SECTION 4
CTD Transect Data

Conductivity, temperature, and depth (CTD) transects were conducted approximately monthly at three locations in Puget Sound in 1999 and 2000 for the MOSS project. Three additional locations were sampled for approximately six months in 2000. Transect names and months of data collections are presented in Table 4-1. Transect locations are provided in Figure 4-1. Data collected during the CTD transects includes the following: depth (m), temperature (^{o}C), turbidity (FTU), salinity (PSS), dissolved oxygen (mg/L), photosynthetically active radiation (µmol/sm^2), and density (sigma-t). The data are presented at the end of this section in Figures 4-2 to 4-50. Each graph represents a cross-sectional view of the water column as viewed to the north. The horizontal axis represents distance from the western shoreline and the terminus of the horizontal axis represents the eastern shoreline.

Table 4-1 Transect Names and Collection Date

Transect	1999	2000
Point Wells	Jan.	Jan.-May
	Mar.-Aug.	July-Nov.
	Oct.-Dec.	
Admiralty Inlet	Jan.	Jan.-May
	Mar.-Aug.	
	Oct.-Dec.	
Possession Sound	Jan.	Jan.-May
	Mar.-Aug.	July-Nov.
	Oct.-Dec.	
Edmonds		Jul.-Nov.
West Point		Jul.-Nov.
Alki		Jul.-Nov.

Figure 4-1. CTD Transect Station Locations

4.1 Temperature

The vertical temperature structure in 1999 exhibited typical seasonal patterns. The water column was essentially isothermal (non-stratified) from January through May, with a 1 ^{o}C or lower difference in water temperature throughout the water column. Thermal stratification became more evident in June with surface waters increasing from 8 ^{o}C to temperatures as high as 16 ^{o}C.

Thermal stratification along the Point Wells transect in 1999 indicated a slight west to east downward slope, with warmer surface waters being evident along the eastern shoreline in all months exhibiting thermal stratification, with the exception of August. The thermocline (a water layer characterized by a rapid change in temperature) at the surface of the western shoreline extended to approximately 50 meters in depth along the eastern shoreline. This east-west difference in thermal structure may be a result of a difference in flow across the central basin of Puget Sound. Colder oceanic water may be entering the sound along the western side and warmer sound water exiting the sound along the eastern shore (Ebbesmeyer et al., 2001).

Thermal stratification at the entrance to Possession Sound was consistent horizontally in 1999. During August, the surface waters along this transect represented the maximum temperature recorded (16.2 ^{o}C). These higher temperatures, relative to the main basin, are a result of solar heating and less dynamic waters in Possession Sound.

The surface thermocline was slightly deeper along the eastern edge of the Admiralty Inlet transect during the summer months of 1999. This deepening was a result of the warmer Possession Sound waters exiting Puget Sound around the south end of Whidbey Island.

Thermal stratification in the central basin during the summer of 2000 showed a similar pattern to 1999. The thermocline was deeper along the eastern shore for the Point Wells and Alki transects. The West Point transect exhibited a flat thermocline with only a slight indication of deepening along the eastern shoreline during August.

The thermocline along the Edmonds transect showed a deepening of the thermocline along both shorelines during the summer months. An explanation for the observed pattern is the upwelling of cooler deep water at the middle of the transect and warmer central basin surface water exiting the sound along either side of the Whidbey shoals.

The Possession Sound transect in 2000 was similar to the 1999 transect with relatively flat thermoclines. As in 1999, the temperatures recorded in the Possession Sound surface water were the highest temperatures encountered.

The Admiralty Inlet transect was only sampled during January through May in 2000 and little thermal structure developed.

4.2 Salinity

Salinity along the Puget Sound transects ranged from 18.6 PSS to 30.9 PSS. Salinities were greatest in October at depth, corresponding to the period where salinities were the most uniform throughout the water column. Salinity stratification became strongest in late spring and early summer with a second peak in stratification during November and December in 1999. The summer peak in salinity was a result of spring and summer runoff from snowmelt. The fall to winter peak in 1999 was likely due to local precipitation. The absence of this stratification in 2000 was a reflection of the abnormally low rainfall during the early winter of that year.

Salinity stratification along the Point Wells transect in 1999 exhibited a pattern similar to the one seen in the temperature profiles, particularly in the dry summer months. The halocline (a layer of water with a large change in salinity) was generally deeper along the eastern shoreline, indicating the influx of more saline ocean water on the western side of the basin and the outflow of less saline Puget Sound water along the eastern shore. During the heavy precipitation of November and December, the surface salinity (<15m) structure was similar across the profile with the sloping halocline limited to deeper structure.

