Totten Inlet Circulation Study

3 January 2006  
EHI Job Number: 5514

Introduction
This study focused on the “over-all” flushing and circulation of Totten Inlet through current and water property measurements, during one complete tidal cycle on 9-26-05, as well as long-term (one month) “site-specific” in-situ data collection at the proposed shellfish farm site.

This report presents numerous oceanographic data products in the form of color current profiles, x-y plots, tabular text, and charts, in relation to the tidally forced circulation, as well as water properties, of Totten Inlet, WA. These data are referred to as Figures 1 – 43, and are attached in the Appendix following this text. Equipment descriptions are also attached at the end of the Appendix. Instrument set-up parameters are available upon request. All products and text presented herein will also be supplied as electronic files.

Methodology
The over-all survey consisted of establishing a series of transect lines across the inlet and using the over the side (OTS) acoustic Doppler current profiler (ADCP) to measure currents along these lines during the tidal cycle. Each OTS transect began near the south bank of the Inlet and extended toward the north bank. Transect 1 is near the mouth of the Inlet and transect 4 crosses the Inlet at the widest point, near the west end (Figure 1).

The OTS ADCP was programmed for 0.5m bins with an initial blanking distance of 0.5m with the transducer mounted at a depth of 0.5m. These values placed the first data point (center of bin 1) at 1.37m depth. Navigational control (position, speed, and heading) was maintained using a Hypack® integrated navigation system with differential global positioning system (DGPS) and electronic compass inputs. Transects were repeatedly surveyed over the same pre-plotted track-line, with the vessel operating at an average speed of 2.5 knots with as near a constant heading as could be maintained. These parameters allowed the ADCP to maintain bottom track throughout the survey and facilitated the collection of high-resolution water column data in relation to the ADCP ping rate (0.5 seconds) and bottom tracking capability, respectively. A magnetic variation of 20 degrees was applied to correct directional data (magnetic compass) coordinates. The ADCP bin size controls the vertical resolution, the boat speed and ADCP ping rate control the horizontal resolution, and the compass and magnetic deviation control the rotational resolution of the OTS survey.

This OTS survey was conducted from 1515 hrs. 9-26-05 Coordinated Universal Time (UTC) (0815 hrs. 09-26-05 Pacific Daylight Time (PDT)) to approximately 0230 hrs. 09-27-05 UTC (1930 hrs. 09-26-05 PDT). Six rounds of 4 transects were collected starting at the beginning of the flood tide and finishing at the end of the ebb tide (figure 2.). In total, twenty-five transects were recorded including a final run of transect line 3 over the acoustic Doppler profiler (ADP) site before demobilizing. A conductivity-temperature-depth (CTD) cast was taken over the ADP site at the completion of each round. Two additional casts were taken near the middle of transect
4, and near the deepest point of transect 1 after round 2, during peek flood tide and one additional cast was taken near the center of transect 2 during round 5, during ebb tide to observe any spatial variability in the water property data.

The site-specific data were collected with deployment of the ADP and CTD units housed within a trawl resistant bottom mount (TRBM (Figure 44)). These instruments were tested and initialized the morning of 9-26-05 and were then deployed (lowered to the inlet floor) from the Taylor Seafood vessel MABLE. The in-situ deployment site was specified by Taylor Seafood’s (see Figure 1, ADP arrow). Upon instrument recovery on 10-27-05 it was discovered that the underwater battery case for the ADP had flooded two hours after deployment on 9-26-05, this caused the ADP to power off at this point and no further data were collected. The CTD collected data for the entire one-month period. The ADP battery case was replaced, the CTD and ADP were re-initialized, and the TRBM was again deployed. Upon recovery of the TRBM on 11-29-05 complete data sets were downloaded from the ADP and CTD instruments.

