MERCURY CONCENTRATIONS IN WATER AND SEDIMENT IN RESURRECTION CREEK, ALASKA

Final Report

Resurrection Creek main channel (May 2004)

"Channel 2" Side Channel (August 2004)

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ABSTRACT

- Water and sediment samples were collected at five sites on Resurrection Creek and its side channels on May 6, 2004 during moderate to high flow conditions, and on August 10, 2004 during low flow conditions. The samples were analyzed for mercury, methylmercury, and other water quality parameters.

- This sampling was conducted to assess the presence or absence of mercury in the system prior to stream and riparian restoration work. Restoration of a placer-mining impacted 0.9-mile reach of Resurrection Creek is scheduled to begin in 2005.

- This study is a follow-up to a fish sampling study conducted in the same reach in September 2003. Resident coho fry and sculpin had mercury levels slightly elevated over reference levels, but these levels were low compared to regulatory standards and levels from fish in disturbed and undisturbed streams nationwide.

- Total mercury concentrations in the water in Resurrection Creek and its side channels ranged from 5.1 to 7.3 parts per trillion (ppt) during the May sampling, and 0.8 to 1.8 ppt during the August sampling, with few differences between the reference reach and the project reach. The temporal differences can be attributed to higher flows and mercury associated with increased sediment and organic material in the water.

- Methylmercury comprised 1 to 3% of the total mercury in the project reach side channels during the May sampling, and up to 58% in the August sampling. The Channel 1 site likely experienced high rates of methylation as a result of stagnant conditions, especially during the August sampling.

- Mercury levels in water in Resurrection Creek were well below the state and federal standards for drinking water, and similar to levels measured in other streams in the Cook Inlet basin.

- Total mercury in sediment in the side channels ranged from 27 to 141 parts per billion (ppb) dry weight, with the highest levels in the Channel 1 and Beaver Pond channel sites. Methylmercury comprised up to 2.4% of the total mercury in these samples. No temporal trends exist, but mercury levels increase with total organic carbon.

- Mercury levels in sediment were below the threshold effects level suggested as a preliminary screening level by NOAA, and are similar to levels measured in other streams in the Cook Inlet basin as well as reference levels in the Puget Sound area, Washington.

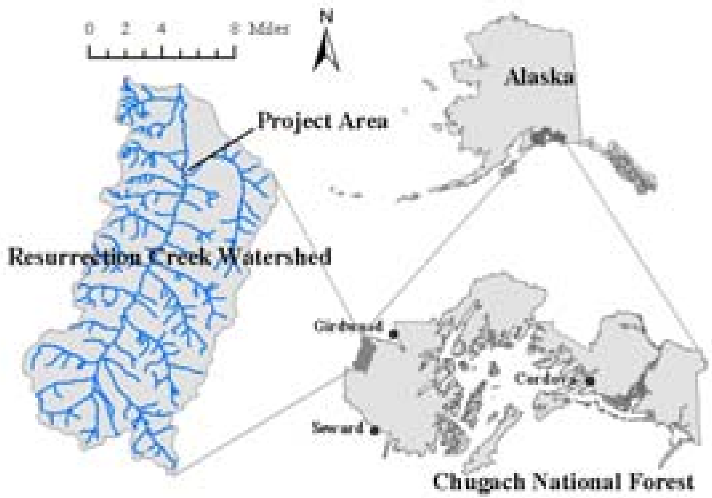
- Mercury levels measured in water and sediment in Resurrection Creek are low and pose little risk to drinking water contamination or aquatic species. Mercury levels may be slightly elevated as a result of past mining operations, but sampling efforts have not detected any large concentrations of mercury.

INTRODUCTION

The Chugach National Forest is planning a large-scale stream restoration project on Resurrection Creek, north of Hope, Alaska (**figure 1**). Resurrection Creek has been the site of extensive gold placer mining over the past century, and placer mining operations in the early 1900's resulted in numerous tailings piles, channelization, and loss of floodplain functionality. Although it is unknown how much mercury was used for mercury amalgamation during these placer mining operations, some mercury may still be in the system, likely within the tailings piles.

This study was conducted to address concerns that some of this mercury might be released into the environment during channel restoration. The objectives of this study were to sample water and sediment to determine the presence or absence of mercury and methylmercury in the system, and compare the mercury concentrations, as well as other parameters, between the reference reach, project reach main channel, and project reach side channels. Sampling was conducted in May 2004 during high water conditions, and in August 2004 during low water conditions.

Figure 1: Location of the Resurrection Creek project area.



CONTEXT

History: Resurrection Creek experienced a gold rush in the early 1900's. The town of Hope served as a mining camp for the numerous placer mining operations that operated on Resurrection Creek, Bear Creek, and the lower portion of Palmer Creek. Miners used hydraulic giants and heavy equipment to move parts of the channel and mine the channel material, resulting in large tailings piles deposited on the floodplains. The tailings piles have greatly confined the channel and its floodplain and remain largely unvegetated because of the coarse nature of the material and the lack of available water and nutrients. Overall, approximately 4 square miles of Resurrection Creek were highly disturbed, from about 2 miles to about 6.5 miles upstream of the mouth.

Mercury Amalgamation: The processing of placer gravels through a sluicebox produces a slurry of heavier materials, or "black sands," that includes tiny specs of gold. Elemental mercury has been used historically during placer operations to extract the tiny gold particles from the slurry. When mixed with the "black sands," the mercury bonds directly to the gold particles, making a mercury amalgam. The mercury amalgam is more easily separated from the black sands than the individual gold flakes.

In the gold separation process, mercury can potentially be spilled directly into the stream or mine tailings. Large scale gold placer operations in California during the 1850's to 1880's made extensive use of mercury for gold separation. Such operations reportedly lost an estimated 10 to 30% of the mercury they used and left thousands of pounds of mercury at each placer mine site (Saiki, 2003). It is unknown how much mercury was used or may have spilled into the environment during placer mining operations on Resurrection Creek in the early 1900's. Anecdotal evidence suggests that mercury was used, but probably not in the quantities used in the California placer operations.

Mercury: Mercury is naturally present in the environment from geologic sources, and also comes from anthropogenic sources such as industrial metal manufacturing and fuel combustion, runoff from mercury mines, and mercury used for gold mining. Mercury in the atmosphere is distributed globally. In 1995, the annual emission of mercury from the US from industrial and combustion sources totaled 158 tons (US Environmental Protection Agency, 1997). Mercury is highly insoluble in water except when attached to dissolved organic material. Mercury generally remains in soils for long periods of time, slowly releasing mercury compounds to the environment. In Resurrection Creek, any elemental mercury spilled into the river likely settled into the substrate because of its high density and low solubility. In the project area, the alluvial deposits from Resurrection Creek comprise a thin layer, in places less than 3 feet thick, over a clay layer possibly deposited by a glacially dammed lake that existed during the Pleistocene. It is likely that any mercury that has settled into the sediment will ultimately stop at this clay layer.

Methylmercury: Bacteria within fine-grained and organic sediments can transform elemental mercury into methylmercury, a highly toxic organic form of mercury. This process generally occurs under anaerobic conditions. Research has shown that elevated water temperatures, low pH, anaerobic conditions, and higher dissolved organic carbon concentrations increase rates of methylation of mercury (US Environmental Protection Agency, 1997; Power et al., 2002). Krabbenhoft et al. (1999) showed that the density of nearby wetlands was the most important factor increasing methylation rates. Methylmercury is readily absorbed or ingested by organisms, and it is transported to all organs, particularly affecting the nervous system. Because methylmercury bioaccumulates in organisms, levels of mercury in fish tissue can be orders of magnitude higher than mercury concentrations found in water and sediments.

