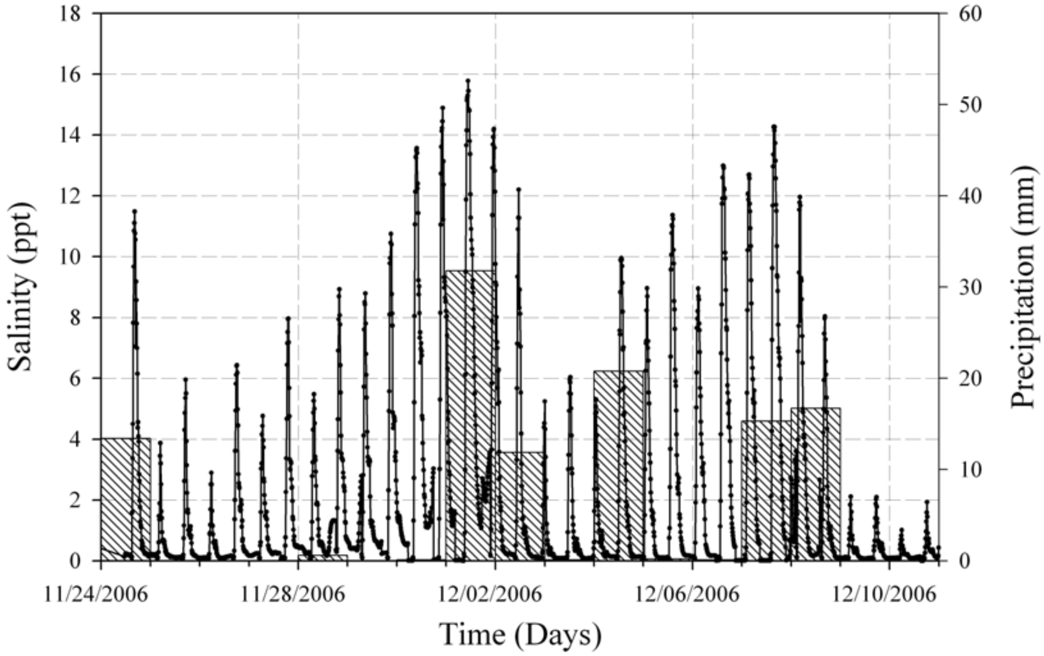


Figure 10 Scatter Diagram of Salinity vs. Water Elevation at Proposed Outfall Site

In reviewing the more recent time-series measurements of salinity and water elevation at the proposed outfall site (Nov 24 – Dec 11, 2006 and Dec 21 –30, 2006), as depicted in Figures 11 and 12, an interesting trend does appear on the graphs for the period between Dec 9 to 11, 2006. Tidal range over this period is quite small (typically below 1.5 meters) with salinity showing very little variability and generally less than 2 ppt for this 2-day period. Although over 30 mm of precipitation was recorded the previous 2-days, salinity at the outfall site remained low even during the flood flow periods. The physical processes that suppress salinity at the outfall site are very complicated but it appears that because the freshwater flows in the river were relatively high and the tidal range relatively small for this period, very little “new” salt water from Cobequid Bay can reach this far upriver. The relatively large freshwater water volumes contained along the 20-km river reach below the outfall appear to be simply pushed back during the small tide with very little mixing of salt water from Cobequid Bay. This observation also tends to support the findings described in the scatter diagram where “new” salt water does not appear in the rising tide until the 6.00-meter geodetic elevation is reached. For the period Dec 09-11, 2006 water elevations were very close to this threshold elevation.

