

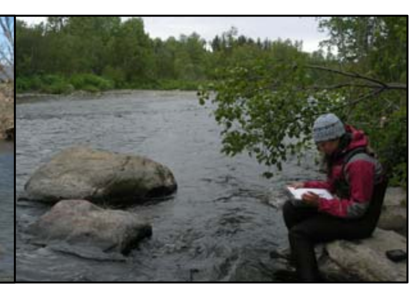

STREAM TEMPERATURE MONITORING NETWORK FOR COOK INLET SALMON STREAMS

FY 2009 REPORT
WORKING DRAFT

Prepared by

COOK INLETKEEPER
HOMER, AK



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Stream Temperature Monitoring Network for Cook Inlet Salmon Streams

SUMMARY

The Cook Inlet basin drains 39,000 square miles of high quality salmon habitat that is at heightened risk due to the effects of climate and land-use change. High stream temperatures stress fish making them increasingly vulnerable to pollution, predation and disease. Yet despite the links between warm water temperatures and reduced salmonid survivorship, there is little consistent, long-term temperature data for salmon streams in Alaska. Cook Inletkeeper is working with partners to implement an expanded temperature data logger network throughout the Cook Inlet basin to identify thermal impacts in coastal salmon habitat. In the summer of 2008, continuous water and air temperatures were taken in 46 non-glacial salmon streams. Stream temperatures exceeded Alaska's Water Temperature Criteria of 13ºC at 35 sites, 15ºC at 30 sites, and 20ºC at three sites. Maximum stream temperatures ranged broadly among sites: 9.2 – 22.0ºC, with the highest temperatures recorded in streams that drain lakes or lowland areas west of the Susitna River. The air-water temperature relationship was stronger with air temperature data from each site than from regional airports, particularly in lower Cook Inlet. Using watershed characteristics, streams were categorized into stream types that helped explain their thermal profile: 1) warm-water streams draining lakes, 2) temperate streams with no lakes and greater than 5% wetlands, and 3) cold-water streams with no lakes and less than 5% wetlands. With continued data collection to capture annual variation, this project will play an important role in helping state and federal resource managers prioritize streams with the greatest potential to buffer stream temperatures for research, restoration and protection efforts to ensure Alaska wild salmon endure as thermal change continues.

BACKGROUND

There is perhaps no greater indicator for gauging the health of wild salmon and their habitat than water temperature. Water temperature plays a critical role in all phases of the salmonid lifecycle, especially in freshwater systems. Stream temperature affects survivorship of eggs and fry, rate of respiration and metabolism, timing of migration, and availability of oxygen and nutrients. Temperature increases have been shown to induce physiological stress in salmon, which makes them more vulnerable to secondary stressors such as pollution, predation and disease. However, across watersheds or even among neighboring creeks within the same watershed, individual stocks or populations do not appear to respond uniformly to thermal variation.[1]

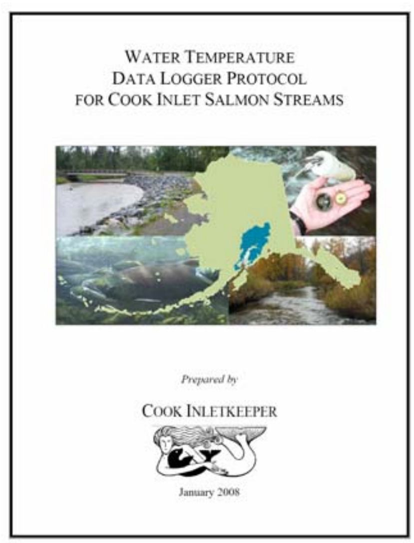
All five species of wild salmon return to the Cook Inlet watershed in South-central Alaska to spawn. Cook Inlet drains 39,000 square miles of high quality salmon habitat that is at heightened risk due to the effects of both climate and land-use change. Alaska is thought to be experiencing the greatest regional warming of any state in the U.S. and warming patterns are expected to continue at least into the next century. In addition, the Cook Inlet watershed is the most populated and fastest-growing region in Alaska.[2]

In 2002, monitoring by the Homer Soil and Water Conservation District and Cook Inletkeeper revealed that wetland-dominated salmon streams on the lower Kenai Peninsula exceeded Alaska's water temperature standards for egg and fry incubation on more than 50 days in the summer. By 2005, exceedances were happening on more than 80 days[3]. Recent studies in Mat-Su salmon streams show temperature exceedances above state water quality standards set to protect fish on Montana Creek[4], a clear water tributary to the Susitna River, and Cottonwood Creek[5], a lake-dominated system. Yet despite the links between warm water temperatures and reduced salmonid survivorship, there is little consistent, long-term temperature data for salmon streams in Alaska. Given Alaska's extreme size, preponderance of waterbodies, and small population base, implementing a Stream Temperature Monitoring Network on a large basin scale, such as the Cook Inlet basin, is prudent and an effective use of financial and human resources.

PROJECT GOALS AND OBJECTIVES

The goal of the Stream Temperature Monitoring Network for Cook Inlet Salmon Streams is to build the science-based knowledge needed to identify thermal impacts in coastal salmon habitat. Data collected through the Network will help identify watershed characteristics with the greatest potential to buffer stream temperatures from climate and land-use change, and provide the knowledge and data needed to prioritize sites for future research, protection, and restoration actions. The two main objectives in 2008-2009 were to: 1) collect consistent, comparable temperature data for non-glacial salmon streams; and 2) analyze data to establish natural conditions and generate GIS maps to illustrate temperature patterns.

With assistance from its Technical Advisory Committee, Cook Inletkeeper has established a standardized protocol and produced a detailed description of methods, equipment needed, how to deploy data loggers in the field, how to program and download data, how to perform maintenance and quality assurance measures. Using these protocols, Cook Inletkeeper's Science Director successfully coordinated with data-collecting Partners (Aquatic Restoration and Research Institute, Wasilla Soil and Water Conservation District, Anchorage Waterways Council, Kenai Watershed Forum), resource agencies, and community-based groups to collect temperature data in 48 salmon streams. Cook Inletkeeper worked with the Kenai Watershed Forum to compile these data and with The Nature Conservancy of Alaska to generate GIS maps to illustrate temperature patterns across the Cook Inlet basin.



METHODS

The Cook Inlet sampling design includes 48 non-glacial salmon streams which represent both large and small watersheds; and clear water and brown water systems (Table 1, Map 1). Also streams were selected because of existing stream gages, fish weirs, ease of access and the availability of partners to perform maintenance and quality assurance checks. The streams selected represent a range of urban development but all of them are considered reference streams (i.e. benchmarks) for the goal of establishing a baseline relationship between air and water temperature in a variety of stream types. Specific sampling locations were selected as far downstream in the watershed as possible, where the stream water is flowing and well mixed and not likely to be dewatered during low flows, and with no tidal influence. Side channels, backwaters, or areas below tributary inputs were avoided. A hand-held thermometer was used to ensure that the water is well mixed and that temperatures are consistent both vertically and horizontally.