Recent History: Large-scale hydraulic mining on Resurrection Creek ceased in the 1940's. Heavy equipment mining continued on some sections of the creek through the 1980's. Mining activity has decreased since the 1980's but still occurs in some areas, primarily as small-scale suction dredging operations. Between 1999 and 2002, fisheries personnel from the Chugach National Forest constructed a series of side channels and small ponds adjacent to Resurrection Creek, about 5 miles upstream of its mouth. These channels and ponds were constructed amongst the large tailings piles on both sides of the creek and are fed by French drains. They were built to improve rearing habitat for juvenile salmon in Resurrection Creek. These channels and associated ponds currently support moderate populations of salmon fry, as well as sculpin and other fish species, and represent some of the only slow-water pool habitat within the proposed restoration reach.

Restoration: The Chugach National Forest is conducting a large-scale restoration project for 0.9 miles of the Resurrection Creek channel and floodplain upstream and downstream of the Palmer Creek confluence, scheduled to begin in 2005. This area is referred to as the "project reach" (**see figure 3**). A reference reach exists about a mile upstream. The purpose of this project is to restore the channel to its natural, self-maintaining form, restore functionality to the floodplain, and provide and improve stream habitat for fish and riparian habitat for mammals and birds. This will require redistributing and removing the tailings piles, creating a new channel, and restoring the channel and floodplain.

Documentation: This study is a follow-up to a study on mercury concentrations in fish in Resurrection Creek conducted in September 2003 (MacFarlane, 2004). The USDA Forest Service has completed an Environmental Impact Statement for the restoration project (USDA Forest Service, 2004). Detailed studies of all aspects of the area were also recently conducted as part of the Resurrection Creek Watershed Association Hydrologic Condition Assessment (Kalli and Blanchet, 2001) and the Resurrection Creek Landscape Analysis (Hart Crowser, Inc., 2002).

HYDROLOGIC CONDITIONS

Watersheds: The Resurrection Creek watershed covers about 103,230 acres (161 square miles) on the northern side of the Kenai Peninsula. Resurrection Creek flows north about 24 miles into Turnagain Arm, and elevations in the watershed range from sea level to about 5,000 feet. The valley and side valleys are glacially carved U-shaped valleys, but glaciers are no longer present in the watershed. Numerous high gradient tributaries flow into Resurrection Creek, and the largest tributary, Palmer Creek, flows from a hanging valley east of the project area.

Climate: The Resurrection Creek watershed has a cool and moist climate. The average mean temperature at Hope, Alaska is about 37 degrees F (Western Regional Climate Center, 2003). Annual precipitation for Hope at the mouth of the watershed averages about 22 inches, and annual precipitation increases to about 40 inches at the head of the watershed. The Resurrection Creek watershed lies in a rain shadow created by the Kenai Mountains and receives considerably less precipitation than watersheds to the east. Hope receives about 90 inches of snow annually, and snowfall increases with elevation. August, September, and October are the wettest months, and winters receive more precipitation than summers.

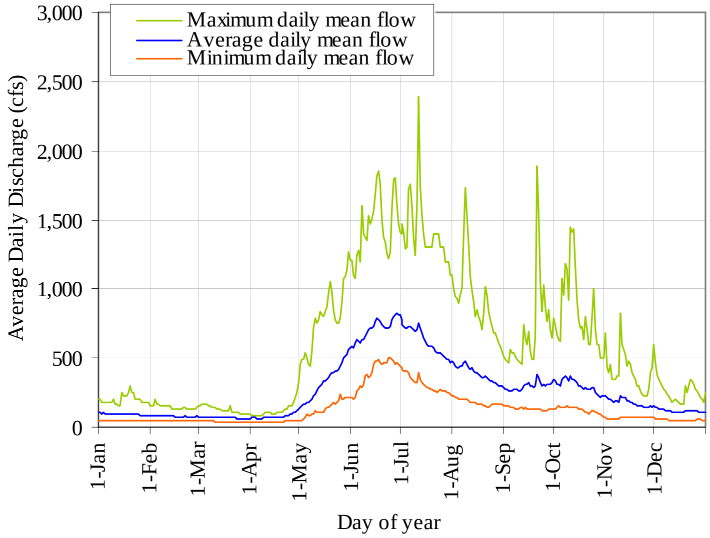
Streams: Based on the Region 10 stream classification system (USDA Forest Service, Alaska Region, 1992), Resurrection Creek progresses from a Moderate Gradient Mixed Control channel in its upper reaches to a Floodplain channel in its lower reaches, with several short canyon sections along its length. The channel within the project area is a Low Gradient Floodplain Channel, with a gradient less than 2% and a cobble and gravel substrate. Portions of the channel that were not placer mined have well-developed floodplains, but channels within the project area, as well as in the mined areas downstream, are confined on one or two sides of the channel by high, steep gravel and cobble tailings piles. These tailings piles do not allow for channel migration and decrease floodplain functionality. Palmer Creek joins Resurrection Creek near the upstream end of the project reach. This channel has a high gradient as it descends from a hanging valley, resulting in an alluvial fan at the confluence.

Side Channels: Near the upstream end of the project reach and upstream of the Palmer Creek confluence, two French drains on the east side of Resurrection Creek feed two small side channels (**see figure 3**). "Channel 1" is about 750 feet long and connects several small ponds. The French drain feeding Channel 1 does not function properly, and flows are generally very low or just a trickle. "Channel 2" contains three small ponds and is only about 400 feet long, fed by a functioning French drain. Beavers persistently build small dams on these channels. On the west side of Resurrection Creek, the "Beaver Pond Channel" starts near the Palmer Creek confluence and re-enters Resurrection Creek about 2700 feet downstream, at the end of the project reach. This channel has a series of small and large beaver ponds.

Streamflows: A USGS stream gauge operated on Resurrection Creek 2 miles upstream of Hope from 1967 to 1986. The average mean daily flow was 274 cfs (US Geological Survey, 2004). The flow regime in Resurrection Creek is primarily controlled by summer snowmelt (**figure 2**). Peak flows, averaging about 800 cfs, generally occur in late June to early July. Heavy fall rainstorms result in high magnitude, short duration peak flow events and a secondary peak in the hydrograph in October. These fall peaks are generally not as large as the summer snowmelt runoff peak. Winter flows from December to April average around 80 to 100 cfs. Ice buildup in the channel is common, and ice dam breakout floods can occur in the winter. The 2-year flood flow is about 1230 cfs, and the 10-year flood flow is about 2390 cfs (Curran et al., 2003).

Water quality: Water quality data were collected on Resurrection Creek near Hope from 1950 to 1959 and from 1968 to 1971 (US Geological Survey, 2004). These data indicate no violations of the State standards for fish and wildlife (Alaska Department of Environmental Conservation, 2003). Data collected in 1980 at placer mining sites on Resurrection and Palmer Creeks showed elevated levels of manganese and lead in the mining wash water, elevated levels of lead in Resurrection Creek downstream of the mining, and elevated levels of lead in Palmer Creek upstream of the mining (Blanchet, 1981). Lead concentrations were as high as 0.17 ppm, and manganese concentrations reached 0.22 ppm. We are not aware of any existing data for mercury in water or sediments of Resurrection Creek.

Figure 2: Resurrection Creek hydrograph, USGS station 15267900. Period of record 1967-1986.



PREVIOUS STUDIES

A study of mercury concentrations in resident fish in the Resurrection Creek project reach was conducted in September 2003 (MacFarlane, 2004). Results of the fish study showed that total mercury concentrations in sculpin and coho tissue ranged from 0.0297 ppm to 0.143 parts per million (ppm) wet weight in the main channel and side channels of the project reach, and 0.0315 ppm to 0.0318 ppm wet weight in the reference reach side channel. These levels are well below the 1.0 ppm "action level," at which the Food and Drug Administration restricts consumption of fish.