The physical processes described above present conditions where volumes of “new” salt water from Cobequid Bay can at times be quite small at the outfall site. Because river water is simply being pushed back to the outfall site during these high freshwater/low tidal range conditions, it will be important to assess the period of time in which brine can be discharged during ebb flow. Understanding the periods of time that ebb flow waters passing the outfall site are effectively flushed into Cobequid Bay will be essential in limiting the amount of residual salt (from brine discharge) in the river

Time-Series Measurements of Salinity and Precipitation at Outfall Site
Deployment Period : November 24 - December 11, 2006
Alton Gas Storage Project



Time-Series Measurements of Water Elevation and Precipitation at Outfall Site Deployment Period : Nov 24 - Dec 11, 2006
Alton Gas Storage Project

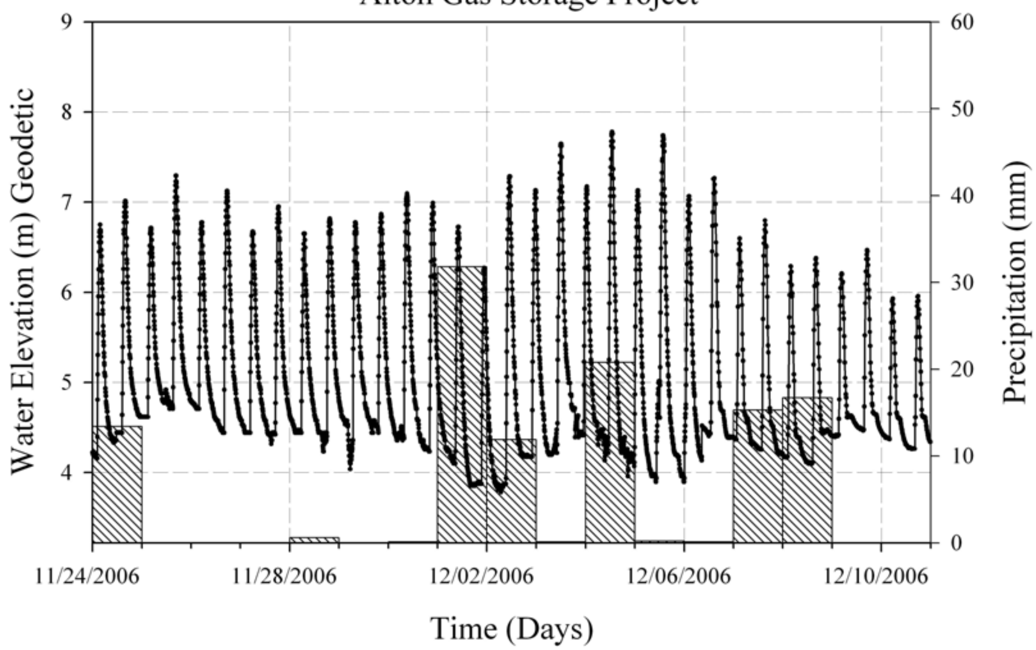
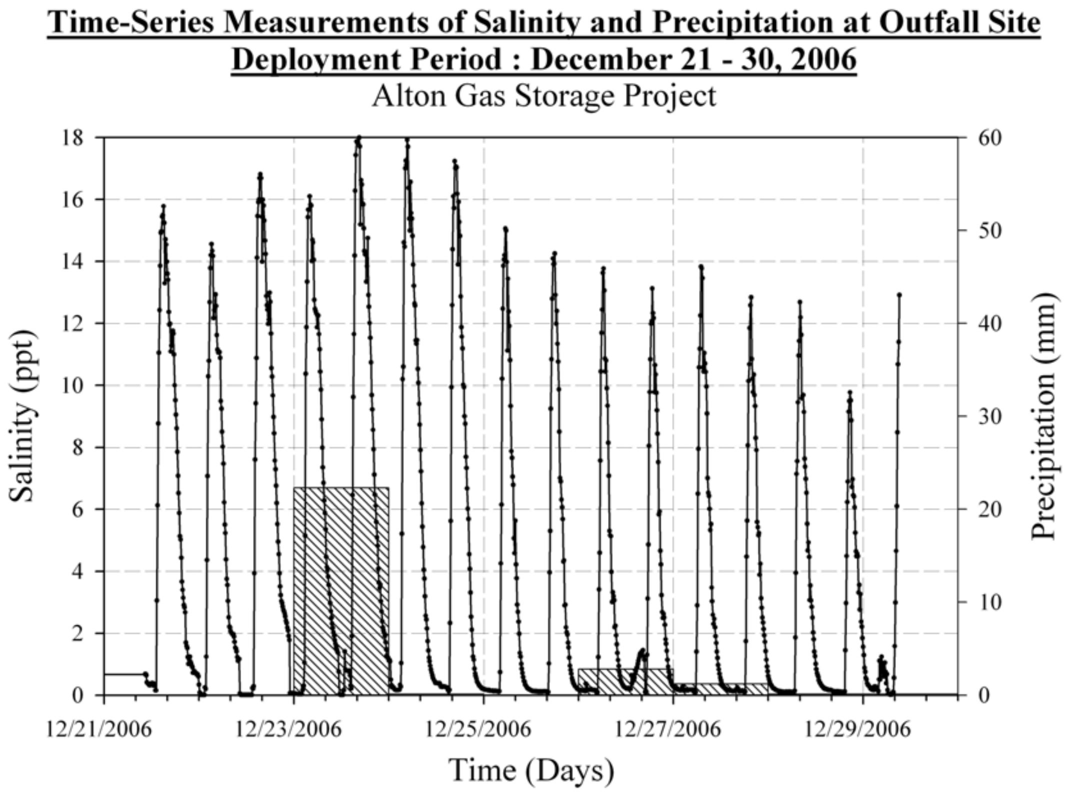