Prior to deployment, data logger accuracy was checked against a National Institute of Science and Technology (NIST)-certified thermometer. Data loggers (StowAway TidbiT, TidbiT v2, and HOBO Water Temp Pro v2) were programmed for a recording interval of 15 minutes. The water loggers were secured instream using one of two methods. 1) The logger was cable tied inside a protective case or PVC housing, which allowed stream water to flow through but protected the logger from direct solar radiation. The housing was attached by a cable to a rebar stake. A stake pounder was used to sink the rebar 3 feet into the stream bottom near a large rock or other landmark. 2) The logger was attached to trees or other stationary objects on the streambank using plastic coated cable. The cable was attached to the logger with clamps and a loop was made at the opposite end of the cable using similar clamps. The cable was wrapped around the stationary object on the bank and the logger passed through the loop and placed within the stream. The cable was buried under the grass to avoid detection and to keep it from catching on passing wildlife. A large cobble or boulder sized rock was placed on the cable in the stream approximately 6 inches above the logger, securing the logger in place.

In addition, air temperatures were recorded at each monitoring location. Air temperature loggers were secured within a solar radiation shield. The solar shield and logger were secured to a post or suspended from vegetation in the area at least 6 feet off of the ground. The air temperature logger was placed 25 - 100 feet from the stream so that water temperatures did not influence local air temperature data. Supplemental site and reach information was also collected including latitude and longitude location, elevation, channel width and depth, extent to which vegetation shades logger, channel flow status, and stream habitat type.

Loggers were deployed mid May - mid July as conditions allowed. Data-collecting Partners periodically checked on loggers to ensure that they were still in place and operating. At the end of the field season (after October 1), the loggers were retrieved and the data downloaded on a data shuttle or base station. The loggers then went through a post-deployment calibration and battery check.

Table 1. Stream Temperature Monitoring Network data logger locations.

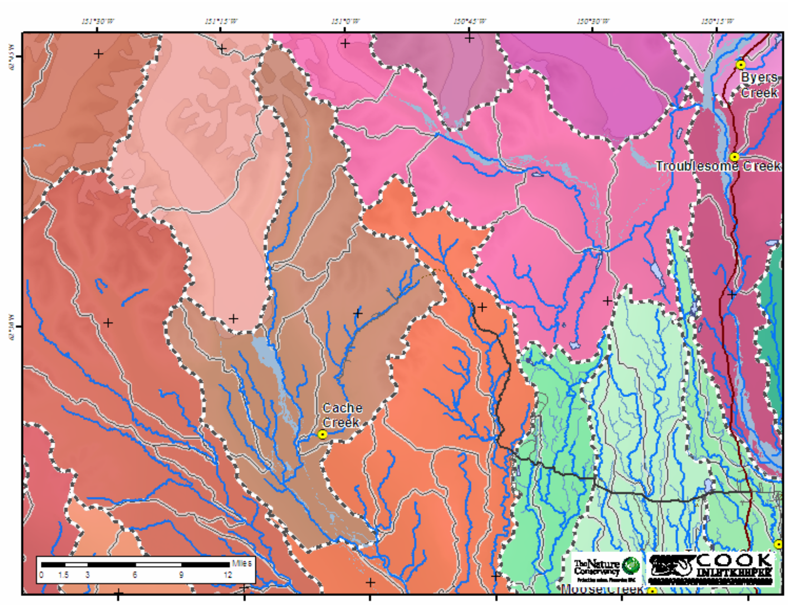
LOCATION	REGION	DESCRIPTION	Latitude	Longitude
Alexander Creek	Mat-su	Approx. 2 miles upstream from Susitna River	61.44000	-150.59600
Anchor River	Kenai	immediately downstream of weir	59.77300	-151.83400
Beaver Creek	Kenai	Togiak Road access	60.56100	-151.12300
Bishop Creek	Kenai	Silvertip Road access	60.76800	-151.10300
Byers Creek	Mat-su	Upstream from Park's Highway	62.71158	-150.20407
Cache Creek	Mat-su	1/2 mile downstream from east end of landing	62.38900	-151.08100
Chenik Creek	West Inlet	incorporated into stream gage set up	59.20900	-154.19000
Chester Creek	Anchorage	downstream of Arctic Blvd	61.20500	-149.89600
Chijuk Creek	Mat-su	At Oilwell Road Crossing	62.07963	-150.58314
Chuitna River	West Inlet	1/4 mile upstream of Beluga Highway bridge	61.10100	-151.19000
Cottonwood Creek	Mat-su	Upstream from Surrey Road	61.52500	-149.52700
Crooked Creek	Kenai	lower site below hwy, Cohoe King Road access	60.31600	-151.28400
Deception Creek	Mat-su	Upstream from Willow-Fishook Road	61.76200	-150.03400
Deep Creek	Kenai	1/4 mile upstream from highway bridge	60.03300	-151.67100
East Fork Chulitna River	Mat-su	Downstream from Park's Highway	63.14500	-149.42100
English Bay River	Kenai	20 feet upstream of weir	59.34300	-151.91200
Fish Creek	Mat-su	Below Knik-Goose Bay Road	61.43800	-149.78100
Fox Creek	Kenai	public access trail above private land at m	59.79900	-151.05600
Funny River	Kenai	upstream of Funny River Road bridge	60.49000	-150.86000
Hidden Creek	Kenai	1000 feet upstream of Kenai River confluence	60.43900	-150.20800
Jim Creek	Mat-su	1 mile upstream of Jim Creek Flats	61.52900	-148.93300
Kroto (Deshka) Creek	Mat-su	1.0 miles upstream from Susitna River	61.74000	-150.32000
Liitle Willow Creek	Mat-su	0.25 miles downstream from Parks Highway	61.81000	-150.09900
McNeil River	West Inlet	incorporated into stream gage set up above	59.11700	-154.27900
Meadow Creek	Mat-su	At Beaver Lakes Road Crossing	61.56300	-149.82400
Montana Creek	Mat-su	End of Access Road South of Helena	62.12800	-150.01900
Moose Creek, (Palmer)	Mat-su	150 yards downstream of Glenn Highway bridge	61.68200	-149.04300
Moose Creek (Talkeetna)	Mat-su	At Oilwell Road Crossing	62.22900	-150.44100
Moose River	Kenai	1 mile up, Otter Trail Rd.	60.55700	-150.73500
NF Campbell Creek	Anchorage	upstream of Diamond Blvd. and Campbell Lake	61.14000	-149.92300
Nikolai Creek	Kenai	boat to mouth, 75 feet downstream of weir	60.19500	-151.00900
Ninilchik River	Kenai	immediately downstream of highway bridge	60.04900	-151.65600
Quartz Creek	Kenai	1.5 miles upstream along highway corridor	60.49300	-149.70000
Rabbit Creek	Anchorage	upstream of Old Seward Hwy crossing	61.08500	-149.82300
Resurrection Creek	Kenai	1/4 mile upstream from highway bridge	60.91800	-149.64300
Seldovia River	Kenai	3/4 mile upstream of mouth	59.38900	-151.68000
Shantatalik Creek	Kenai	boat to mouth, 75 feet upstream of weir	60.29100	-150.98500
Ship Creek	Anchorage	downstream of Reeve Blvd.	61.22700	-149.83100
Silver Salmon Creek	West Inlet	1/2 mile upstream from Ranger station	59.98184	-152.67859
Slikok Creek	Kenai	Chugach Rd access	60.48300	-151.13100
Soldotna Creek	Kenai	upstream of East Redoubt Rd. crossing	60.48900	-151.04400
Stariski Creek	Kenai	1/4 mile upstream from highway bridge	59.85100	-151.78700
Swanson River	Kenai	North Kenai Road crossing	60.79200	-151.01200
Theodore Creek	Mat-su	500 yards upstream from Beluga Highway bridge	61.26600	-150.88400
Trapper Creek	Mat-su	At Bradley Road Crossing	62.26600	-150.18400
Troublesome Creek	Mat-su	Downstream from Park's Highway	62.62700	-150.22700
Wasilla Creek	Mat-su	Nelson Road access	61.55300	-149.31400
Willow Creek	Mat-su	0.25 miles upstream from Susitna River	61.78000	-150.16100

Map 1. Stream Temperature Monitoring Network data logger locations.