The highest concentrations of mercury in sculpin were found in the small artificial side channels of the project reach, where more stagnant water, higher water temperatures, decreased dissolved oxygen, and increased organic matter may have led to increased methylation of mercury. Although mercury levels in sculpin were somewhat elevated in the project reach side channels, these levels are low compared to mercury levels in fish in degraded as well as non-degraded systems throughout North America. Data suggest that mercury levels measured in fish in Resurrection Creek and its side channels would not be toxic to the fish or their developing eggs and fry.

SAMPLING LOCATIONS AND METHODS

Sample mediums: Mercury concentrations can be analyzed in soil, sediment, water, fish tissue, or other organic samples. If miners did spill mercury, it could be concentrated in specific areas, but no such areas have yet been located. For this study, water and sediment were sampled in Resurrection Creek to determine what mercury concentrations may be present, and to further address any concerns about mercury in the system prior to restoration. Because mercury bioaccumulates in aquatic species, mercury concentrations in sediment and water are likely to be orders of magnitude lower than those in fish.

Sample locations: Water was sampled at a total of five sites on May 6, 2004, and the same sites were re-sampled on August 10, 2004. These sites included three side channel sites and one main channel site in the project reach, and one main channel site in the reference reach (**figure 3**). Total mercury was sampled at all sites, and methylmercury was sampled only in the three side channel sites. As a result of the coarse substrate in the main channel, sediment samples were taken only in the three side channel sites.

SC-CH1: Water and sediment samples were taken from Channel 1, at the downstream end of "Pool 1," the 5th pond downstream of the French drain. Samples were taken where the flow comes together in a 3-foot wide channel. The flow was very low because the French drain feeding the channel was not functioning properly. Leaves and other organic material were abundant on the bottom of the pond, and the water quickly became murky when the substrate was disturbed. Below the layer of organic material, the substrate was mostly sand and gravel. The banks were mostly vegetated.

SC-CH2: Water and sediment samples were taken from Channel 2, in the "Berm Pool," just downstream of the Channel 2 French drain. Samples were taken at the downstream end of the pool, where the channel narrows to 6 feet wide. Leaves and organic material were abundant on the bottom of the pond, and the water quickly became murky when disturbed. Below the layer of organic material, the substrate was mostly sand and gravel. The sand and gravel banks at this site were bare and unstable.

SC-BP: Water and sediment samples were taken from the Beaver Pond channel, at the upstream end of the third large beaver pond from the end of the channel. Samples were taken where the flow begins to slow down and spread out into the pond. This large pond contained dead tree trunks and down logs, with very fine sediments, organics, and vegetation growing within the channel.

RC-DS: Water samples were taken from the left side of the main channel of Resurrection Creek at the downstream end of the project reach, about 60 feet downstream of the outlet of the Beaver Pond side channel. The main channel at this site was relatively steep, with high water velocities, and the substrate was gravel and cobbles. The left bank was a high, eroding bank composed of gravel and cobbles.

RC-REF: Water samples were taken from the left side of the main channel of the Resurrection Creek reference reach, about 1 mile upstream of the project reach, and about 200 feet upstream of the inlet to the western side channel. This site was in a riffle just upstream of a small slough on the left bank, and the substrate was gravel and cobbles.

Sampling methods: All sampling bottles and equipment were pre-cleaned at the laboratory prior to shipping. Bottles were kept in double zip-lock bags. Because these samples were analyzed for ultra-trace levels of mercury, "ultra-clean" techniques were used when handling bottles and conducting sampling to prevent contamination of the samples (US Environmental Protection Agency, 1996). Sample bottles were handled only wearing non-powdered latex gloves by the sampler designated "clean hands." The field assistant, designated "dirty hands," handled only the outside of the outer zip-lock bag, never touching the sampling bottles. Latex gloves were changed at each sample site. Samples were frozen overnight and shipped overnight delivery to the laboratory in a cooler packed with ice. Samples were kept below 4 degrees C.

Water samples: For mercury and methylmercury samples, water was collected in 500 mL fluoropoly bottles with hydrochloric acid preservative. Water samples for sulfate and dissolved organic carbon were collected in 500 mL and 250 mL plastic bottles with no preservative. Samples were taken about 6 inches below the water surface, capped immediately, and placed on ice in a cooler. Water samples were not filtered. Water temperature and dissolved oxygen were measured at the time of sampling using a YSI Model 55 DO meter.

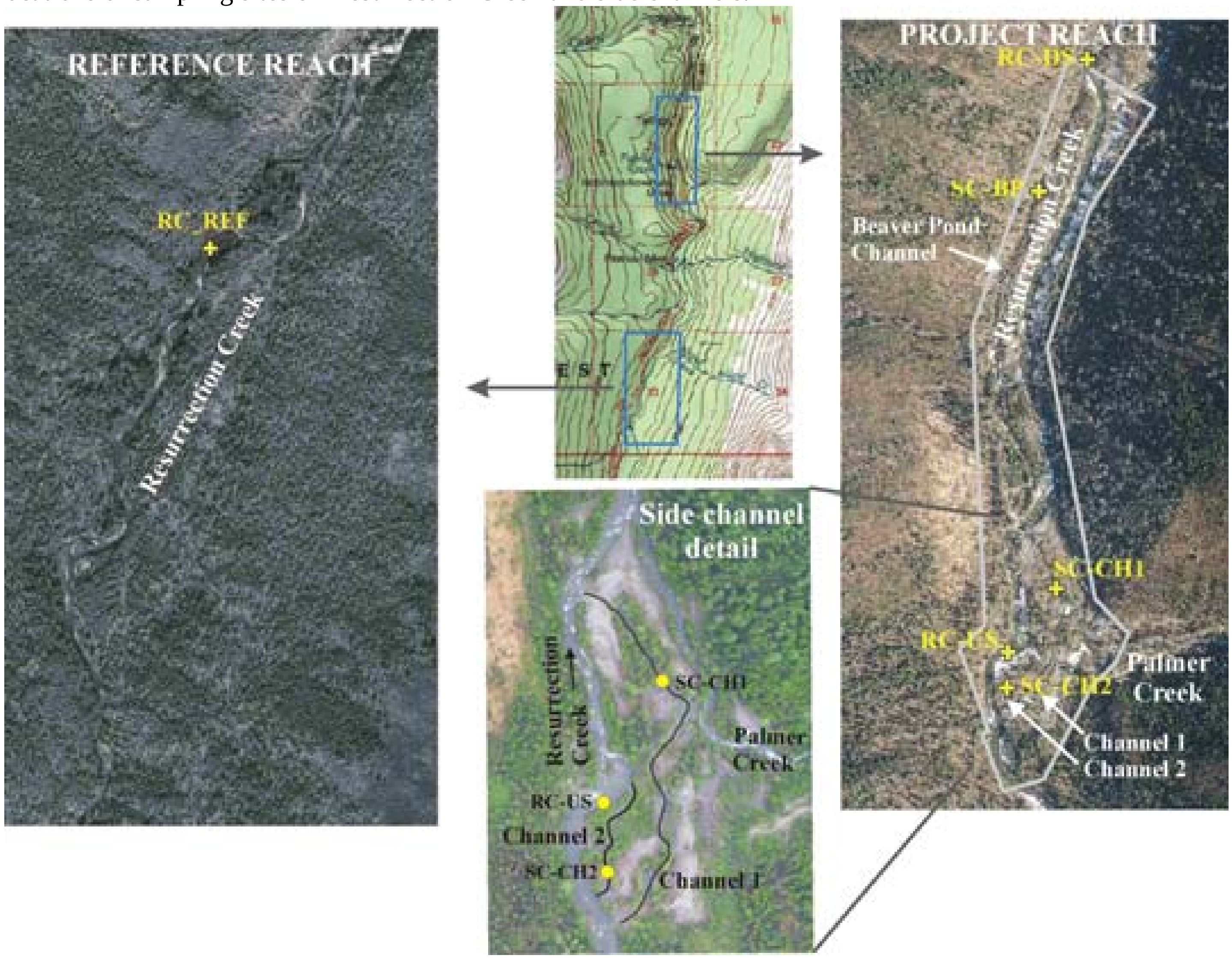
Sediment samples: Sediment samples were collected in 8-ounce wide-mouth glass jars for mercury and 4-ounce wide-mouth glass jars for methylmercury. Sediment was scooped from the substrate using a laboratory-cleaned 16-ounce wide-mouth jar. Samples were capped immediately and placed on ice in a cooler.

