Mercury in the Sediments of Sinclair Inlet, Puget Sound, Washington (1990–2007)

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Greater Sinclair Inlet

Abstract

Mercury concentrations in sediment of Sinclair Inlet, adjacent to Bremerton, Washington, and the Bremerton Naval Complex, have been known to be higher than average mercury concentrations in the Puget Sound since the 1980s. The slope of the mercury to total organic carbon relation of mid-estuary sediments is deemed a good indicator of overall mercury contamination. Mercury concentrations in sediments are highly correlated with total organic carbon content in most Puget Sound estuaries. Sinclair Inlet is in the top tier of overall mercury contamination in urban estuaries of Puget Sound, along with Bellingham and Elliott Bays. A 50 percent decrease in the slope of the offshore relation of mercury to total organic carbon in Sinclair Inlet after CERCLA dredging indicates that physical transport processes redistributed sedimentary mercury throughout Sinclair Inlet.

In the early 1980s, the sediments of Sinclair Inlet (fig. 1) were known to have elevated concentrations of a number of elements and organic compounds (Malins and others, 1982). When Puget Sound Ambient Monitoring Program (PSAMP) began monitoring the sediments of Puget Sound, Sinclair Inlet had the highest concentrations of mercury (fig. 2) of all the long-term monitoring sites (Tetra Tech, 1990). The U.S. Navy began sediment sampling in Sinclair Inlet in 1990 (U.S. Navy, 2007).

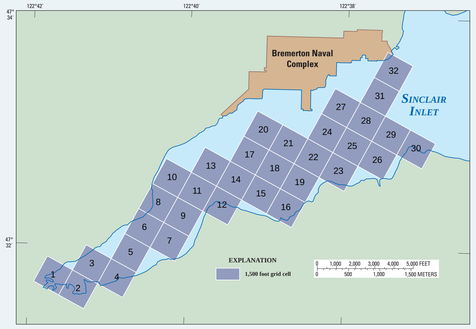

Figure 1. Cells in the 1,500-foot grid, Sinclair Inlet outside of the Bremerton Naval Complex boundary (U.S. Navy, 2005).

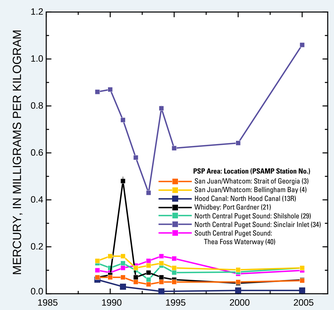

Figure 2. Mercury concentrations in surface sediments (0–3 centimeters) at seven Long-Term Temporal Monitoring stations of the Puget Sound Ambient Monitoring Program (PSAMP) between 1989 and 2005.

PSAMP completed three sediment studies of estuaries throughout Puget Sound between 1997 and 1999 (Long and others, 1999; 2000; 2002). The slope of mercury to total organic carbon relation of mid-estuary sediments is deemed a good indicator of overall mercury contamination because mercury concentrations in sediments are highly correlated with total organic carbon (TOC) content in most Puget Sound estuaries (fig 3). Mercury concentrations in Sinclair Inlet are comparable to those of Elliott and Bellingham Bays and the slopes of mercury to TOC are higher than those of other urban estuaries (fig. 4).

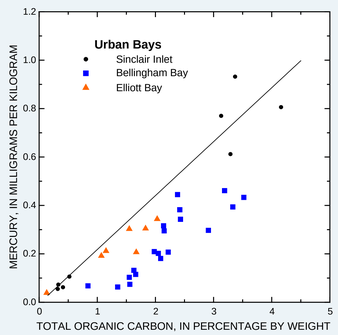

Figure 3. Mercury versus total organic carbon in the surface sediments (0–3 centimeters) from PSAMP focus study from Sinclair Inlet, Elliott Bay off Seattle, and Bellingham Bay. (The line is the regression of the Sinclair Inlet samples.)

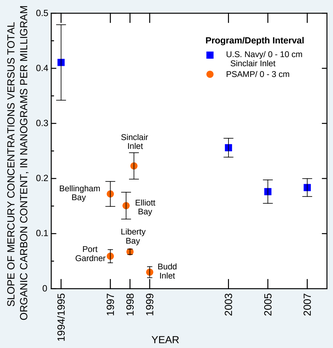

Figure 4. Slopes of the relation between mercury concentrations and total organic carbon content from Sinclair Inlet and other Puget Sound Embayments. (Vertical bars are the variance [one standard error] on the slope from the regression analyses. Note the different depth intervals of the two sampling programs.)