OTS Data Interpretation

The OTS transects are presented as Figures 3 – 27 as color contour profile plots with both current magnitude and direction as well as a depth averaged X-Y line graph. For a point of reference, the transect OTS data plots are viewed as progressing into the inlet (e.g. toward the south). All transects were surveyed with the starting point near the east or southeast bank of the inlet, therefore all OTS products X-axis reference of “distance from start” places these data as viewed from looking “east to west”. Current velocities are reported in centimeter per second (cm/s), for reference: 51.4 cm/s = 1 knot = 1.15 miles per hour. CTD profile data collected during the OTS survey are presented as Figures 28 – 36 and may be referenced for correlation.

Round 1 (Figures 3 – 6) the beginning of the flood tide (reference Figure 2 versus plot title time).
Transect 1 (Figure 3) - data indicate low velocity (25 cm/s) water entering the inlet through the main channel. Flood water is initially evident at depth while surface waters are still weak and variable. The mixing and shear feature are not significant enough to alter the depth-averaged data, indicating majority flow as low velocity flood into the inlet.

Transect 2 (Figure 4) – magnitude and directional data indicate bank-to-bank homogenous flood-tide water moving into the inlet at low velocity.

Transect 3 (Figure 5) – low velocity westerly flow with some very low velocity mixing near surface over the main channel. The velocity drop and directional ambiguity near the north bank indicate water that has not yet started moving with the tide.

Transect 4 (Figure 6) – the low velocity and variable directions indicate this area is just starting transition from slack to flood water movement.
**Round 2** (Figures 7 – 10) flood tide.  
Transect 1 (Figure 7) – velocity has increased to an average of 50 cm/s in the main channel in the expected flood direction, to the south-southwest. A low velocity back eddy and mixing occurs from the east bank to approximately 400m offshore.  
Transect 2 (Figure 8) – similar to Round 1 data, bank-to-bank southwesterly flow, yet with slightly increased velocity near mid-channel.  
Transect 3 (Figure 9) – generally a southwesterly flow across the expanse of the inlet with a small area of very low velocity mixed-direction parcels near the north bank.  
Transect 4 (Figure 10) – predominantly west–southwesterly flow with increasing velocity towards mid-channel. Some mixing is still evident near the banks.

**Round 3** (Figures 11– 14) maximum flood tide.  
Transect 1 (Figure 11) – highest velocity observed during the OTS survey (>50 cm/s) through the main channel on the west side of the transect. Current reversal (eddy) with significant velocity in the eastern half of the transect. A current shear (near 0 cm/s) is evident at mid-channel.  
Transect 2 (Figure 12) – flood water (with >25 cm/s velocity) has followed the topographic shape of the inlet along the deeper channel now located near the southern bank. A reverse flow, averaging 25 cm/s, has begun along the northern bank.  
Transect 3 (Figure 13) – a consolidated lobe of flood water continues southwesterly through the main channel, mixing is occurring on the south bank and some reverse flow occurs near the north bank.  
Transect 4 (Figure 14) – velocity has decreased yet the flood remains evident near mid-channel. Water parcels at the north and south sides of the transect have begun low velocity variable direction mixing.

**Round 4** (Figures 15 – 18) end of flood tide to slack to the beginning of ebb.  
Transect 1 (Figure 15) – flood water continues to enter the inlet along the north bank, but at lower velocities. Reverse flow in the eastern half of the transect shows velocity now actually exceeding “inbound” water velocity. The current shear has moved ~100m west, closer to mid-channel.  
Transect 2 (Figure 16) – westbound flood water parcels continue through the main channel. Flow reversal has begun along both banks.  
Transect 3 (Figure 17) – a lobe of west bound very low velocity water parcels continue along the south bank of the main channel, directionally unified water has begun moving with slightly increasing velocity, in ebb direction, in the northern half of the transect.  
Transect 4 (Figure 18) – slack water, weak currents and variable direction.