Laboratory methods: Laboratory analyses were conducted by Columbia Analytical Services, Inc., in Kelso, Washington. Methylmercury analyses were subcontracted by Brooks Rand LLC, in Seattle, WA. Samples were analyzed for mercury using EPA Method 1631E (US Environmental Protection Agency, 2002). This involves oxidation of the sample, followed by purging of the mercury onto a gold trap. Mercury is then detected using a cold-vapor atomic fluorescence spectrometer (CVAFS). Quality control included analysis of sample blanks and measurement of the percent recovery of a matrix spike in sample duplicates.

Samples were analyzed for methylmercury by a modification of EPA draft method 1630, as detailed in the Brooks Rand Method BR-0011. Sample preparation involved distillation of water samples and acid bromide/methylene chloride extraction of sediment samples. Samples were analyzed by cold vapor atomic fluorescence detection (CVAFS). Quality control included analysis of sample blanks and measurement of the percent recovery of a matrix spike in sample duplicates.

Water samples were analyzed for sulfate using ion chromatography as detailed in EPA method 300.0 (US Environmental Protection agency, 1999). Water samples were analyzed for dissolved organic carbon using EPA method 415.1. Sediment samples were analyzed for total organic carbon using method ASTM D4129-82M.

Figure 3: Locations of sampling sites on Resurrection Creek and side channels.



RESULTS OF SAMPLING

Sampling conditions

During the May 6, 2004 sampling, the flow in Resurrection Creek was moderate to high, and the water was relatively turbid. This was the result of several days of dry, unseasonably warm temperatures prior to sampling, resulting in a rapidly depleting snowpack. Snow was almost completely melted from the lower valley bottom. The flow in the reference reach was about 1 foot below bankfull, and the gauge height at the Hope Highway varied from 2.15 to 2.20 feet during the day.

During the August 10, 2004 sampling, the flow in Resurrection Creek was low, and the water was clear. These conditions were the result of warm, dry conditions, with no rain in the previous 1 to 2 weeks. The gauge height at the Hope Highway was 1.30 feet.

Water samples

Total Mercury in Water: Total mercury levels ranged from 5.1 to 7.3 parts per trillion (ppt) during the May sampling, and from 0.8 to 1.6 ppt during the August sampling (**table 1, figure 4**). The highest total mercury levels during the May sampling were at the Channel 1 site, and the lowest were in the Beaver Pond Channel site. The highest total mercury levels during the August sampling were at the Beaver Pond Channel site, and the lowest were in the reference reach site.

Methylmercury in Water: Methylmercury concentrations in water, measured only in the side channel sites, ranged from 0.089 to 0.193 ppt during the May sampling, comprising 1.6 to 2.6% of the total mercury (**table 1, figure 4**). During the August sampling, methylmercury ranged from 0.122 to 0.867 ppt, comprising 9.6 to 57.8% of the total mercury. For both sampling dates, the highest methylmercury concentrations were in the Channel 1 site and the lowest were in the Channel 2 site.

Other parameters: Sulfate ranged from 4.9 to 5.1 mg/L during the May sampling, and from 4.8 to 11.2 mg/L during the August sampling. Dissolved organic carbon ranged from 4.2 to 5.3 mg/L during the May sampling, and from 1.0 to 1.9 mg/L during the August sampling. During the May sampling, water temperatures ranged from 3.7 degrees C in the reference reach to 6.6 degrees C in the Channel 1 pond. During the August sampling, water temperatures ranged from 9.0 degrees C in the reference reach to 15.6 degrees C in the Channel 1 pond. Dissolved oxygen ranged from 8.3 mg/L in the Channel 1 pond to 12.3 mg/L in the reference reach during the May sampling, and from 7.4 mg/L in the Channel 1 pond to 10.5 mg/L in the reference reach during the August sampling.

Table 1: Results of mercury sampling in water and sediment in Resurrection Creek.

					SIDE CHANNELS			MAIN CHANNEL	
					SC-CH1	SC-CH2	SC - BP	RC - DS	RC-REF
				Detection Limit	Channel 1, Pool 1	Channel 2, Berm pool	Beaver Pond channel	Downstream end of project reach, main channel	Reference Reach, main channel
WATER	Mercury	**Total Mercury (ppt)**	6-May-2004	0.1	7.3	5.6	5.1	6.0	5.7
			10-Aug-2004	0.2	1.5	1.0	1.6	1.0	0.8
		Methylmercury (ppt)	6-May-2004	0.045	0.193	0.089	0.119	-	-
			10-Aug-2004	0.02	0.867	0.122	0.153	-	-
		Percent of total as Methylmercury (%)	6-May-2004	-	2.6	1.6	2.3	-	-
			10-Aug-2004	-	57.8	12.2	9.6	-	-
	Other	**Sulfate (mg/L)**	6-May-2004	0.18	5.1	5.1	5.0	4.9	5.1
			10-Aug-2004	0.18	4.8	11.2	10.4	10.0	11.2
		Dissolved organic carbon (mg/L)	6-May-2004	0.07	4.5	4.9	5.3	4.2	5.1
			10-Aug-2004	0.07	1.9	1.1	1.6	1.0	1.0
		Water temperature (degrees C)	6-May-2004	-	6.6	5.7	6.2	6.5	3.7
			10-Aug-2004	-	15.6	10.9	14.7	12.5	9.0
		Dissolved oxygen (mg/L)	6-May-2004	-	8.3	11.1	11.2	11.3	12.3
			10-Aug-2004	-	7.4	10.5	9.1	9.9	10.5
SEDIMENT	Mercury	**Total Mercury (ppb)-dry weight**	6-May-2004	0.3	55.1	42.0	141	-	-
			10-Aug-2004	0.3	97.2	27.2	66.1	-	-
		Methylmercury (ppb) - dry weight	6-May-2004	0.02	0.651	0.066	1.797	-	-
			10-Aug-2004	0.02	2.289	0.247	1.063	-	-
		Percent of total as Methylmercury (%)	6-May-2004	-	1.2	0.2	1.3	-	-
			10-Aug-2004	-	2.4	0.9	1.6	-	-
	Other	**Total percent solids (for total Hg analysis)**	6-May-2004	-	80.6	66.8	20.5	-	-
			10-Aug-2004	-	75.5	81.9	58.5	-	-
		Total percent solids (for Me-Hg analysis)	6-May-2004	-	78.2	75.9	33.5	-	-
			10-Aug-2004	0.05	77.3	80.2	61.7	-	-
		Total organic carbon (%) - dry weight	6-May-2004	0.02	0.46	0.46	10.2	-	-
			10-Aug-2004	0.02	1.41	0.51	1.9	-	-

Sediment samples

Total mercury: Total mercury concentrations in sediment samples in the side channel sites ranged from 42.0 to 141 parts per billion (ppb) dry weight basis during the May sampling, and from 27.2 to 97.2 ppb during the August sampling (**table 1, figure 5**). The highest levels were recorded in the Channel 1 and Beaver Pond Channel sites, with lower levels in the Channel 2 site.

Methylmercury: Methylmercury concentrations in sediment samples in the side channel sites ranged from 0.066 to 1.797 ppb dry weight basis during the May sampling, comprising 0.2 to 1.3% of the total mercury, and from 0.247 to 2.289 ppb during the August sampling, comprising 0.9 to 2.4% of the total mercury (**table 1, figure 5**). The highest levels were recorded in the Channel 1 and Beaver Pond Channel sites, with lower levels in the Channel 2 site.

