The near-bottom current regime and the role of the benthic nepheloid layer in transport and accumulation of particulate matter in Puget Sound, Washington

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Acknowledgments

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Project Summary

Historical physical oceanographic data reveal the presence of a 60-80 meter thick, turbid benthic nepheloid layer (BNL) in the near-bottom waters of Puget Sound (Figure 1). The BNL is likely formed during neap tides when intrusions of Pacific Ocean waters are able to move southward into Puget Sound through Admiralty Inlet (Cannon et al. 1990). Where shoreline headlands constrict water moving through the Sound, the estuary floor is characterized by pairs of depressions separated by a shallower axial ridge (Figure 2). A restricted passage tends accelerate tidal flow, resulting in faster flood currents on the western side of the basin, and faster ebb currents on the eastern side. Whereas the near-surface (above 200 m depth) current structure in the Main Basin has been extensively studied (Ebbesmeyer and Cannon 2000, 2001; Sauers 2000; Kende 2001), the relationship between tidal currents, the BNL, and the formation of this W-shape has never been investigated. This relationship will be investigated using an array of measurements over a transect crossing the most striking example of these depressions. Over two cruises conducted during March 2004 on the R/V *Clifford A. Barnes*, an acoustic Doppler current profiler (ADCP) will measure current velocities by running a racetrack pattern during a spring (strong) and a neap tide to obtain the full range of tidal currents. The racetrack is located in the Main Basin of Puget Sound from Jefferson Head to approximately Point Wells. In addition, a conductivity, temperature, and depth (CTD) profiler will record salinity, temperature, and light transmission throughout the water column at three stations within the ADCP racetrack. I will attempt to calculate particle concentration in the water based on light attenuation levels as recorded by the CTD. Sediment grain size, distribution, and deposition rates obtained from classmate Maureen Davies' research will also be incorporated into the analysis. Understanding

how particulate matter is transported and deposited throughout the Main Basin may provide key insights into the sources and distribution of chronic pollutants in Puget Sound.

Introduction

Puget Sound circulation

Puget Sound is a fjord-like estuary located on the western side of Washington state (Figure 2). Connected to the Pacific Ocean by way of the Strait of Juan de Fuca, the Sound consists of four primary basins, from north to south: Whidbey Basin, Main Basin, Hood Canal, and South Sound (Burns 1985). Fjords are formed when retreating glaciers and subglacial flows scour the land surface. They are defined by the presence of a sill at their mouth, and Puget Sound is no exception. Admiralty Inlet possesses two sills, the shallowest at about 65 m. Main Basin is connected to the Strait of Juan de Fuca through Admiralty Inlet, and is the largest basin by both length and volume.

Circulation in the Puget Sound is estuarine, and driven by tides. Warm freshwater from rivers, urban runoff, and other drainage sites flows out near the surface, while dense saltwater from the Pacific Ocean flows in at depth. This circulation resembles the salt wedge typically recorded at a river mouth during flood tide, only on a much larger scale. Current research indicates that the deep water of Puget Sound is renewed fortnightly, based on the spring-neap cycle of the moon (Cannon et al. 1990). It is postulated that these deep water intrusions from the Pacific are able to transit southward over the Admiralty sills when the tidal currents are weakest. Because this water flows along the bottom of the Sound, it forms a turbid benthic nepheloid layer as bottom sediments are resuspended (Holmes, M. pers. comm.).

The physical transport of nutrients, sediment, and therefore pollutants through Puget Sound by tidally-induced currents determines the quality of the water in the Sound. As one wise observer notes, “The health of the water affects everybody!” (Maynor, J.M. pers. comm.)

Background

One predicament facing this research project is the apparent sparseness of data connecting current regimes with sedimentary processes. Many recent studies have focused on the current regime in the upper water column because of a proposed sewage plant in north King County/south Snohomish County (Ebbesmeyer and Cannon 2000, 2001). Two University of Washington alumnae collected ADCP data in the Junction region (Sauers 2000; Kende 2001). Ed Baker conducted a thorough analysis of the suspended particulate matter in Elliot Bay, but that research occurred in the early 1980's (Baker et al. 1983; Baker 1982). A class of 2003 student conducted research that correlated heavy metal concentrations in sediments with their position relative to a recurring eddy (Bever 2003). It is difficult to record near-bottom currents with great accuracy because of bathymetric interference with the reflecting ADCP signal. Sediment collection in the Main Basin is also difficult because of the depth. However, many attempts have been made at both physical and geological measurements. Several groups, such as the Washington State Department of Ecology (DOE) and the Puget Sound Ambient Monitoring Program (PSAMP) have collected data on currents, light transmission and nutrients for the last decade. Though the data are readily available, the relationship between tidally-generated currents, the BNL, and the W-shaped bottom morphology have gone unexplored. To date, there is very little research in Puget Sound correlating near-bottom currents with their possible impact on the resuspension and transport of sediment.