Temperature metrics, including overall maximum temperature; daily, weekly and seasonal average, maximum, and minimum temperature; monthly cumulative degree days (sum of average daily temperatures); maximum 7-day rolling average/maximum temperature; and maximum daily fluctuation, were generated. Regression equations were used to determine the relationship between daily and weekly average water temperatures and air temperatures. Air temperatures from each site as well as from regional weather centers (National Oceanic and Atmospheric Administration (NOAA) web site (http://www.ncdc.noaa.gov/oa/ncdc.html)) were compared with water temperatures. Linear regressions provide a measure of the strength of the relationship through the R^2 value; R^2 values closest to 1.0 represent the strongest relationship.

Watershed metrics including watershed size, aspect, and percent land-cover types (% wetlands, % forested, % open water, % developed, % scrub/shrub) were generated using a variety of mapping tools. In an effort to use a systematic process for determining watershed size, we used Hydrologic Unit Codes (HUC) GIS layers (Hydrography and Watersheds USGS, BLM 2006). 10-digit (5^{th} level) HUC watersheds are 40,000 to 250,000 acres in size (62.5 to 390 square miles); 12-digit (6^{th} level) HUC sub-watersheds are 10,000 to 40,000 acres in size (15.5 to 62.5 square miles) (see Map 2). Some drainages were smaller than the 12-digit HUC level so watershed boundaries were generated from topographic maps. Based on HUC and topographic delineations, land-cover statistics were derived for each watershed from 30 meter resolution LANDSAT imagery (1999, 2003) from the USGS (2007).

Based on these watershed metrics, streams were grouped to determine if there are stream types with unique thermal responses. One-way analysis of variance (ANOVA) was used to test the hypothesis that there is no difference in mean values between stream types for a variety of temperature metrics.



Map 2. Examples of 10-digit (5^{th} level) HUC watersheds which are outlined in the hatched black/white boundary. 12-digit (6^{th} level) HUC sub-watersheds are depicted by black lines outlined in white. Cache Creek is a 12-digit sub-watershed within the 10-digit North Kahiltna River watershed.

RESULTS

We deployed air and water loggers at 48 sites and ended up with 46 air temperature datasets (missing Chester Creek, Crooked Creek) and 46 water temperature datasets (missing Jim Creek, Fox Creek), which is a 95.8% retrieval rate. The Chester Creek air logger may have been removed from the solar shield by a homeless group camping near the site. The air logger at Crooked Creek failed to record data after one month. We don't know if it was programmed improperly or if the battery died. The water logger on Jim Creek is either buried deep in the soft sediment or was snagged by folks fishing. The logger was never found after the initial deployment. Jim Creek may be too large and depositional for this deployment method. On Fox Creek, there is a great deal of bed movement and it is likely the rebar and housing got flushed out of the system.

Bear damage at Chenik Creek resulted in some data being discarded. We have video of the bear playing with the metal pipe that the logger was secured to so we have the date and time of bear vandalism. ADF&G had a stream level gage inside the pipe also so we could compare hourly temperatures. After the bear disturbance the two datasets started drifting. Both the data logger and the stream level gage checked out fine during post-deployment calibration but the logger has a crack in the epoxy. The Alexander Creek water logger, which was tethered by cable to the stream bank, apparently got caught up on the bank during a high flow event or by wildlife/human tampering and was no longer recording water temperatures after August 8th based on the temperature profile. The logger on Kroto (Deshka) Creek shows a similar pattern for one week (July 1-6). These data were deleted from the analysis.

TEMPERATURE EXCEEDANCES

Due to the critical role that water temperature plays in the function of aquatic ecosystems and because human activities may impact temperature, the Alaska Department of Environmental Conservation has adopted maximum water temperature criteria under Alaska's Water Quality Standards (18 AAC 70) to meet the federal Clean Water Act's fishable and swimmable goals[6]. Numeric water temperature criteria are included in the water quality standards for the growth and propagation of freshwater fish, shellfish, other aquatic life and wildlife (see box).

ALASKA'S
WATER TEMPERATURE CRITERIA

The following maximum temperatures shall not be exceeded, where applicable:

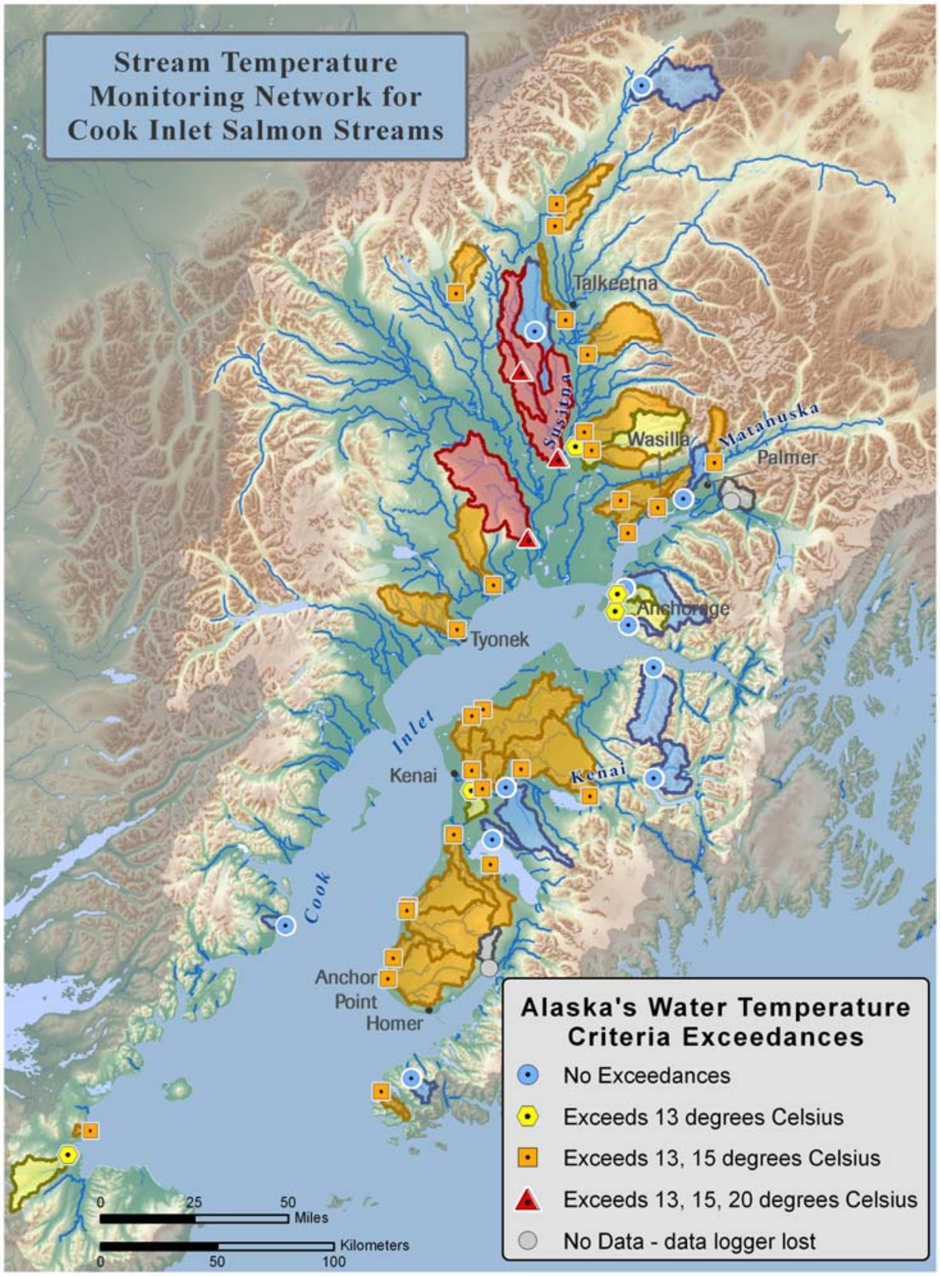
egg & fry incubation = 13°C
spawning areas = 13°C
migration routes = 15°C
rearing areas = 15°C