Other parameters: Total organic carbon ranged from 0.46 to 10.2% dry weight basis during the May sampling, and from 0.51 to 1.9% during the August sampling. Substrates were predominantly sand and clay with some gravel in the Channel 1 and Channel 2 sites, and predominantly clay and organic material in the Beaver Pond Channel site.

Figure 4: Results of mercury sampling in water in Resurrection Creek.

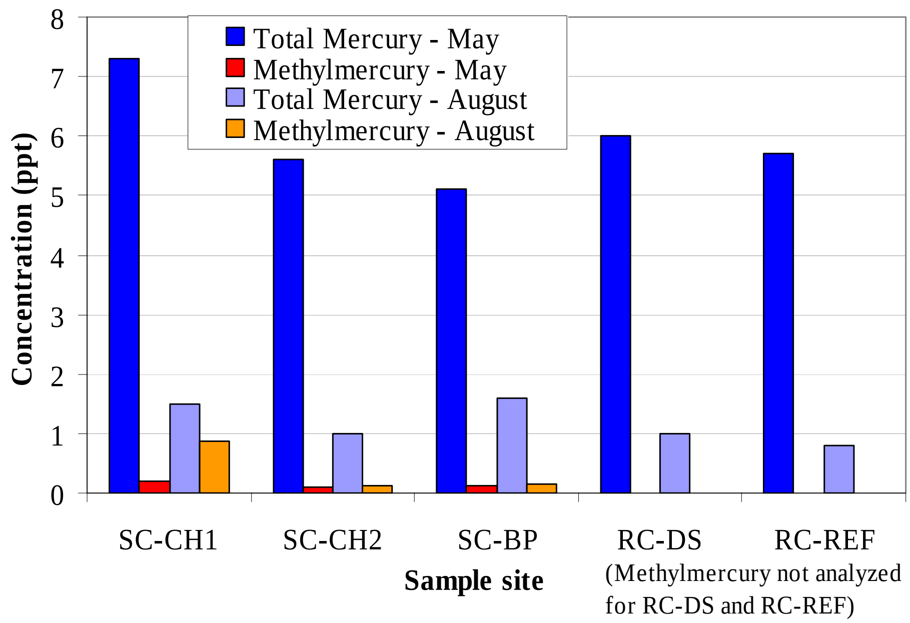
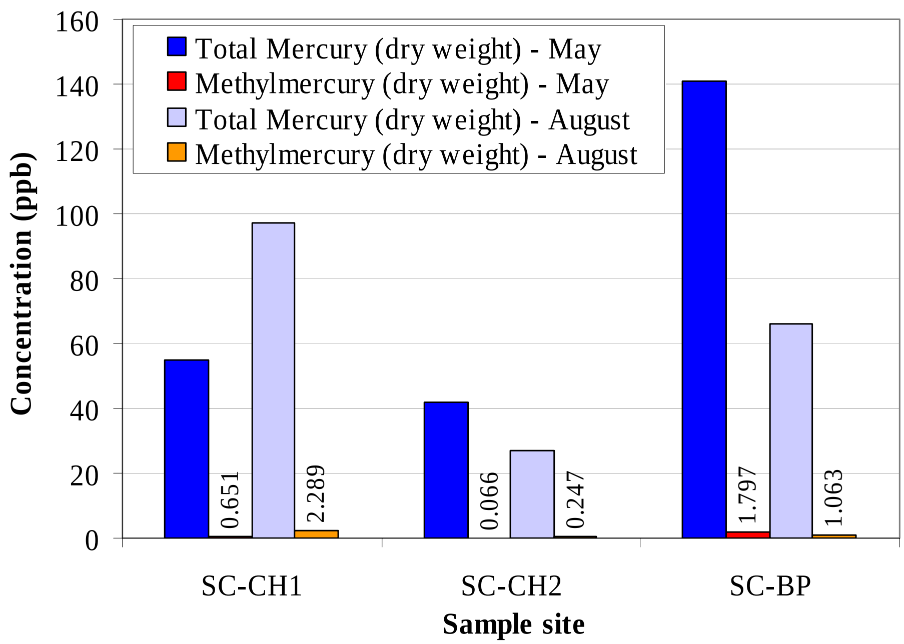


Figure 5: Results of mercury sampling in sediment in Resurrection Creek.



DISCUSSION

Mercury levels in water

Standards: The Alaska Department of Environmental Conservation (ADEC) primary contaminant limit for mercury and the US Environmental Protection Agency standard for mercury in drinking water are both 2 ppb, or 2000 ppt (Alaska Department of Environmental Conservation, 2003; US Environmental Protection Agency, 2004). The ADEC 1-hour acute aquatic life criteria for total dissolved mercury in fresh waters is 1.4 ppb (1400 ppt), and the 4-day average chronic standard is 0.77 ppb (770 ppt). Mercury concentrations in water samples taken from Resurrection Creek and its side channels during both sample dates were orders of magnitude lower than these standards.

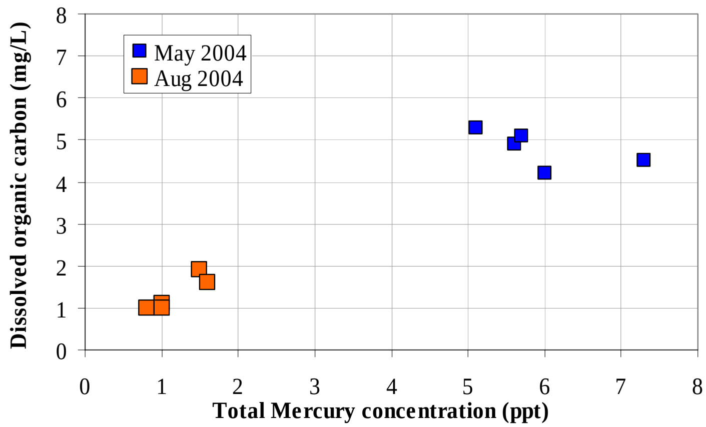
Total Mercury: On both of the sample dates, total mercury levels in water were relatively consistent between all five sample sites, and no clearly defined spatial trends were evident. Although the highest total mercury levels were generally measured in the side channels, this trend was not consistent, as the Beaver Pond Channel had the lowest mercury levels during the May sampling. Mercury levels were not consistently lower in the reference reach site than in the project reach sites, although during the August sampling, total mercury levels were slightly lower in the reference reach and main channel sites than in the side channel sites.

The main differences in water conditions between the main channel sites and the side channel sites included considerably greater flow, lower water temperatures, and higher dissolved oxygen levels in the main channel. In general, the side channels had low flows, stagnant pond areas, and abundant organic material, whereas the main channel and reference reach had high flows and clear water with little organic material. Although these factors can affect the rate of methylation of elemental mercury, they are less likely to affect the total mercury levels, as methylmercury is usually only a small percentage of the total mercury.

Total mercury concentrations in the August samples were consistently about five times lower than those in the May samples, indicating that discharge and other related variables can have an effect on mercury concentrations in the water. Compared to low flow conditions, high flows were accompanied by substantially increased levels of dissolved organic carbon, lower temperatures, and slightly higher dissolved oxygen levels. The variable that most likely explains the five-fold increase in total mercury at high water is dissolved organic carbon, and a positive correlation exists between total mercury and dissolved organic carbon (**figure 6**). The 2 to 5 times increase in dissolved organic carbon concentrations from low water to high water correspond to a 3 to 7 times increase in total mercury levels from low water to high water.