The W-shaped seabed occurs in two other locations in the Main Basin: in Possession Sound, sound of Whidbey Island, and also from West Point near Seattle to Skiff Point on the Kitsap Peninsula. Research will occur over the most dramatic of the three, from Point Wells to Jefferson Head. The current meter study conducted by Ebbesmeyer and Cannon (2000) in this area shows that incoming water hugs the western boundary, and is slower, deeper, and more diffuse relative to the higher-velocity core of water flowing out at the surface. My primary hypothesis is that velocity shear between water masses is creating a vertical zone of low- to no-net-motion over the axial rise, leading to the deposition of fine grain sediments. The end result of this deposition is the W-shape across the channel. However, fathometer data collected during a preliminary cruise revealed several slump or landslide deposits in the flank depressions. This suggests that convective currents generated by mass wasting could be responsible for the axial rise. Another theory is that the channel is entirely glacially carved. In addition, all three hypotheses could be correct to some degree. If no correlation is found between current speeds and sediment grain size, then the physical transport mechanism may be ruled out as a cause of the W-shape.

The discovery of the mechanism(s) responsible for creating this morphology will tell scientists much about how sediment, nutrients, and pollutants are transported at depth through Puget Sound, and also has the potential to end the debate between geologists and oceanographers over whether the present bathymetry is due primarily to glacial scouring during the last glacial epoch or to the modern depositional environment.

Proposed Research

Data collection

Volumetric particle transport is determined by the carrying capacity of a flow, which is a function of its speed. By obtaining the full spectrum of near-bottom tidal currents, conclusions about the capacity of the flow can be made. The capacity describes a flow's ability to erode, entrain, transport, or deposit particles of specific densities. Constant monitoring of the currents is not possible; therefore, ADCP data will be collected on the *R/V Barnes* during both a spring tide and a neap tide to obtain both the highest and the lowest current velocities. The transitional period between tidal stages is when the greatest current speeds occur. A spring tide, where fortnightly tidal currents will be greatest, occurs over the cruise conducted 10-12 March 2004. The neap tide, during which currents are at their weakest, occurs on 29 March. However, in order to allow time for a potential deep water intrusion to transit southward to the Edmonds/Seattle area, data should be collected no earlier than 31 March.

To complete the ADCP work, a racetrack pattern will be run across the Main Basin stretching from south of Jefferson Head to approximately Richmond Beach (Table 1), which is south of Point Wells. The distance around this track is approximately 13 km. For adequate ADCP resolution and to reduce sampling error, the *Barnes* will travel at 11 km h^{-1}. In addition, three CTD casts will be made along the track line to gather data on salinity, density, and light attenuation throughout the water column (Table 2).

Historic light attenuation data are available electronically through the University of Washington School of Oceanography.

Project budget

Funding for this project is provided entirely by the University of Washington's School of Oceanography. Field work for this research requires two days of ship time (Table 3).

Data analysis

ADCP data are best processed by a computer program. Matlab will be used to visualize flow regimes throughout the water column. Directional components of the velocity, i.e. east-west and north-south, will also be mathematically separated in Matlab.

Light attenuation readings from the CTD can be converted into particle concentrations in the water column. These calculations may be especially helpful in visualizing what type of transport (suspended, transitional, or bedload) is occurring at different depths in the water column, and lead to a better understanding of the composition and development of the benthic nepheloid layer.

Printouts and electronic files of historical light transmission readings are available. These will be compared to data collected during both cruise days to see whether there is a change in the physical properties and extent of the BNL.

The final analysis will describe the capacity of the BNL to erode or deposition sediment across the Main Basin, and the impact that resuspension may have on current and future contaminant levels in the deep sediments of Puget Sound.