and may not exceed 20°C at any time.

Water temperatures above 13°C were recorded at 35 sites and above 15°C at 30 sites (Table 2, Map 3) during the 2008 summer season. Temperatures exceeded 20°C at 3 sites: Alexander Creek, Chijuk Creek and Kroto (Deshka) Creek. Loggers at 8 sites were deployed after June 21st so summer exceedances may be under reported; the logger on Alexander Creek went dry in August and the loggers at McNeil River and Chenik Creek were pulled early so exceedances may also be under reported.

Table 2. Temperature exceedances for the summer season (June 21- September 22, 94 days total) and dates of logger deployment in 2008. Loggers were deployed by 6/21 and pulled out after 9/30 unless otherwise noted with an asterisk.

Temperature Logger Site	# Days Exceeds 13°C	# Days Exceeds 15°C	# Days Exceeds 20°C	Deployment Dates
Alexander Creek	48	31	2	*6/16-8/08
Anchor River	37	11	0	6/10
Beaver Creek	28	1	0	5/12
Bishop Creek	71	44	0	5/13
Byers Creek	78	30	0	5/31
Cache Creek	7	1	0	6/08
Chenik Creek	22	1	0	*6/25-9/05
Chester Creek	11	0	0	5/19
Chijuk Creek	62	31	2	*6/28
Chuitna River	41	16	0	*7/10
Cottonwood Creek	76	51	0	5/07
Crooked Creek	17	2	0	6/16
Deception Creek	10	1	0	5/30
Deep Creek	25	3	0	6/13
East Fork Chulitna River	0	0	0	5/31
English Bay River	44	6	0	6/19
Fish Creek	75	54	0	6/01
Fox Creek	No data	No data	No data	6/17
Funny River	0	0	0	6/12
Hidden Creek	65	20	0	6/02
Jim Creek	No data	No data	No data	6/04
Kroto (Deshka) Creek	76	56	2	6/16
Little Willow Creek	6	1	0	6/02
McNeil River	4	0	0	*6/11-8/24
Meadow Creek	72	32	0	6/08
Montana Creek	16	2	0	5/30
Moose Creek, (Palmer)	0	0	0	6/03
Moose Creek (Talkeetna)	58	16	0	5/15
Moose River	41	5	0	6/16
NF Campbell Creek	3	0	0	5/19
Nikolai Creek	8	1	0	5/29
Ninilchik River	29	7	0	6/13
Quartz Creek	0	0	0	*6/27
Rabbit Creek	0	0	0	5/20
Resurrection Creek	0	0	0	*7/17
Seldovia River	0	0	0	6/19
Shantatalik Creek	0	0	0	5/29
Ship Creek	0	0	0	5/19
Silver Salmon Creek	0	0	0	*7/18
Slikok Creek	8	0	0	5/12
Soldotna Creek	35	6	0	5/12
Stariski Creek	30	5	0	6/11
Swanson River	67	41	0	6/11
Theodore Creek	26	1	0	*7/10
Trapper Creek	71	25	0	5/15
Troublesome Creek	15	3	0	5/31
Wasilla Creek	0	0	0	6/03
Willow Creek	4	0	0	*6/30



Map 3. Stream temperatures exceeded Alaska's Water Temperature Criteria of 13°C at 35 sites, 15°C at 30 sites, and 20°C at three sites.

RANGE OF VARIABILITY

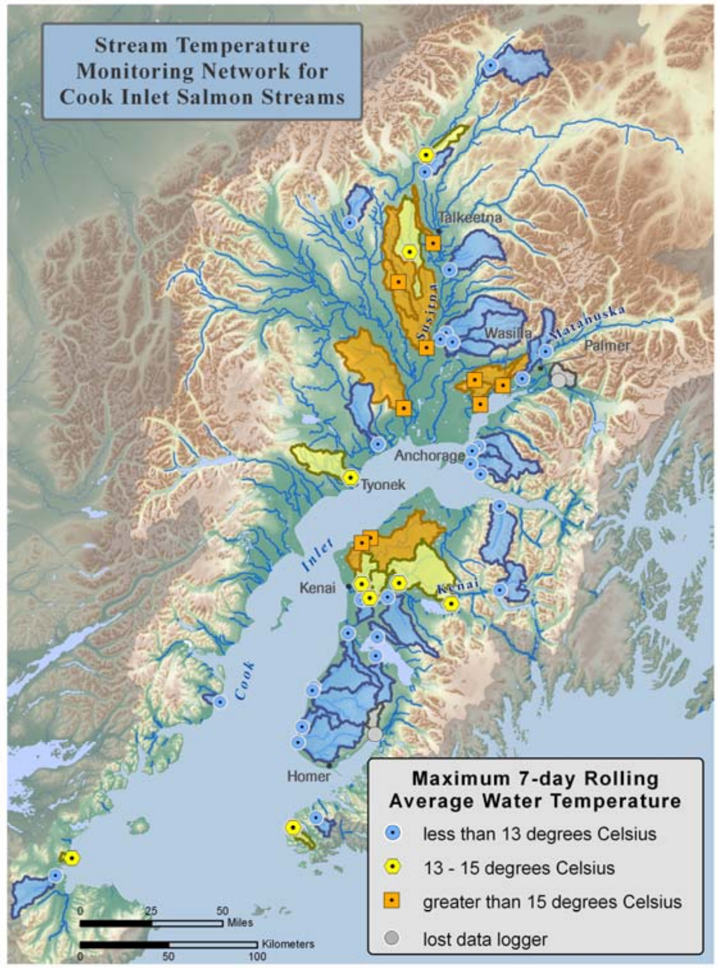
Across the Cook Inlet basin, the range in maximum stream temperatures was 9.2 - 22.0°C and average summer temperatures ranged from 6.7 - 13.9°C (Table 3). Maximum daily temperatures were recorded in June for 1 site, in July for 38 sites, and in August for 7 sites. Average monthly temperatures across all sites for July and August were similar: 6.5 - 14.8°C and 7.2 - 14.5°C; July and August cumulative degree days ranged from 214 - 457 and 225 - 450, respectively. The maximum daily fluctuation was greatest at Kroto (Deshka) Creek at 9.1°C and smallest at English Bay River at 1.7°C.