Possession Sound surface salinity was more dominated by a lens of low salinity water when compared to greater depths in the main basin. This low salinity water (generally <24 PSS) represented the freshwater input of the Snohomish River located at the northern reaches of Possession Sound. The lens of low salinity surface water was present throughout the year but its magnitude is diminished subsequent to the dry summer months. Beneath the lens of low salinity water the halocline runs generally flat, typical of a salt wedge type estuarine system.

Admiralty Inlet exhibited a relatively flat salinity structure, with a slight deepening of the halocline along the western shoreline. This deepening of the halocline was most prevalent in the spring and early summer as the low salinity surface lens of Possession Sound flows out of the main basin.

The Point Wells salinity structure in 2000 again showed the deepening of the halocline along the eastern shore as the lower salinity south Puget Sound water flows north, although the structure is not as consistent in 2000, perhaps due to drier conditions. Dry conditions are particularly evident in the surface salinities during the late fall and early winter. The lack of precipitation creates uniform salinities throughout the water column for both October and November.

The 2000 salinity profiles in Possession Sound were similar to the 1999 profiles from January through the summer months. Despite low rainfall amounts, surface salinities remained low due to river runoff. The surface lens was shallower in 2000 due to low rainfall amounts

Admiralty Inlet salinity profiles in the early part of 2000 showed a similar structure to that of 1999, with the surface lens of low saline water somewhat reduced in thickness.

The Edmonds transect was marked by evidence of upwelling towards the middle of the transect in August. The sharp peak in salinity at 29 PSS was indicative of the upward movement of the more saline bottom water. This pattern in salinity layers was also observed in the temperature

profiles. Since evidence of this potential upwelling is lacking in all other months, it is not possible to determine the consistency of this feature, although an upwelling mechanism is believed to occur in the area (Ebbesmeyer, personal communication).

The West Point and Alki transects in 2000 were slightly stratified in the summer and were generally uniform in the fall and winter months due to low rainfall and a well-mixed water column.

4.3 Density

Density profiles are a function of both salinity and temperature. As such, the vertical structure of the density will closely mimic the salinity and temperature profiles discussed above. Salinity has a greater impact on density than temperature and is evidenced by the fact that the highest density measurements corresponded to the highest salinity measurements in every instance except one. In general, density stratification was greatest during the summer due to solar heating and freshwater runoff. The water column was weakly stratified in the winter due to the reduced solar influence and wind induced mixing.

The density profile along the Point Wells transect exhibited a general slope downward to the east, which was also seen in the temperature and salinity profiles. As with the salinity profiles, the magnitude and consistency of this pattern was not as strong compared to the temperature data. It is consistent with the outflow of water along the eastern shore and the inflow of denser oceanic water along the western shore.

The density profiles in Possession Sound were generally consistent horizontally and, as with Point Wells, the near surface structure matched the surface salinity characteristics of the area. The cooler more saline bottom water at depth along this transect was indicative of oceanic water flowing up into Possession Sound with the warmer, fresher water flowing out at the surface. There was a slight depression in the pycnocline (a layer of a rapid change in density) along the western edge of the transect, indicating that the out-flowing surface water was tending to move toward the western portion of the water column.

The 1999 Admiralty Inlet transect was similar to the Possession Sound transect in that the density profiles were essentially level and the surface density structure mirrored the salinity structure. In March, May, and August, there was a slight deepening of the pycnocline along the eastern edge of the transect, which may be resulting from the outflow of Possession Sound and central basin surface water.

The 2000 Point Wells density profiles more clearly demonstrate the sloping pycnocline towards the eastern shoreline. The decrease in the depth of the pycnocline was likely the result of outflow of Puget Sound water along the surface of the eastern shore and the inflow of oceanic water along the western shore.

The 2000 Possession Sound density profiles were similar to the 1999 profiles but the western depression of the pycnocline was more evident, suggesting a greater intensification of the western shoreline outflow.

The 2000 Admiralty Inlet transect exhibited moderate to weak stratification from January through the first May profile. By the end of May, the summer stratification pattern had become established. The pycnocline depth tended to deepen along the western shoreline suggesting the influence of the outflow of Possession Sound and central basin water.

Along the Edmonds 2000 transect, the upwelling signature observed in the August profile for both salinity and temperature was still evident. Additionally, the October profile showed a rapid shallowing of the pycnocline in the same area, further suggesting an upwelling event.

In 2000, the density profiles of both West Point and Alki exhibited a flat to slightly deepening (west to east) pycnocline, primarily during the more stratified summer and early fall months. The November transects at these locations were flatter and the water column was much less stratified.

4.4 Chlorophyll-*a*

Chlorophyll-*a* concentrations reached their highest concentrations along all transects during the summer months and concentrations were low both during the winter and at depths greater than 50 m during all seasons. This pattern in primary production is typical in Puget Sound and of temperate nearshore areas.