References

Baker, E.T. 1982. Suspended particulate matter in Elliot Bay. NOAA Technical Report ERL 417-PMEL 35.

Baker, E.T., G.A. Cannon and H.C. Curl, Jr. 1983. Particle transport processes in a small marine bay. Journal of Geophysical Research. **88**: 9661-9669.

Bever, A. 2003. Concentration of heavy metals in sediments beneath tidally induced eddies; a case study from Hood Canal, Puget Sound, Washington. Unpubl. B.S. thesis. Univ. of Washington.

Burns, R. 1985. The shape and form of Puget Sound. University of Washington Press.

Cannon, G.A., J.R. Holbrook, and D.J. Pashinski. 1990. Variations in the onset of bottom-water intrusions over the entrance sill of a fjord. Estuaries. **13**:31-42.

Ebbesmeyer, C.C. and G.A. Cannon. 2000. Interim ocean integration report #1. Unpubl. Draft for Brightwater marine outfall siting study, King County, Washington.

Ebbesmeyer, C.C. and G.A. Cannon. 2001. Review: Puget Sound physical oceanography related to the Triple Junction region. Brightwater marine outfall siting study, King County, Washington.

Finlayson, D.P., R. Haugerud and R. Greenberg. 2001. Building a seamless digital elevation model of the Puget Sound Basin, Puget Sound regional research 2001: Abstracts and biographies, Puget Sound Water Quality Action Team, Olympia, Washington.

Kende, A. 2001. Characterization of current behavior and circulation in theTriple Junction of Puget Sound, WA. Unpubl. B.S. thesis. Univ. of Washington.

Sauers, K. 2000. Tidal current structure around Point Edwards in Puget Sound, Washington. Unpubl. B.S. thesis. Univ. of Washington.

Sternberg, R.W. 1972. Predicting initial motion and bedload transport of sediment particles in the shallow marine environment, p. 61-82. *In* D.J.P Swift, D.B. Duane, and O.H. Pilkey [eds.], Shelf sediment transport: process and pattern. Dowden, Hutchinson & Ross, Inc.

Table 1. Location of ADCP waypoints and CTD casts.

Station Name	Latitude (N)	Longitude (W)	Depth (m)
CP 1	47 44.32’	122 28.34’	-
CP 2	47 45.80’	122 23.75’	-
CP 3	47 45.61’	122 23.61’	-
CP 4	47 44.13’	122 28.21’	-
SK 1	47 45.025’	122 25.78’	289
SK 2	47 45.29’	122 24.935’	199
SK 3	47 45.455’	122 24.415’	236

Table 2. Timing of data collection.

Date	Station	Time (PDT)	Operation	Time required
12 Mar 04	CP 1	1100-1230	ADCP	1.5 hours
12 Mar 04	CP 2		ADCP	
12 Mar 04	CP 3		ADCP	
12 Mar 04	CP 4		ADCP	
12 Mar 04	SK 1	1230	CTD cast +ADCP	1.5 hours for all 3 casts
12 Mar 04	SK 2	1300	CTD cast +ADCP	
12 Mar 04	SK 3	1330	CTD cast +ADCP	
31 Mar 04	CP 1	1030-1200	ADCP	1.5 hours
31 Mar 04	CP 2		ADCP	
31 Mar 04	CP 3		ADCP	
31 Mar 04	CP 4		ADCP	
31 Mar 04	SK 1	1200	CTD cast +ADCP	1.5 hours for all 3 casts
31 Mar 04	SK 2	1230	CTD cast +ADCP	
31 Mar 04	SK 3	1300	CTD cast +ADCP	
31 Mar 04	CP 3	1330-1500	ADCP	1.5 hours
31 Mar 04	CP 4		ADCP	
31 Mar 04	CP 1		ADCP	
31 Mar 04	CP 2		ADCP	

Table 3. Project budget.

Category	Item	Provided By	Cost	Days required	Total Cost	Cost to Project
Ship & Equipment	*R/V Clifford A. Barnes*	School of Oceanography	$1700/day	2	$3400	$0
	ADCP		(included)	-	$0	$0
	CTD		(included)	-	$0	$0

Total funding required: $3400.00

Figures

Figure 1. A plot of light attenuation and other physical properties from PRISM station 28, located south of the study area. The transmissometer records a relatively constant percentage of light attenuation

Figure 2. A map illustrating the Puget Sound shoreline and some major cities. The three sites where W-shaped morphology occurs are boxed. Study area is located in the boldfaced box.