The results of sediment sampling during the Remedial Investigation throughout Sinclair Inlet (1990–1995) and an initiative to expand the capabilities of the Bremerton Naval Complex (BNC) led to navigational and CERCLA dredging of large areas off the waterfront of the BNC that was completed in 2001. In 2003, the U.S. Navy's Long-Term Monitoring Program (LTMP) began collecting samples in 32 cells within the greater Sinclair Inlet every other year. As the 2007 sediment sampling in greater Sinclair Inlet indicates (fig. 5), mercury concentrations in sediments are strongly correlated with TOC. The mercury:TOC relation in Sinclair Inlet decreased by 50 percent between 1995 and 2003 when dredging removed a significant amount of mercury. This decrease over areas not dredged indicates that physical transport processes redistributed the remaining sedimentary mercury throughout Sinclair Inlet.

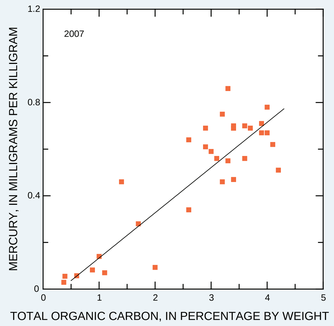

Figure 5. Mercury compared with total organic carbon in surface sediments (0–10 centimeters) from the 2007 Long Term Monitoring Program (U.S. Navy) of offshore sediments. (The slope of the line is shown in figure 4.)

Summary

The Sinclair Inlet site in the Long-Term Temporal Monitoring Program of the Puget Sound Ambient Monitoring Program has elevated mercury concentrations relative to all other sites (fig. 2). However, the relation of mercury to total organic carbon of offshore sediments is deemed a good indicator of overall mercury contamination of an embayment. The slopes of mercury to total organic carbon in offshore sediments (0–3 centimeters) from Elliott and Bellingham Bays are comparable to the slope of offshore Sinclair Inlet sediments (fig. 4). The removal of a substantial mass of mercury from Sinclair Inlet during navigational and CERCLA dredging (2000–2001) lowered the overall contamination of mercury in surface sediments (0–10 centimeters) of Sinclair Inlet.

Deviations from the relation of mercury to organic carbon of the offshore Sinclair Inlet sediments were used to identify areas of concern for mercury in the sediments of the Bremerton Naval Complex (fig. 7). About 80 percent of the sediments in the Bremerton Naval Complex are within 0.6 milligrams per/kilogram mercury of the offshore relation of mercury to total organic carbon. Three areas of concern for mercury contamination have been identified by evaluation of the severity and frequency of these deviations: cell 39, cell 71, and the area between piers 3 and 6 (fig. 9).

Bremerton Naval Complex

Abstract

The mercury/total organic carbon indicator of greater Sinclair Inlet was used to identify an area adjacent to the Bremerton Naval Complex that may be affected by legacy sediment contamination or by continuing sources from the operation of the naval facility. The differences between the actual mercury concentrations and the expected mercury concentrations (residuals) were calculated and ranked to identify two levels of outliers (fig. 7). During three random stratified sampling events following remediation in 2003, 2005 and 2007, about 75 percent of the area within the Bremerton Naval Complex had differences between actual and expected values that were less than 0.6 mg/kg. The level and frequency of outliers identified three areas of concern for mercury (table 1).

The Remedial Investigation of the Bremerton Naval Complex (BNC) (U.S. Navy, 2002) resulted in dredging several areas, sediment capping (thick isolation caps and thin-layer caps leading to natural recovery) and shoreline stabilization (fig. 6). Beginning in 2003, the LTMP sampled 71 cells of a 500-foot grid within the BNC. If all current and historical sources of mercury from the BNC were completely eliminated, mercury concentrations in sediments within BNC would be controlled by the same physical and sedimentary transport processes that control mercury concentrations in greater Sinclair Inlet. The differences (residuals) between the actual mercury concentrations and expected mercury concentrations using regression of mercury versus TOC (fig. 5) were calculated and rank ordered to identify two levels of outliers. Tier 1 and Tier 2 samples were identified by breaks in the ranking of residuals (fig. 7).