The 1999 Point Wells profile depicted two distinct blooms, the first occurring in May and the second in July. By August, chlorophyll-*a* concentrations were depressed below summer highs. Horizontally, there was no difference in the pattern of chlorophyll-*a* concentrations, with production essentially equivalent across the surface of the transect.

Possession Sound chlorophyll-*a* concentrations were temporally similar to those of the Point Wells transect, with concentration peaks in May and July and limited horizontal variation in the concentrations. In addition to the May and July peak, there was a third bloom along the western edge of the transect in October.

The 1999 Admiralty Inlet transect exhibited the May and July peaks in chlorophyll-*a* concentration, however the peak levels of chlorophyll-*a* were concentrated on the western side of the transect. A slight peak along the western shore in June was likely the remnants of the May peak and there was only a slight indication of the October peak observed in Possession Sound. The shift of the peak chlorophyll-*a* concentrations to the western side of the transect suggested that the blooms were associated with the in-flowing oceanic water, rather than the out-flowing Puget Sound water.

In 2000, the Point Wells transect again showed a peak in May and July. However, in contrast to the 1999 transect, the late summer peak in chlorophyll-*a* concentration persisted from July

through September. The dry conditions of 2000 likely contributed to this extended bloom, with the increase in solar input allowing the blooms to persist.

The 2000 Possession Sound transect also had an extended plankton bloom with surface chlorophyll-*a* concentrations remaining elevated from the end of May through September. The vertical extent of the increased chlorophyll-*a* concentrations was reduced relative to the 1999 transect, the reasons for this are not clear from the CTD data but may be related to a decrease in nutrient availability.

The 2000 Admiralty Inlet chlorophyll-*a* concentrations exhibited a similar horizontal distribution as was observed for the 1999 transect. The May peak in chlorophyll-*a* concentrations was shifted toward the western side of the inlet.

There is further indication of upwelling along the Edmonds 2000 transect, with peaks in chlorophyll-*a* concentrations occurring along the shorelines and relatively low levels at the mid point of the transect. This distribution of chlorophyll-*a* may only be a result of increased primary production in the nearshore area, but coupled with the profiles of salinity, temperature and density, upwelling is more likely the cause of this distribution.

The West Point and Alki transects in the summer and fall of 2000 showed the progression of a phytoplankton bloom. The start of the bloom was evident along the western shore in July and the bloom peaked in August, before declining in September.

4.5 Dissolved Oxygen

The Washington State Department of Ecology considers a dissolved oxygen (DO) concentration below 5.0 mg/L to be an indicator of depressed water quality (Ecology, 1998). Depressed DO concentrations can result from the natural cycles of primary production or can be induced by the anthropogenic introduction of nutrients to the system.

Dissolved oxygen concentrations below 5.0 mg/L were observed in 11 of 70 transects. Five were recorded in Possession Sound, which historically has low DO concentrations due to the limited circulation and high riverine input of organic matter. Only the Admiralty Inlet transect did not have measured DO concentrations below 5.0 mg/L. All of the minimum DO concentrations were measured during the late fall and winter months.

The 1999 Point Wells DO transect mirrored the chlorophyll-*a* profile at the surface. The peak surface DO concentrations corresponded temporally and spatially with the peaks in chlorophyll-*a*. Dissolved oxygen levels reached minimums at depth during the late fall. There was a slight depression in the DO isocline along the eastern edge of the transect, which is characteristic of the higher DO Puget Sound water exiting the southern basin along this shoreline. The lower DO oceanic water was evidenced along the western edge by the shallower and more compact isoclines.

The 1999 Possession Sound transect also showed increases in surface DO concentrations that were spatially and temporally associated with chlorophyll-*a* levels. During the late summer and fall, the bottom waters along the transect were consistently below 5.0 mg/L.

The 1999 Admiralty Inlet transect DO levels reflected the increase in primary productivity along the western edge of the transect, with higher DO levels and deeper isoclines along that shoreline. At depth, the minimum DO levels remained above 5.0 mg/L throughout the year.

The 2000 Point Wells transect again showed a strong correlation to chlorophyll-*a* concentrations. The deepening of the DO isoclines along the eastern edge of the transect are less evident when compared to the 1999 transect. The most notable feature of this series of transects was the large volume of the water column with DO concentrations <5.0 mg/L during the winter months. The mean DO for the November transect was 4.86 mg/L. The low DO concentrations were probably a consequence of the mild and dry weather, reducing the mixing of the water column.

The 2000 Possession Sound transect re-emphasizes the pattern observed with chlorophyll-*a* concentrations. The DO levels at the surface reflected the chlorophyll-*a* concentrations and, as with the chlorophyll-*a*, the depth of penetration was reduced compared to the 1999 transect.