Table 3: Summary of water temperature metrics for 2008. All values are in degrees Celsius (C).

Stream Name	Highest temperature in dataset	Average summer temperature	June average temperature	July average temperature	August average temperature	September average temperature	June degree days	July degree days	August degree days	September degree days	Maximum 7-day rolling average temperature	Maximum 7-day rolling maximum temperature	Maximum Daily Difference
Alexander Creek	22.03			14.32				443.79			15.90	18.32	7.47
Anchor River	16.44	10.82		11.50	11.47	8.04		356.56	355.68	241.07	12.56	14.97	6.87
Beaver Creek	15.67	11.17	10.80	12.07	11.65	8.26	324.14	374.30	361.02	247.77	13.06	14.04	4.05
Bishop Creek	18.84	13.54	13.55	14.65	14.23	9.76	406.57	454.02	440.99	292.68	15.88	17.61	6.15
Byers Creek	19.63	12.76	10.61	13.58	13.11	10.37	318.21	420.98	406.30	311.09	14.19	17.28	7.01
Cache Creek	15.29	8.65		8.84	9.71	6.60		274.01	301.12	198.14	10.31	12.67	7.42
Chenik Creek	15.15			9.66				299.31			13.29	14.22	3.27
Chester Creek	14.61	10.80	10.41	11.36	11.07	8.90	312.26	352.23	343.05	267.04	11.90	13.62	5.19
Chijuk Creek	20.82			13.83	13.28	8.98		428.78	411.73	269.30	15.74	18.00	6.31
Chuitna River	17.82				12.87	8.13			398.82	243.83	13.89	15.80	5.24
Cottonwood Creek	18.75	13.54	13.39	14.57	14.15	9.92	401.73	451.79	438.52	297.59	15.72	17.85	5.13
Crooked Creek	15.56	9.85		10.57	10.27	7.17		327.71	318.52	215.08	11.71	13.65	5.78
Deception Creek	15.68	10.17	9.41	10.66	10.61	7.71	282.26	330.41	328.76	231.32	12.06	13.96	5.73
Deep Creek	16.69	10.23		10.90	10.98	7.59		337.96	340.27	227.63	12.48	14.39	6.66
East Fork Chulitna River	11.57	6.88	5.87	7.34	7.21	5.21	176.11	227.60	223.65	156.27	8.05	10.97	6.69
English Bay River	15.29	12.44		12.25	14.09	10.34		379.87	436.94	310.13	14.29	14.94	1.70
Fish Creek	19.03	13.85	14.06	14.76	14.50	10.07	421.93	457.41	449.46	302.06	16.04	17.87	5.61
Funny River	12.93	8.47		8.72	9.20	6.57		270.29	285.19	197.15	10.50	11.66	4.90
Hidden Creek	17.06	12.71	10.95	13.28	13.66	10.50	317.60	411.59	423.36	315.14	14.50	15.86	5.94
Kroto (Deshka) Creek	20.39	13.85			14.52	10.11			450.11	303.44	17.64	19.67	9.13
Little Willow Creek	15.58	9.96	8.82	10.42	10.49	7.55	255.70	323.03	325.34	226.58	11.52	13.41	5.03
McNeil River	13.91			6.92				214.43			10.68	13.08	8.01
Meadow Creek	18.77	12.56		13.56	12.98	8.91		420.49	402.48	267.30	15.21	17.96	6.94

Stream Name	Highest temperature in dataset	Average summer temperature	June average temperature	July average temperature	August average temperature	September average temperature	June degree days	July degree days	August degree days	September degree days	Maximum 7-day rolling average temperature	Maximum 7-day rolling maximum temperature	Maximum Daily Difference
Montana Creek	16.51	10.35	8.93	10.92	10.71	8.08	267.81	338.60	332.05	242.44	11.90	14.06	5.61
Moose Creek, (Palmer)	12.00	7.54	6.78	7.78	7.89	6.23	189.91	241.19	244.74	186.85	8.42	10.66	5.59
Moose Creek (Talkeetna)	19.77	12.04	12.31	13.08	12.30	9.08	369.20	405.59	381.18	254.27	14.60	16.95	6.19
Moose River	16.32	11.73		12.43	12.55	8.52		385.43	389.19	255.50	14.22	15.19	5.78
NF Campbell Creek	13.93	9.55	8.32	9.91	10.29	7.42	249.54	307.29	319.13	222.46	10.70	12.27	5.78
Nikolai Creek	15.20	9.01	7.73	9.54	9.54	6.75	232.04	295.67	295.77	202.49	10.92	12.73	7.04
Ninilchik River	16.70	10.55		11.28	11.08	7.75		349.80	343.57	232.55	12.56	14.69	6.96
Quartz Creek	10.41			7.18	8.06	6.42		222.67	249.83	192.50	8.25	9.47	5.49
Rabbit Creek	9.19	6.67	5.11	6.50	7.31	6.06	153.25	201.45	226.46	181.82	7.55	8.44	5.82
Resurrection Creek	9.76				7.29	5.82			225.93	174.55	7.51	8.77	4.33
Seldovia River	10.96	7.79		7.20	9.04	7.34		223.23	280.24	220.26	9.54	10.37	4.15
Shantatalik Creek	12.65	8.96	7.99	9.23	9.61	7.10	239.59	286.08	297.94	213.09	10.89	11.78	4.94
Ship Creek	11.29	8.17	6.78	8.32	8.83	6.72	203.46	257.96	273.79	201.72	9.16	10.50	5.21
Silver Salmon Creek	9.57				7.71				238.89		8.07	9.41	3.18
Slikok Creek	14.87	9.59	9.04	10.32	9.96	7.38	271.33	319.97	308.90	221.49	11.96	13.00	6.35
Soldotna Creek	17.07	11.07	10.29	11.94	11.72	8.24	308.68	370.12	363.36	247.23	14.22	15.31	7.80
Stariski Creek	15.66	10.60		11.26	11.22	7.89		348.92	347.83	236.66	12.22	14.17	6.06
Swanson River	18.28	13.16		14.09	14.10	9.43		436.74	436.95	282.86	15.88	16.88	5.82
Theodore Creek	15.13				11.82	8.35			366.42	250.51	12.35	13.68	4.77
Trapper Creek	19.25	13.09	13.34	14.22	13.37	9.47	400.27	440.93	414.39	284.23	15.54	17.21	5.06
Troublesome Creek	16.96	10.29	8.48	11.04	10.68	7.75	254.55	342.35	331.11	232.64	12.01	14.30	5.47
Wasilla Creek	12.46	9.21	9.26	9.86	9.42	7.06	259.21	305.51	292.12	211.81	10.44	11.68	2.97
Willow Creek	14.84			10.16	10.45	7.69		315.04	324.04	230.59	11.14	12.86	4.80