Snowmelt runoff in May resulted in abundant organic and inorganic material washing into Resurrection Creek from upland sources, and high water in Resurrection Creek at this time mobilized sediments and organic material from the channel bed. This likely explains the increased levels of dissolved organic carbon in the water. The increased levels of total mercury in the water in May compared to August could be explained by a combination of two factors. First, atmospherically derived and natural sources of mercury deposited throughout the watershed over the winter could likely have become concentrated in Resurrection Creek during spring runoff, which coincided with the May sampling. Second, because elemental mercury is insoluble in water, it can only exist in water if it is bound to other particles. The high flow conditions during the May sampling carried more sediment and organic matter, which could have included mercury derived from upland sources as well as mercury stirred up from the channel bed.

Figure 6: Relationship between dissolved organic carbon and total mercury in water.

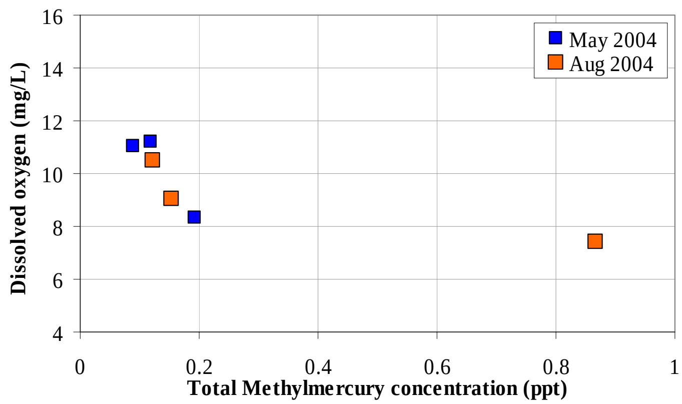


If mercury were present at high levels in the project reach, total mercury concentrations would be expected to be higher in water in the project reach side channels than the reference reach site. Although this is consistently the case only in the Channel 1 site, it suggests that some areas of the project reach could be the source of a small amount of mercury, or that mercury is being concentrated and retained in these more stagnant waters at times of low flow. The residence time of the water in the project reach was greatest during low flows in August, but the greatest mercury concentrations were measured at high flows in May, when the water moved through the project reach relatively quickly. The magnitude of the increase in total mercury between August and May is the same between the reference reach and the project reach, suggesting that the project reach is probably not the source of most of the mercury in the water.

Methylmercury: Methylmercury was only measured in water samples from the three side channels. In contrast to the total mercury data, methylmercury levels were generally higher during the August sampling than the May sampling. Channel 1 had considerably higher methylmercury levels during the August sampling, whereas methylmercury levels in Channel 2 and the Beaver Pond channel were only slightly higher during the August sampling.

Methylmercury levels in water are primarily related to the rate of methylation of elemental mercury. The high methylmercury levels in the Channel 1 site are related to bacterial activity resulting from the highly stagnant, warm, oxygen-depleted water with abundant organic material at this site. These conditions are largely the result of the nonfunctional French drain at the head of the channel. The relationship between dissolved oxygen and methylmercury shows a negative correlation, suggesting that such conditions are promoting increased methylation in the side channels (**figure 7**). The consistently lower methylmercury levels in the Channel 2 site than in the Channel 1 site suggest that methylation rates are lower in this pond because of its proximity to the French drain that supplies larger volumes of colder, more oxygenated water from Resurrection Creek.

Figure 7: Relationship between dissolved oxygen and methylmercury in water.



The percentage of total mercury as methylmercury was also considerably higher during the August sampling than in May, suggesting that rates of methylation were generally higher during low water conditions in August. Conditions were more favorable for methylation during the August sampling, with increased water temperatures and decreased dissolved oxygen levels. The percentage of total mercury as methylmercury in the Channel 1 site during the August sampling was very high, also showing that high rates of methylation were associated with the stagnant conditions in that pool.

Comparisons: Numerous studies have been conducted on mercury in impaired and unimpaired streams nationwide and regionally. Wiener et al. (2002) suggested that total mercury concentrations in lakes and streams with no anthropogenic or geologic sources of mercury generally range from about 0.3 to 8 ppt. Total mercury concentrations in water in Resurrection Creek and its side channels were within this range and were similar to levels from other Cook Inlet basin streams (Krabbenhoft et al., 1999) (**figure 8**).

Streams in which mercury mining, industrial pollution, or gold mining have occurred can have total mercury levels in water exceeding 10 ppt, or even over 1000 ppt (Wiener et al., 2002). As an extreme example, the Dutch Flat mining district in California, an area that was extensively placer mined using mercury amalgamation processes in the 19th Century, contained streams with as much as 10,400 ppt mercury in unfiltered water samples and 225 ppt mercury in filtered samples (Hunerlach et al., 1999). Total mercury levels in water measured for a national pilot study of mercury contamination in a variety of locations and land uses were similar to those in Resurrection Creek and its side channels, but the average total mercury concentrations in areas associated with mining greatly exceeded those of Resurrection Creek (Krabbenhoft et al., 1999) (**figure 8**).

Methylmercury levels in water in Resurrection Creek were considerably higher than those measured in other Cook Inlet streams (Krabbenhoft et al., 1999) (**figure 9**). The percentage of the total mercury as methylmercury was also higher in the Resurrection Creek sites, especially during the low water August sampling. However, with the exception of the high methylmercury level measured in August in the Channel 1 site (0.87 ppt), these levels were similar to the average background levels at other sites measured as part of the national pilot study on mercury contamination (Krabbenhoft et al., 1999). The high level of methylmercury in the Channel 1 site during the August sampling is probably the result of the stagnant pond at that site, which has conditions that promote methylation. Nationwide, high methylmercury levels in water have also been measured in urban and rural areas in New England, where values ranged from 0.04 to 1.8 ppt (US Geological Survey, 2003), and in the heavily mined Dutch Flat District, California, where levels ranged from 0.01 to 1.0 ppt (Hunerlach et al., 1999).

Figure 8: Comparison of ranges of total mercury concentrations in water between Resurrection Creek and other sites nationwide.

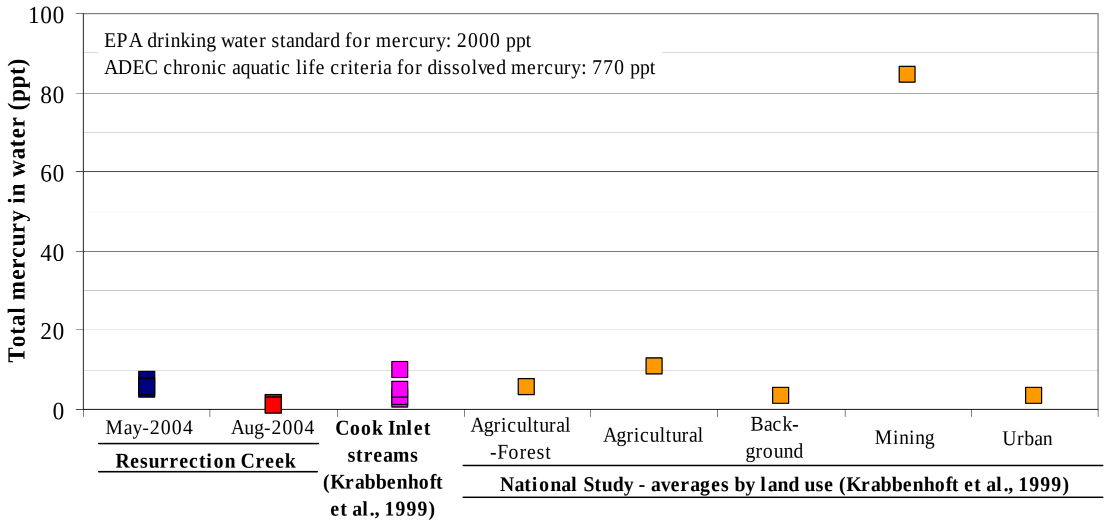
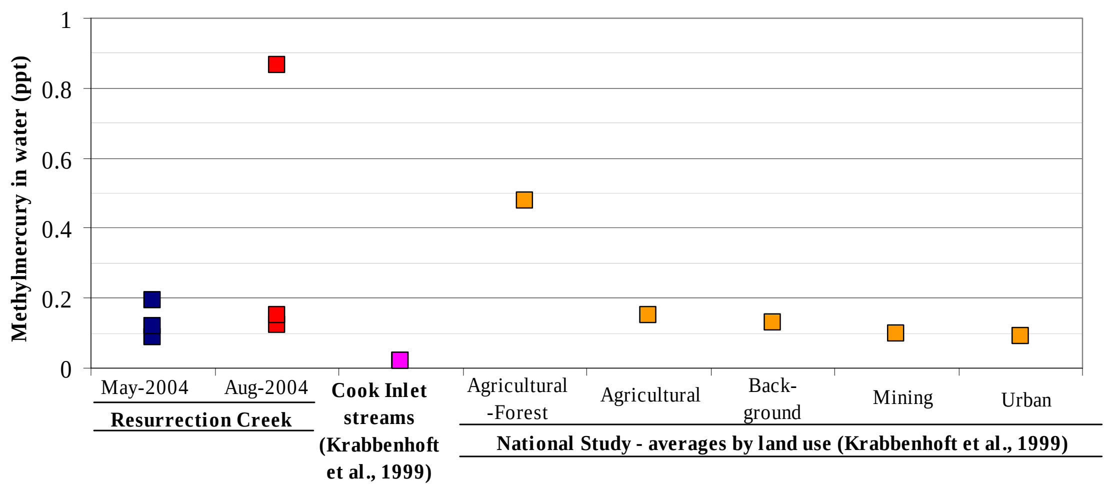