**Round 5** (Figures 19 – 22) ebb tide.  
Transect 1 (Figure 19) – a lobe of ebb water is moving “outbound” along the center of the inlet. Mixing is occurring along both banks.  
Transect 2 (Figure 20) – bank to bank ebb tide water averaging <25 cm/s.  
Transect 3 (Figure 21) – bank to bank ebb tide water with a small lobe of stationary water center channel.  
Transect 4 (Figure 22) – the majority the inlet water has begun very slow movement (~10 cm/s) in the northeasterly ebb direction.
**Round 6** (Figures 23 – 26) ebb tide.
Transect 1 (Figure 23) – unified ebb water at 20 cm/s in the main channel, slack water with a lack of unified direction in the south half of the transect.
Transect 2 (Figure 24) – consolidated ebb flow at 10 – 20 cm/s across the expanse of the transect.
Transect 3 (Figure 25) – all water parcels basically moving in the ebb direction, the deep section of the main channel is still nearly slack with an ebb direction velocity of only 5 – 10 cm/s.
Transect 4 (Figure 26) – low velocity (5-10 cm/s) ebb water across the transect.
Transect 3 (Figure 27) (extra transect) – the water parcels in the main channel have low velocity and lack directional continuity. The northern half of the transect remains in a relatively unified ebb direction at ~10 cm/s.

**CTD Cast Data during OTS Survey**
Water property data parameters of pH, salinity, dissolved oxygen (DO), turbidity and temperature were collected on each cast. All parameters remained quite consistent throughout this tidal cycle with the exception of turbidity, which ran higher during flood tide. Only a slight variance occurred in surface water temperature as the survey progressed into the day and the rise in air temperature affected surface water. DO, pH, temperature and salinity generally stayed within a one unit of their respective scales, from cast to cast, below a depth of 7 m. Changes of these variables in the very near surface layer were not significant.

These water quality parameters are the same units as collected by Washington State Department of Ecology (WDOE) Marine Water Quality Monitoring Program. This offers a comparison to the last online data available from the WDOE Windy Point sample station. The Windy Point station is near centerline of OTS Transect 3. The online data chosen for comparison is September 1999 and can be accessed through the following link:

Comparison of these WDOE data to the OTS “CTD casts over ADP” site data, which are separated by 6 years, indicates considerable consistency in all categories. September 2005 data generally average ~1 mg/l lower in DO, 1 degree (C) higher in temperature, 1 PSU higher in salinity and 0.3 counts higher in pH when compared to WDOE 1999 data.

All CTD data collected during the OTS survey are presented as following:
Table 1. CTD cast locations and depths.
Figure 28. Round 1 CTD cast profiles over ADP.
Figure 29. Round 2 Range 4 CTD cast profiles.
Figure 30. Round 2 CTD cast profiles over ADP.
Figure 31. Round 2 Range 1 CTD cast profiles.
Figure 32. Round 3 CTD cast profiles over ADP.
Figure 33. Round 4 CTD cast profiles over ADP.
Figure 34. Round 5 Range 2 CTD cast profiles.
Figure 35. Round 5 CTD cast profiles over ADP.
Figure 36. Round 6 CTD cast profiles over ADP.
Additional CTD casts were acquired on October 27 prior to recovery of and prior to redeployment of the TRBM. These profiles offer correlation to the in-situ CTD data, comparison to the OTS CTD data, and are presented as:
Figure 37. Recovery CTD cast profiles over ADP.
Figure 38. Redeployment CTD cast profiles over ADP.

**In-Situ ADP**
The ADP data collected from October 27 through November 29, 2005 indicate consistent data in relation to the September 29 OTS survey data. Current magnitude rarely exceeds 50 cm/s and tends to run slightly faster on flood tide. Current direction is consistently to the southwest during flood tide and northeast during ebb.

One item of that may be of interest in these data in relation to this site as a potential shellfish farm, is that there is not any considerable “lag” time observed at the 0 cm/s crossing of the Average Current Magnitude graph. In other words, there is not a considerable slack tide at this site, the water parcels are generally moving in one direction or the other, regardless of tidal stage.
The In-Situ ADP data are presented as:
Figure 39: ADP current magnitude and direction.