The Admiralty Inlet 2000 transect was conducted from January through May and little structure in dissolved oxygen developed.

The August upwelling seen along the Edmonds 2000 transect in other parameters was evident in the DO concentrations as lower DO water from the bottom is brought towards the surface. As with the Point Wells 2000 transect, DO concentrations in November were low with a large area below the 5.0 mg/L level.

The low DO concentrations along the bottom were more pronounced and appear in October and November along the more southern transects, West Point and Alki.

4.6 Turbidity

In general, water column turbidity was greatest during the winter months when there is high precipitation runoff. Also evident in many of the transects is a dramatic increase in turbidity along the bottom. The increase in turbidity values comes from the benthic nepheloid layer in which physical forcing results in the trapping and suspension of particulate material along the bottom.

In the Point Wells, Possession Sound, and Admiralty Inlet 1999 transects, there were two noticeable increases in turbidity. The first occurred near the surface during the spring and summer and resulted from the increase in primary productivity. The second increase was the winter maximum. The clearest water occurred during the late winter and early spring. Each of the transects was marked by the benthic nepheloid layer along the bottom.

These same transects showed slightly different patterns in 2000. The wintertime maximum extended through the first portion of the year and was not as intense in the latter part of the year. The spring and summer increases were also muted due to the relatively lower levels of primary production seen in 2000 compared to 1999. The intensity of the nepheloid layer decreased during the summer months and increase in the late fall and winter as the summertime production settles towards the bottom.

The 2000 Edmonds, West Point and Alki transects showed no definitive pattern in the turbidity aside from the increases along the bottom. The lack of summertime increases in turbidity reflected the observed decreased levels of primary productivity. This decrease in productivity was also evident in the diminished benthic nepheloid layer of the fall and winter 2000.

4.7 Photosynthetically Active Radiation

Photosynthetically active radiation (PAR) is a measure of the intensity of the fraction of light available for photosynthesis. Since light levels attenuate relatively quickly in the water column, the data presented here are collected only to a depth of 30 meters. The occasional passing of a cloud or other shading action can dramatically alter the reported levels of PAR. Because correction for daily changes in incident radiation was not available, the transects for 1999 and 2000 are discussed only in a general manner.

Light penetration through the water column was greatest during the summer months, with light levels remaining at 10% of the surface values up to 15 meters below the surface. The surface light levels during the winter months are generally an order of magnitude lower than summer surface levels and light levels do not drop as rapidly with depth during the winter.

4.8 Summary of CTD Data

The CTD transects conducted during 1999 and 2000 were consistent with the observed and suspected circulation patterns of the Puget Sound Central Basin and Possession Sound. Inflowing oceanic water enters the system along the western edge of Admiralty Inlet beneath the surface. This oceanic water is evident in the salinity and density profiles as the denser and more saline oceanic water decreases the depth of the isoclines along the western edge of the transects. The influx of oceanic water and out-flow of central basin water is also evident in the salinity, temperature, and density profiles of the Point Wells transects. The deepening of the isoclines along the eastern shoreline reflects the outflow of central basin water along the surface layers, while the more shallow isoclines along the western edge is a continuation of the pattern seen along the Admiralty Inlet transect. The pattern of deepening of the isocline along the eastern shoreline was also observed in the profiles at West Point and Alki.

The transect at the entrance to Possession Sound indicates that out-flowing surface waters may be concentrated along the western shoreline. At depth, the horizontal isoclines reflect the inflow of denser central basin water.

The Edmonds transect showed an area of possible upwelling south of Whidbey Island. The profiles of salinity, temperature, and density all show a peak in the isocline during the month of August. This peak is less evident or absent for other months along the same profile, therefore, it is not possible to conclude that this is a consistent feature of the system. An upwelling flow in the area has been suggested (Ebbesmeyer, personal communication).

Three measures of biological activity and seasonal changes, chlorophyll-*a*, dissolved oxygen, and turbidity, exhibited patterns typical of the Puget Sound region and reflected differences seen in the weather patterns. Primary productivity, measured by chlorophyll-*a* and DO, showed summertime maximums and wintertime minimums. Chlorophyll-*a* and surface DO levels peaked in May followed by a second peak in July or August. Between 1999 and 2000, primary productivity was higher in 1999. The decrease in the productivity in 2000 is likely a consequence of the decrease runoff and nutrient input due to the low level of precipitation. This lower level of productivity in 2000 resulted in a less intense benthic nepheloid layer in the winter of 2000. The winter DO levels in 2000 were also lower than the 1999 levels. Again, decrease in precipitation and associated storms during 2000 likely limited the mixing of the water column and leading to the depressed oxygen levels.