Figure 9: Comparison of ranges of methylmercury concentrations in water between Resurrection Creek and other sites nationwide.



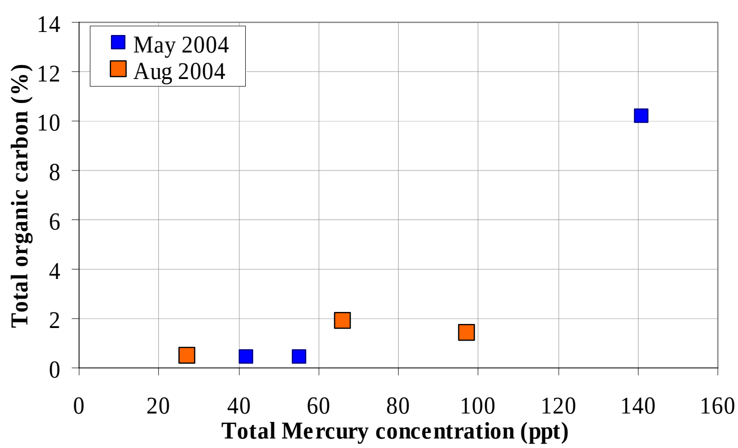
Mercury levels in sediment

Total mercury: Mercury levels in sediment were only measured in the three side channel sites of the project reach. In general, mercury levels in sediment were higher in the Channel 1 and Beaver Pond Channel sites than in the Channel 2 site. The fine grained sediment in the Beaver Pond channel contained abundant organic matter to which elemental mercury could bind, resulting in high mercury levels. Sediments in the Channel 1 and Channel 2 sites consisted of mostly sand and gravel. The Channel 1 site had abundant organic material accumulated over the bed surface and stagnant conditions in the pond, which could have contributed to the high mercury levels at that site. The Channel 2 site likely had the lowest mercury levels because it had clear water and less organic material, as it is close to the French drain and receives consistent flow directly from Resurrection Creek.

No clear trends in mercury concentrations in sediment exist between the two sample dates. In May, mercury levels were by far the highest in the Beaver Pond Channel site, and in August, mercury levels were the highest in the Channel 1 site. Mercury levels in the Channel 2 site were somewhat higher in May than in August. Mercury levels in the Beaver Pond Channel site were twice as high in May as in August, but levels in the Channel 1 site were almost twice as high in August as in May.

The highest levels of mercury in sediment do not correspond with the highest levels of mercury in water in the side channels. Elemental mercury can exist in sediment by itself or attached to organic particles. A slight correlation exists between total mercury in sediment and total organic carbon in sediment, suggesting that some portion of the mercury that exists in the sediment is associated with organic material (**figure 10**). Differences in total mercury concentrations could also be attributed to slight local variations in the point of sampling. Duplicate samples from the same location could contain varying amounts of organic material, which could affect the total mercury concentration in the sample.

Figure 10: Relationship between total organic carbon and total mercury in sediment.



Methylmercury: Methylmercury levels were considerably higher in the Channel 1 and Beaver Pond Channel sites than in the Channel 2 site. The highest concentrations of methylmercury were measured in the Channel 1 site in August, where methylmercury levels reached 2.3 ppb, or 2.4% of the total mercury. This is likely because of the high rate of methylation of mercury in the sediment at this site resulting from the highly stagnant conditions in that pond. The low dissolved oxygen levels, warm temperatures, and abundant organic matter are all conditions that can lead in increased rates of methylation. Methylmercury concentrations in sediment show a weak correlation with water temperature as well as dissolved oxygen. The high levels of methylmercury in sediment at the Channel 1 site correspond to the high levels measured in the water at the same site. High methylmercury levels in the Beaver Pond Channel can be attributed to elevated rates of methylation and the predominance of organic matter in the sediment. Low levels of methylmercury in the Channel 2 site are attributed to conditions such as colder water temperatures and higher dissolved oxygen, which are not favorable for methylation of mercury.

Comparisons: Preliminary screening levels for mercury contamination in sediment have been suggested by the National Oceanic and Atmospheric Administration (NOAA). Although they do not represent sediment quality standards, these guidelines suggest that background levels of total mercury in sediment are 4 to 51 ppb (dry weight), the Threshold Effects Level is 174 ppb (dry weight), the Probable Effects Level is 486 ppb (dry weight), and the Upper Effects Threshold is 560 ppb (dry weight) (National Oceanic and Atmospheric Administration, 1999). Total mercury levels in the Channel 1 and Beaver Pond Channel sites were over the background levels, but below the Threshold Effects Level. Mercury levels in the Channel 2 site were within the background levels (**figure 11**).

Total mercury and methylmercury levels in sediment in the side channel sites are similar to levels measured in other Cook Inlet region streams (Krabbenhoft et al., 1999; Frenzel, 2000) (**figure 11, figure 12**). These levels are also similar to mercury levels in streams in agricultural and forested sites in the Puget Sound area, Washington, but considerably lower than the urban sites in the Puget Sound area (MacCoy and Black, 1998) (**figure 11**). Mercury and methylmercury levels in sediment in the Resurrection Creek side channels are within the lower range of levels measured in sediments from the national pilot study on mercury contamination (Krabbenhoft, 1999) (**figure 11, figure 12**).

The percentage of the total mercury as methylmercury in the sediments in Resurrection Creek ranged from 0.2 to 2.4%. In rural and urban sites in New England, the percentage of the total mercury as methylmercury ranged from 0.3 to 25%, with methylmercury levels reaching as high as 15.6 ppb (US Geological Survey, 2003). Of the Resurrection Creek side channels, the Channel 1 site had the highest percentage of mercury in sediment as methylmercury (2.4%) as well as the highest percent of mercury in water as methylmercury (57.8%). This suggests that the rate of methylation is high in this particular site, probably because of the stagnant conditions, warm water, and low dissolved oxygen levels.

Figure 11: Comparison of ranges of total mercury levels in sediment (dry weight) between Resurrection Creek and other sites nationwide.