**In-Situ CTD data**
In-Situ CTD data were collected for a two-month period (September 26 through November 29, 2005). The break in the data on October 27 was for servicing of the instrumentation and redeployment due to failure of the ADP battery case. The water properties collected were salinity, depth, temperature and DO. It should be noted that the CTD was mounted inside of the TRBM, on the platform base, which places the instrument only 2 inches above the seabed. This proximity to the seabed may attribute to the continual low DO values. Also, the interior of the TRBM will experience reduced water circulation, possibly delaying response time to conditional changes.
The In-Situ CTD data plots are presented as:
Figure 40. Deployment 1 In Situ CTD data
Figure 41. Deployment 2 In Situ CTD data.
Figure 42. Deployment 1 In Situ CTD measured versus predicted tides.
Figure 43. Deployment 2 In Situ CTD measured versus predicted tides.

**Summary**
The composite of OTS current meter data collected indicate a trend of 25-50 cm/s flood tide (southwesterly) water, which decreases in velocity as distance west from the inlet mouth increases. The flood tide southwesterly velocity dissipation occurs due to topographic change between OTS Transects 2 and 3 as the channeling effect of the deep, narrow inlet mouth is lost with transition into the wider, shallower main body of the inlet. Significant eddy currents occur during maximum flood. Ebb tide velocities (<25 cm/s) averaged much lower than flood with only a slight increase in velocity as the water parcels move easterly toward the inlet mouth.

Water parcel circulation over the proposed shellfish farm site began on Round 1 (one hour after slack at the beginning of the flood tide) and continued through Round 4 (at the end of flood and
beginning of slack tide). Flushing (easterly parcel flow), although at very low velocity, occurred at the proposed shellfish farm site shortly after slack, early in the ebb tide cycle and continued until one hour before slack tide. To summarize, there was measurable water movement at the proposed site immediately before and after slack water periods during the OTS survey.

Water properties observed during the OTS survey remain very consistent throughout the tide cycle observed, the only exception being a station-to-station variance in turbidity. These data offer strong correlation when compared to historic WDOE CTD data at this site.

In-Situ ADP data coincide with the OTS data pertinent to the proposed shellfish farm site, which indicate ventilation and flushing occurs through consistent, low velocity water movement during both flood and ebb tidal cycles. In-Situ CTD data produced consistent water property data as would be expected at the seabed in this area.
Appendix
Reference Tide During OTS Survey
Figure 3. Round 1 Transect 1.
Figure 4. Round 1 Transect 2.
Figure 5. Round 1 Transect 3.
Figure 6. Round 1 Transect 4.
Figure 7. Round 2 Transect 1.
Figure 8. Round 2 Transect 2.
Figure 9. Round 2 Transect 3.
Figure 10. Round 2 Transect 4.
Figure 11. Round 3 Transect 1.

Site: Totten Inlet; Transect 1 - Flood Tide - September 26, 2005 19:07
Figure 12. Round 3 Transect 2.
Figure 13. Round 3 Transect 3.
Figure 14. Round 3 Transect 4.
Figure 15. Round 4 Transect 1.
Figure 18. Round 4 Transect 4.
Figure 19. Round 5 Transect 1.
Figure 20. Round 5 Transect 2.
Figure 21. Round 5 Transect 3.
Figure 22. Round 5 Transect 4.
Figure 24. Round 6 Transect 2.
Figure 25. Round 6 Transect 3.
Figure 26. Round 6 Transect 4.
Figure 27. Round 6 Transect 3 (extra transect).
Table 1. CTD cast locations and depths.

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<th>Date (UTC)</th>
<th>Time (UTC)</th>
<th>Location</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
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Figure 30. Round 2 CTD cast profiles over ADP.
Figure 31. Round - 2 Range 1 CTD cast profiles.
Figure 32. Round 3 CTD cast profiles over ADP.
Figure 33. Round 4 CTD cast profiles over ADP.

Tottren Inlet
CTD - Cast Profile
Round 4 - ADP, Ebb Tide

Turbidity sensor out of alignment.
Totten Inlet
CTD - Cast Profile
Round 5 - Range 2, Ebb Tide

Figure 34. Round 5 – Range 2 CTD profiles over ADP.
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Figure 43. Deployment 2 In Situ CTD measured versus predicted tides.
Table 2. Equipment Description

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