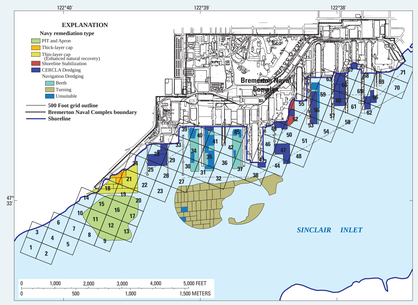

Figure 6. Bremerton Naval Complex showing types of sediment remediation completed in 2001 and cells of the 500-foot grid.

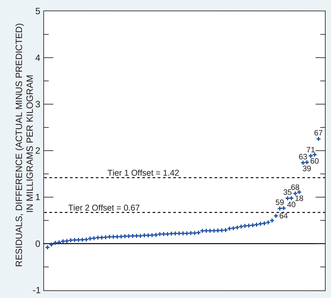

Figure 7. Rank ordered deviations of sediments of the Bremerton Naval Complex during 2007 relative to the offshore regression shown in figure 5. (Cells above the Tier 1 and Tier 2 breaks are labeled and shown in figure 8.)

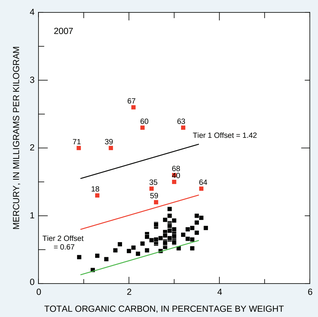

Figure 8. Mercury versus total organic carbon in the surface sediments (0–10 centimeters) from the 2007 Long Term Monitoring Program (U.S. Navy) of sediments from the Bremerton Naval Complex. (Cells above the Tier 1 and Tier 2 offset are labeled and shown in figure 6 and table 1.)

Areas of concern for mercury contamination with the BNC were identified by the level and frequency of Tier 1 and Tier 2 outliers (fig. 8). The area between Piers 3 and 6 (fig. 9) is the largest area of concern. Samples from three cells (60, 63, and 67) were classified as Tier 1 outliers in eight of nine instances. Samples from four cells were classified as Tier 2 outliers eight times. Because a large fraction of the sediment between Piers 3 and 6 was not dredged in 2001, mercury contamination could be a legacy of World War II activities. Continuing discharge of particulate mercury from the numerous storm drains flowing from this waterfront area also could have contributed to elevated mercury concentrations.

In 2007, two cells (39 and 71) were classified as Tier 1 outliers. Both these cells are adjacent to upland areas that contain monitoring wells in which total mercury concentrations were measured in excess of 1,000 ng/L (U.S. Navy, 2007).

Cells 11 and 19 were classified as Tier 1 outliers only in 2003. The high mercury concentration could have been a transient effect of the filling and covering of the Confined Aquatic Disposal Pit site, labeled PIT in figure 6.

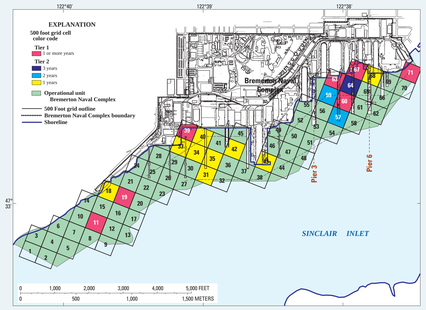

Figure 9. Areas of concern for mercury contamination in the sediments of the Bremerton Naval Complex based on the severity and frequency of deviations from the mercury to total organic carbon relation in greater Sinclair Inlet.

Grid Cell Number	Number of Times Cell Was an Outlier	Year Mercury Concentration in Cell Was an Outlier		
		2003	2005	2007
Mooring E (West of Pier D)				
39	2		X	X
34	1	X		
31			X	
33			X	
Between Piers 3 and 6				
60	3	X	X	X
63	3	X	X	X
67	3	X	X	X
64	3	X	X	X
56	1	X		
57	2	X	X	
59	2		X	X
East of Pier D				
35	1			X
40	1			X
42	1		X	
Remediated Areas off OU A				
11	1	X		
18	1			X
19	1	X		
Central OU B Marine				
43	1		X	
Eastern OU B Marine				
68	1			X
71	1			X

Table 1. Years in Which Mercury Concentrations in 500-ft grid cells within Bremerton Naval Complex deviated from the regression of mercury versus total organic carbon for Sinclair Inlet. (Locations of Grids are shown on figure 9. Red X indicates a Tier 1 outlier.)

References are listed on the sheet attached to the poster.

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