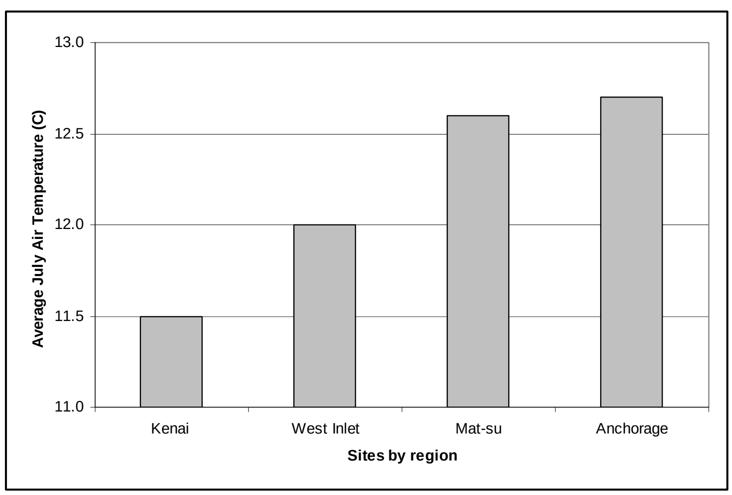
Nine sites had maximum 7-day (or weekly) rolling averages (MWAT) above 15°C (Map 4). MWAT is a metric being used to classify temperature sensitive streams in British Columbia, Canada[7], correlates well with various aspects of salmonid life history[,8], and has been a useful predictor for fish species distributions in the United States[9]. Both Washington and Oregon have incorporated a similar metric: MWMT - maximum of a 7-day running average of the daily maximum temperature, into their state water temperature criteria. These criteria describe both a magnitude as well as duration of exposure in contrast to the instantaneous criteria used in Alaska.



Map 4. Maximum 7-day rolling averages (MWAT) or the maximum recorded value of daily average water temperature when averaged over 7 consecutive days.

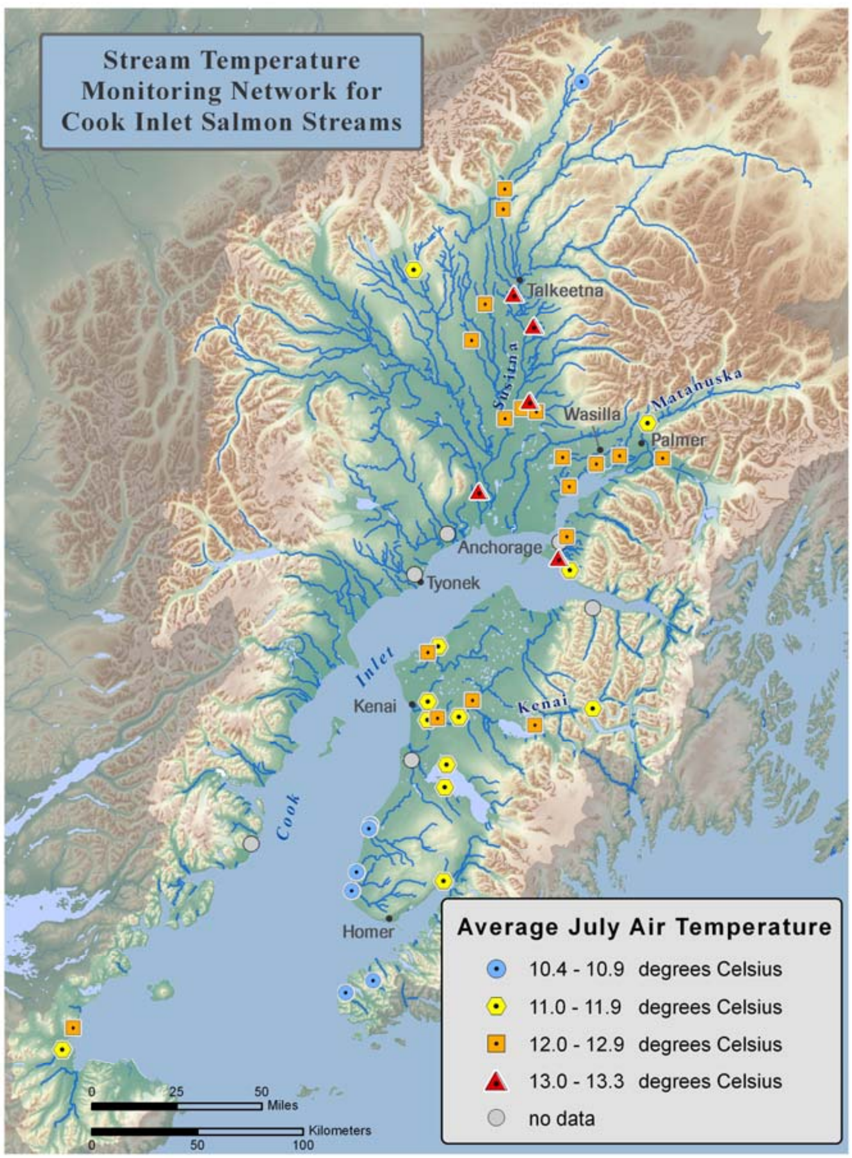
Relationship to Air Temperature

Average summer air temperatures measured at each site ranged from 9.1°C (East Fork Chulitna River) to 12.2°C (Campbell Creek) with over 80% of the sites between 10.0 - 11.9°C. Trapper Creek recorded the highest maximum temperature of 28.8°C (84°F!) on July 4th, 2008. Generally, air temperatures varied along a latitudinal gradient with warmer temperatures recorded in Anchorage and the Mat-Su basin (Map 5). High elevation sites like East Fork Chuilitna, Byers Creek and Cache Creek were cooler than other sites in their region. North Fork Campbell Creek had the highest average July temperature which may reflect the high density of urban development in Anchorage. Chester Creek is the most urban watershed but the air logger was stolen so we do not have air temperature data for that site.



R-square values of regression equations between average air temperature and water temperature at each site ranged from 0.27 - 0.94 (daily) and 0.33 – 0.99 (weekly). The daily air-water relationship was weakest at Chenik Creek, McNeil River, Seldovia River and Silver Salmon Creek and strongest at Theodore River and Resurrection Creek (Table 4). The dataset at Alexander Creek was not included in this analysis due to the short deployment period.

Regressions were run with air temperature data from the Talkeetna, Palmer, Kenai, Homer and Anchorage Airports also. The air-water relationship was generally stronger using air temperature data from each site rather than from an airport; R-square values were compared from each airport and the highest R-square value is described in Table 4. The average difference in daily R-square values from a site to a regional airport was smallest in Talkeetna and Palmer (0.02, 0.06) and greatest in Homer and Kenai (0.25, 0.32). Data for west inlet sites were compared with Port Alsworth but the relationship was extremely weak. Although air temperature data from each site provide a better relationship with water temperature, using regional airport data might be a consideration for keeping long-term monitoring costs down, especially in the Mat-Su basin. In addition, airport data provide an historical perspective of air temperatures which may be useful for back casting water temperatures once annual variability has been better defined through continued monitoring.