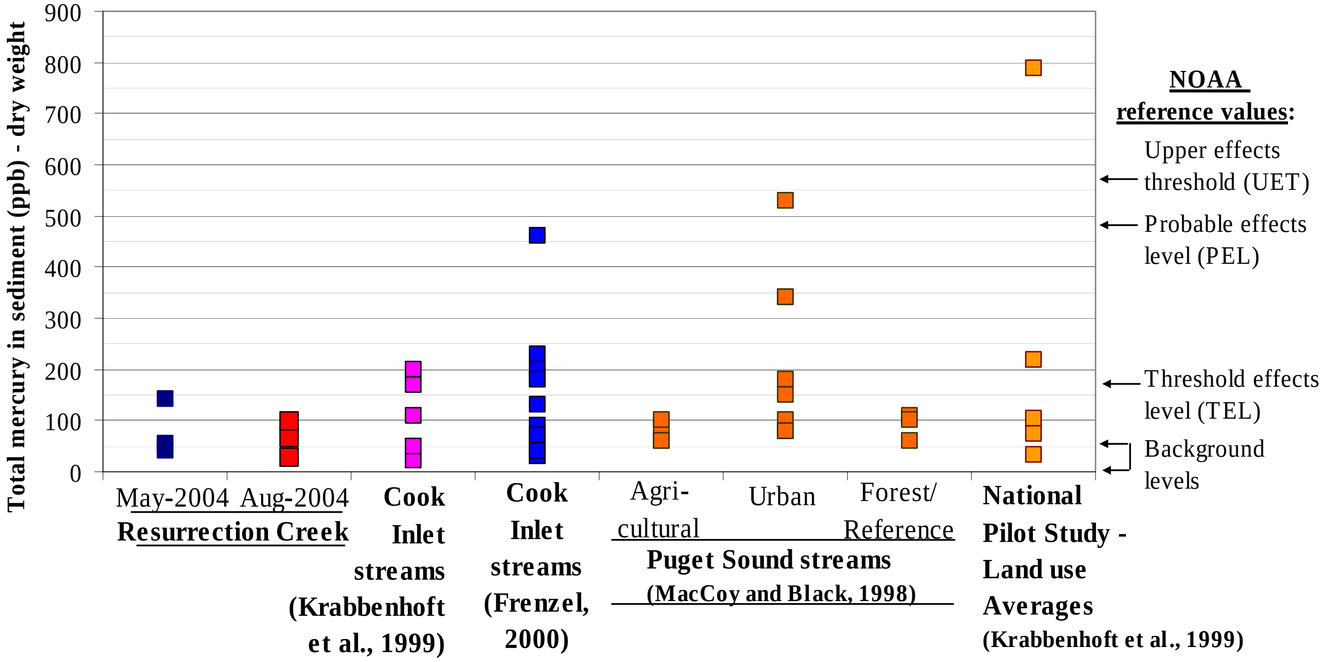
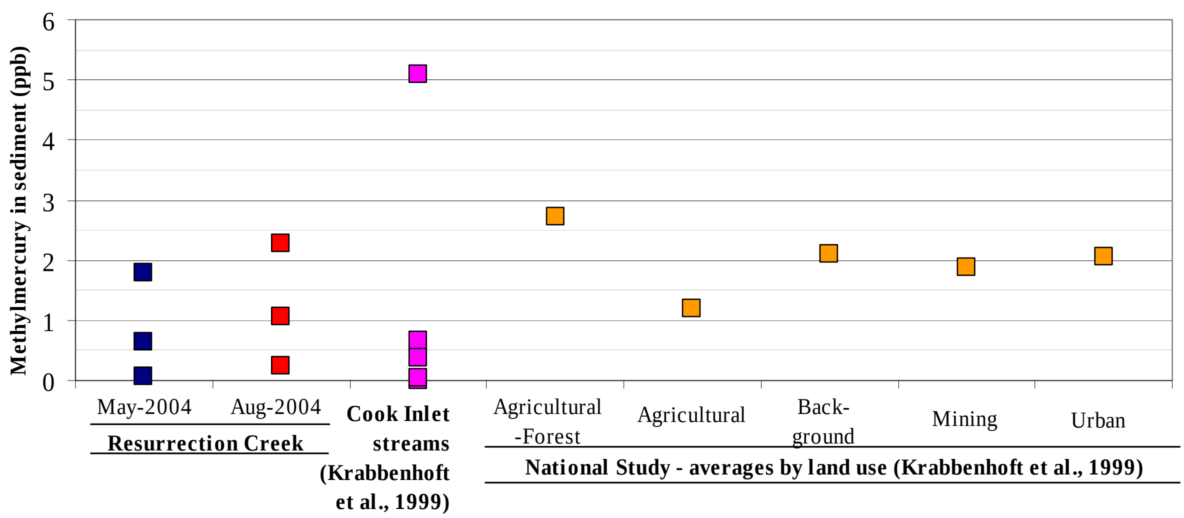


Figure 12: Comparison of ranges of methylmercury levels in sediment (dry weight) between Resurrection Creek and other sites nationwide.



CONCLUSIONS

Many factors have been shown to affect mercury and methylmercury concentrations in streams. Clearly, point sources of mercury pollution and geologic sources affect mercury concentrations in water and sediment. Atmospheric deposition of mercury from global sources can be a large contributor of mercury to surface waters. A study in the coastal basins of New England showed that precipitation contained total mercury concentrations of 2 to 20 ppt in 2002 (US Geological Survey, 2003). Although mercury is deposited globally in this manner, such influences are more prevalent in the more industrial areas. Levels of methylmercury are a function of the conditions that favor methylation of elemental mercury, such as high water temperatures, low pH, anaerobic conditions, higher dissolved organic carbon concentrations, and the density of nearby wetlands.

Mercury levels in Resurrection Creek and its side channels showed some trends, but the data are limited. Differences in total mercury concentrations in water between May and August were the result of different flow levels and differences in sediment and organic material transported by the water. In general, total mercury levels in water increased with concentrations of dissolved organic carbon, suggesting that mercury attaches itself to organic particles in water. Methylmercury levels in water increased with decreasing dissolved oxygen levels, suggesting that rates of methylation were greater in the sites with more stagnant conditions such as Channel 1. Mercury concentrations in sediment between May and August showed no clear trend and are likely affected by local variability within the sample sites. Mercury and methylmercury levels in sediment increased with total organic carbon and were generally higher in sites with finer sediments.

Mercury levels in the water in the project reach were generally not elevated above those of the reference reach and were similar to levels found in other streams in the Cook Inlet basin. Mercury levels in sediment in the side channels were also within the range of levels found in streams of the Cook Inlet Basin. Methylmercury concentrations in water and sediment in these sites were similar to levels measured nationwide, but higher than in streams of the Cook Inlet basin. The Channel 1 site contained considerably more methylmercury than the other sites as a result of the stagnant conditions.

The results from this study, in conjunction with the mercury data from resident fish sampled in September 2003, suggest that mercury concentrations in the Resurrection Creek project reach are relatively low. It is likely that mercury levels may be slightly elevated in the project reach as a result of mercury deposition during past gold mining operations, but sampling efforts have not detected levels that would be of concern for drinking water or effects on aquatic species. Total mercury concentrations in Resurrection Creek were lower than those measured at several other sites nationwide that have been impacted by gold mining and mercury amalgamation processes.

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APPENDIX A: SAMPLE SITE PHOTOGRAPHS

SC-CH1: Project Reach side channel, east side (Channel 1, Pool 1)

May

August

SC-CH2: Project Reach side channel, east side (Channel 2, Berm Pool)

May (view downstream)

August (view upstream)

SC-BP: Project Reach side channel, west side (Beaver Pond Channel)

May (view downstream)

August (view downstream)

RC-DS: Project Reach main channel, downstream end of project reach, left bank


May (view upstream)


August (view downstream)

RC-REF: Reference Reach main channel, left bank


May (view upstream)


August (view downstream)

APPENDIX B: LABORATORY DATA

Laboratory analyses were conducted by

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