Figure 3. Bathymetry of the study area, including all three sites of W-shaped morphology: Possession Sound, Point Wells, and West Point. Taken from the Puget Sound Digital Elevation Model (Finlayson, D. et al. 2001).

Figure 1. Percentage of light attenuation versus depth at PRISM 28, showing the development of a BNL below 110 m.

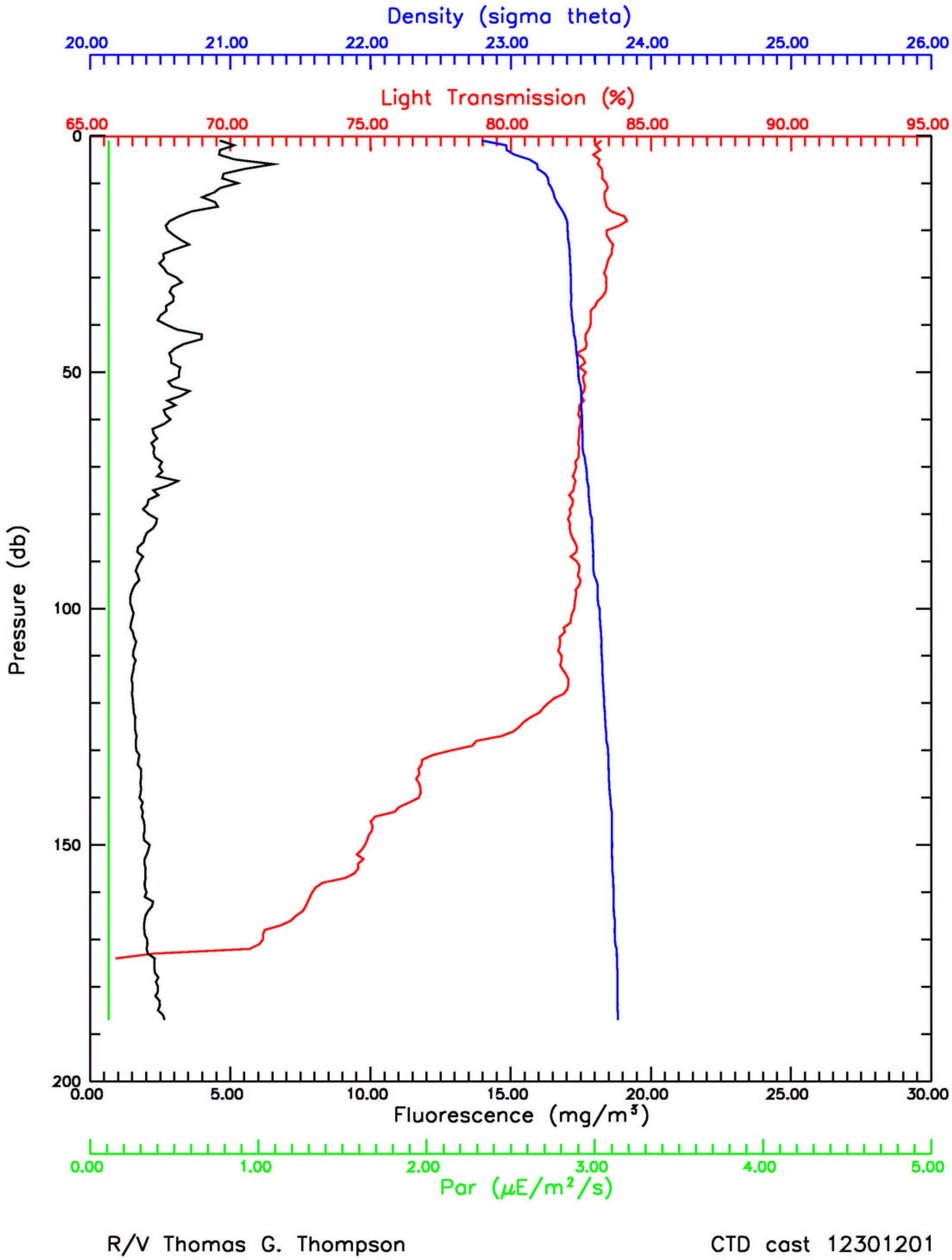

Figure 2. Map of the Puget Sound shoreline.