Map 5. Average July air temperatures at each site.

Table 4. R-square values of the regression equation between air temperature and water temperature. Air temperature values include average daily temperature at the water logger site, at a regional airport; and average weekly temperature at the water logger site.

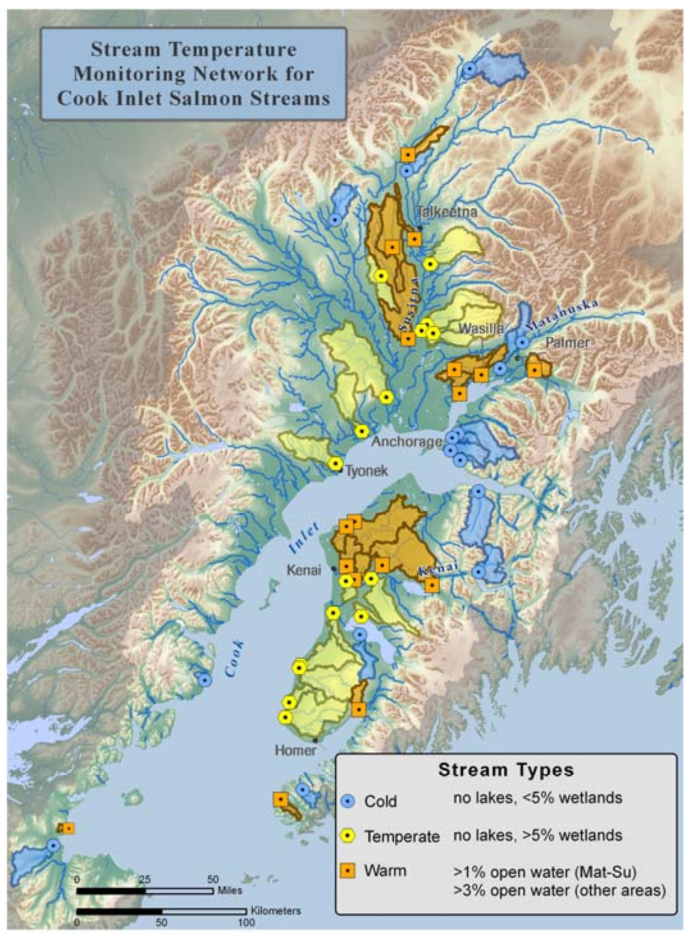
Stream Name	R^2 of daily temp at site	R^2 of daily temp from airport	Airport used for comparison	R^2 of weekly temp at site
Chijuk Creek	0.88	0.86	Talkeetna	0.95
Fish Creek	0.87	0.79	Talkeetna	0.95
Moose Creek (Talkeetna)	0.85	0.82	Talkeetna	0.97
Trapper Creek	0.84	0.82	Talkeetna	0.96
Deception Creek	0.83	0.77	Talkeetna	0.85
Meadow Creek	0.81	0.79	Talkeetna	0.91
Kroto (Deshka) Creek	0.79	0.79	Talkeetna	0.90
Montana Creek	0.75	0.75	Talkeetna	0.68
EF Chulitna River	0.71	0.70	Talkeetna	0.59
Troublesome Creek	0.66	0.69	Talkeetna	0.58
Cache Creek	0.61	0.61	Talkeetna	0.43
Byers Creek	0.55	0.59	Talkeetna	0.44
Wasilla Creek	0.90	0.81	Palmer	0.97
Moose Creek (Palmer)	0.90	0.78	Palmer	0.91
Cottonwood Creek	0.89	0.82	Palmer	0.95
Willow Creek	0.88	0.85	Palmer	0.94
Little Willow Creek	0.77	0.77	Palmer	0.85
Resurrection Creek	0.94	0.69	Kenai	0.96
Slikok Creek	0.89	0.49	Kenai	0.95
Swanson River	0.83	0.48	Kenai	0.91
Bishop Creek	0.82	0.47	Kenai	0.90
Beaver Creek	0.78	0.53	Kenai	0.87
Deep Creek	0.92	0.61	Homer	0.97
Shantatalik Creek	0.91	0.62	Homer	0.97
Soldotna Creek	0.90	0.54	Homer	0.97
Nikolai Creek	0.89	0.61	Homer	0.96
Ninilchik River	0.88	0.45	Homer	0.95
Anchor River	0.87	0.48	Homer	0.95
Quartz Creek	0.87	0.67	Homer	0.88
Funny River	0.86	0.63	Homer	0.95
Stariski Creek	0.86	0.48	Homer	0.95
Moose River	0.84	0.54	Homer	0.89
Hidden Creek	0.75	0.56	Homer	0.87
English Bay River	0.61	0.53	Homer	0.69
Silver Salmon Creek	0.48	0.39	Homer	0.52
McNeil River	0.45	0.25	Homer	0.64
Seldovia River	0.41	0.33	Homer	0.33
Chenik Creek	0.27	0.04	Homer	0.41
Theodore River	0.93	0.90	Anchorage	0.99
NF Campbell Creek	0.92	0.80	Anchorage	0.96
Chuitna River	0.92	0.86	Anchorage	0.97
Ship Creek	0.86	0.76	Anchorage	0.85
Rabbit Creek	0.76	0.54	Anchorage	0.71

WATERSHED CHARACTERISTICS

Watershed size and clear vs. brown water streams were expected to be important drivers in stream temperature patterns and thus were used to develop the original sampling design. When sites were classified (large, clear; large brown; small clear; small brown) there was no significant difference between means for any of the temperature metrics. Watershed size was not a good predictor of temperature patterns. Brown-water streams were generally warmer than clear-water streams, but the brown- vs. clear-water distinction was not always obvious.

We could better quantify the wetland component that contributes to a brown-water stream and the influence of lakes, identified in previous research in the Mat-Su basin[10], through the land-cover analysis. By classifying streams first by those with open water, and then by percent of wetlands, streams fell into 3 significantly different categories: 1) streams with >1% (Mat-Su)/>3% (all others) open water in the watershed, 2) streams with no lakes and with greater than 5% wetlands, and 3) streams with no lakes and less than 5% wetlands (Map 6, Table 5). Between these stream types, there was a significant difference between means for many of the temperature metrics in Table 3. For example, the difference in means between groups 1, 2, and 3 for the number of days (26, 7, 0.3 respectively) above 15°C was highly significant ($F_{2, 43}$=15.85, p = 0.000007). Due to the variability in deployment dates, many metrics could not be compared across all stream types. For instance summer maximum was only comparable for 36 sites and June average temperature for 23 sites.

The absolute values of the thermal characteristics of these three groups will vary year to year. For instance, the number of days that group 1 streams exceed 15°C will not remain constant. Defining the groups with specific temperature ranges may not be useful until we have additional data to help understand annual variation. For now, we will refer to the stream types as warm-water (group 1), temperate (group 2), and cold-water (group 3). When we examine specific metrics there are certain streams that consistently fall out of their stream type characterization: Alexander Creek, Chijuk Creek, Chuitna River, and Troublesome Creek. All are warmer than predicted based on their land-cover characteristics.