Figure 11.0 Time-Series Measurements of Salinity at Proposed Outfall Site (Nov 24-Dec 11, 2006)



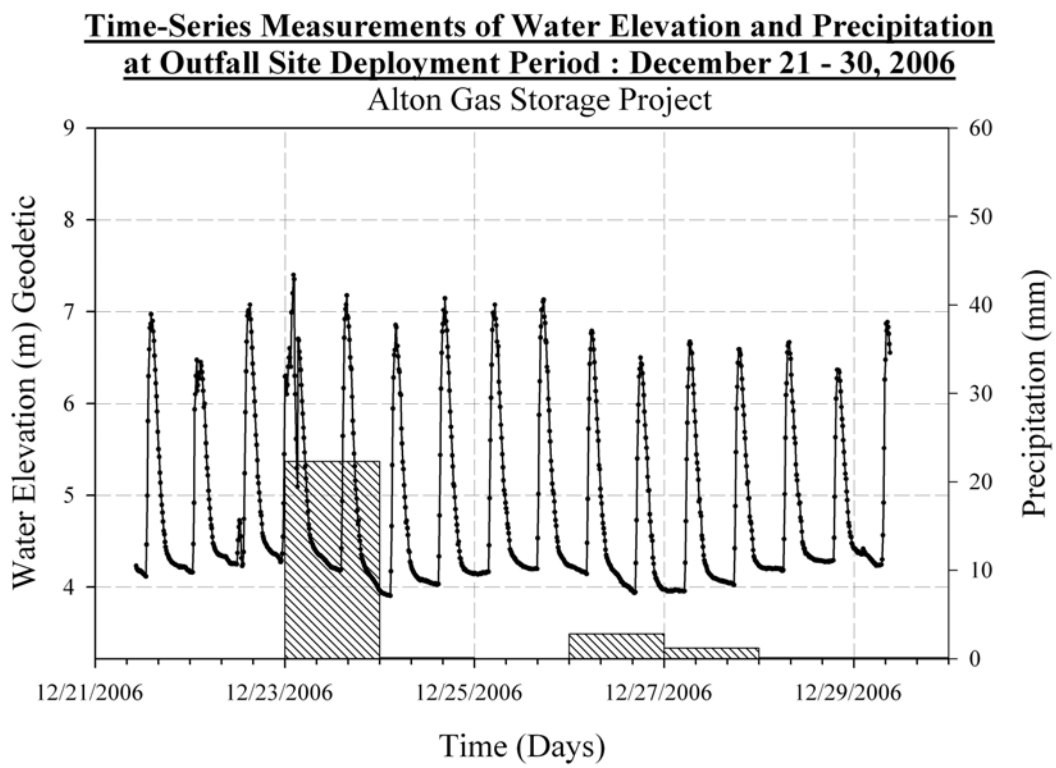


Figure 12.0 Time-Series Measurements of Salinity at Proposed Outfall Site (Dec 21-Dec 30, 2006)