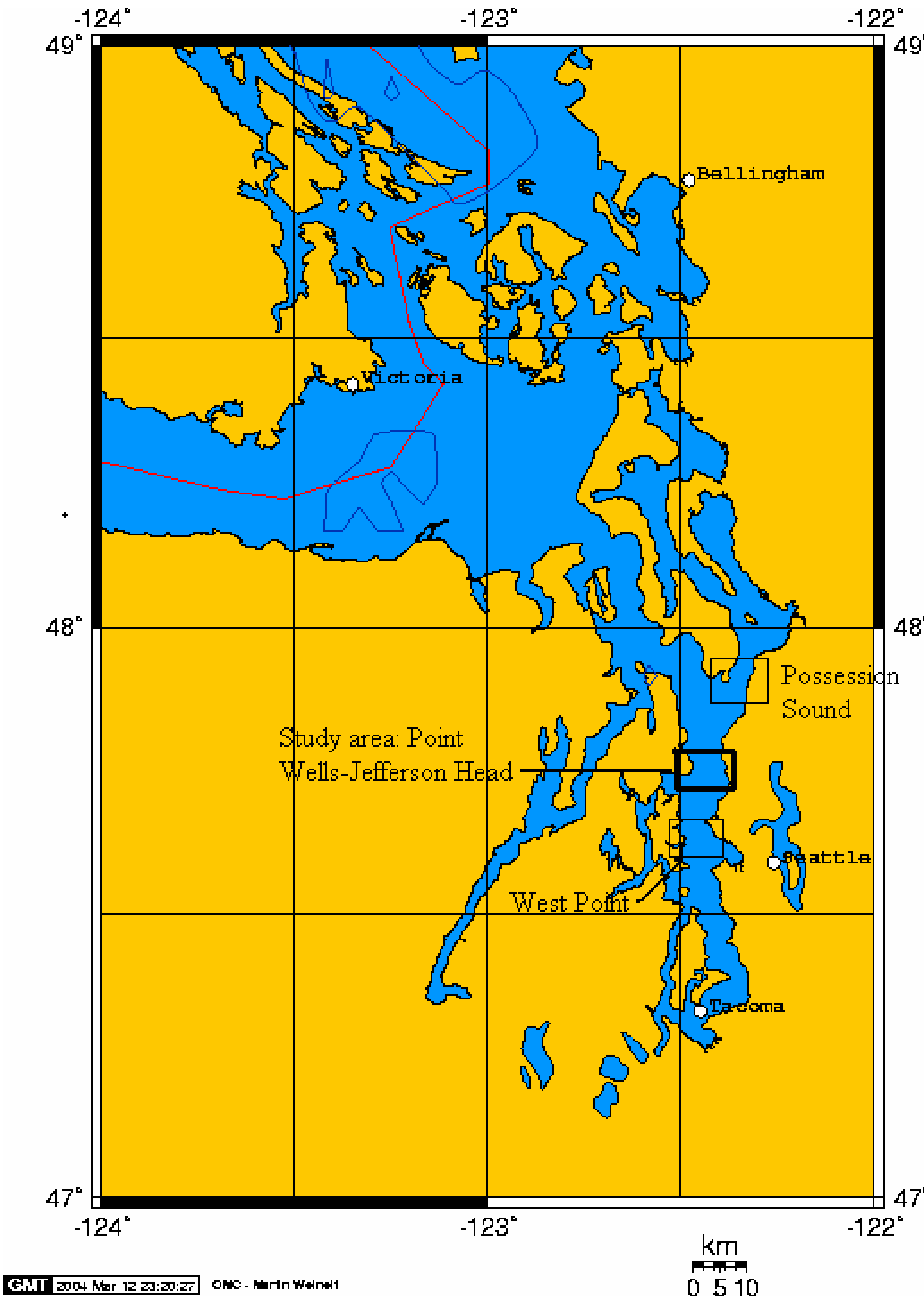

Figure 3. Bathymetry of study area. From the Puget Sound Digital Elevation Model (Finlayson, D. et al. 2001).