Map 6. Stream-type classifications were developed using land- cover data.

Table 5. Classification of stream types: 1) warm water (orange), 2) temperate (yellow), and 3) cold water (blue), are based on land-cover percentages.

Stream Name	% Open Water	% Wetland	% Forest	% Developed	% Scrub/Shrub
Fish Creek	**12.55**	28.43	41.72	4.60	11.70
Hidden Creek	**12.20**	4.08	65.99	0.91	16.81
Bishop Creek	**10.94**	11.80	70.03	1.73	5.28
Swanson River	**9.48**	17.42	69.94	0.48	2.66
Soldotna Creek	**7.89**	15.13	67.27	4.35	5.30
Chenik Creek	**7.43**	0.02	5.68	0.00	82.17
Meadow Creek	**6.46**	18.09	54.61	14.85	5.36
Cottonwood Creek	**6.05**	7.42	62.51	20.69	2.79
Moose River	**4.74**	26.91	64.36	0.61	2.84
Beaver Creek	**3.96**	35.34	53.51	1.50	4.52
Fox Creek	**3.38**	18.59	34.35	0.25	43.27
Jim Creek	**3.21**	19.31	28.55	0.49	34.16
English Bay River	**3.05**	0.42	47.89	0.00	47.60
Trapper Creek	**2.20**	27.45	65.49	0.99	1.33
Byers Creek	**1.91**	3.19	37.77	0.21	53.06
Kroto Creek	**1.69**	42.23	53.15	0.05	2.88
Moose Creek (Talkeetna)	**1.16**	41.53	53.39	0.23	3.52
Slikok Creek	2.15	**28.21**	60.56	4.33	4.37
Chijuk Creek	0.59	**28.18**	69.71	0.03	1.50
Stariski Creek	0.02	**26.64**	38.61	2.06	31.92
Alexander Creek	0.70	**24.20**	45.13	0.00	29.32
Ninilchik River	0.11	**21.46**	48.98	2.21	27.10
Crooked Creek	1.29	**20.24**	46.85	1.72	29.90
Theodore River	0.14	**13.33**	47.41	0.09	39.00
Little Willow Creek	0.25	**12.14**	44.02	0.35	37.79
Anchor River	0.04	**11.55**	39.69	1.87	46.48
Funny River	0.51	**11.24**	71.83	0.30	15.56
Deception Creek	0.29	**11.06**	75.51	0.25	12.84
Deep Creek	0.05	**8.66**	34.53	1.03	55.64
Chuitna River	0.53	**7.79**	37.07	0.22	54.14
Montana Creek	0.61	**7.69**	34.24	0.33	52.56
Willow Creek	0.86	**5.63**	39.33	1.05	45.77
Shantatalik Creek	1.75	**5.47**	83.80	0.00	8.97
Cache Creek	0.10	**3.82**	16.58	0.05	76.26
Chester Creek	0.62	**3.73**	31.88	44.68	18.48
Nikolai Creek	0.61	**3.38**	65.78	0.00	30.23
Wasilla Creek	0.50	**2.66**	58.53	12.87	22.16
Silver Salmon Creek	1.57	**2.54**	23.31	0.00	62.33
NF Campbell Creek	0.54	**2.54**	20.91	24.86	39.95
Troublesome Creek	0.83	**2.35**	26.50	0.02	69.41
East Fork Chulitna River	0.33	**2.29**	9.49	0.06	53.94
Ship Creek	0.14	**1.72**	16.55	9.48	58.20
Quartz/Crescent Creek	2.38	**0.73**	18.95	0.69	58.54
Rabbit Creek	0.02	**0.42**	21.29	7.55	57.55
Moose Creek (Palmer)	0.10	**0.09**	18.50	0.58	47.49
Resurrection Creek	0.01	**0.09**	17.57	0.06	73.85
Seldovia River	0.80	**0.01**	47.85	0.00	45.64
McNeil River	1.69	**0.00**	0.28	0.00	73.30

DISCUSSION

Based on 2008 data, the highest stream temperatures in Cook Inlet were recorded in streams that drain lakes or lowland areas west of the Susitna River. Regional temperature maps were a valuable tool to elucidate temperature patterns inherent in multiple datasets that can be difficult to see when the data are not spatially organized. In creating our map layers we sought resources like the Hydrologic Unit Code system and USGS land-cover dataset because they are state-wide resources that will be useful as the Stream Temperature Monitoring Network expands to other basins in Alaska.

Air temperatures varied across the basin spatially relative to latitude and elevation. To better understand how air temperatures are likely to change temporally, we will use regional climate projections from Scenarios Network for Alaska Planning (SNAP). In 2009, SNAP will generate future scenarios of air temperature and precipitation conditions. SNAP will produce maps and statistics derived from climate projection data which will be a useful tool to predict future thermal conditions in Cook Inlet salmon streams.

Connections between stream temperature and water volume are becoming more important to understand because climate change may alter Cook Inlet watersheds by affecting flooding frequencies, precipitation levels, surface and ground water volumes, soil nutrient dynamics, and other hydrologic characteristics. In addition, climate change may impact geographic distribution of wetlands. If a warmer climate means less snow and less water storage on the landscape, low summer water levels, and thus warmer water temperatures, may become more common. Incorporating hydrologic data into the temperature monitoring program is an important next step to more fully understand climate-related risks.

The relationship between air and water temperature typically differs from stream to stream due to varying degrees of shading, differences in the sources of water (groundwater, surface runoff) and elevation[11]. By changing the landscape, humans can influence water temperatures by removal of stream-side vegetation, increased water withdrawals, wetland loss, and more impervious surfaces. In Cook Inlet, watersheds in the Anchorage and Wasilla area have reached a level of development (>5%) that has been linked to stream degradation in Alaska.[12] Presently, development does not appear to be driving the thermal response as these streams responded as expected based on their stream type. However, in Cottonwood and Meadow Creeks (lake systems), development pressures may exacerbate an already warm stream profile.

Non-glacial salmon streams in the Cook Inlet watershed consistently exceed Alaska's numeric water quality standards even during a relatively cool, wet summer as in 2008. The summer of 2009 will provide a valuable contrast to capture a realistic range of variability in current weather conditions. Due to the temperature exceedances, these streams should qualify as Impaired Waterbodies with recovery plans to ensure future attainment of state numeric standards; however, as impairment cannot be tied to a point source or habitat degradation by direct human activity, a recovery plan is not likely to be effective.

Alaska's instantaneous temperature criteria and threshold values lead to a lot of questions that need to be address in order to serve fisheries managers, land-use managers and fishermen, as well as salmon, best. We need to know if the 13, 15 and 20 degree Celsius thresholds are physiologically and behaviorally relevant to Alaska's salmon populations. We need to determine if our fish are more or less tolerant to thermal variation than the laboratory fish used to generate these values. We need to quantify the duration of these exceedances and their relevance to the timing of fish runs, spawning activity and rearing periods. Creating temperature criteria that incorporate spatiotemporal variability as described in Poole[13] or that incorporate duration of exposure may be a worthwhile direction for addressing thermal change.

Salmon have a complex life cycle with their migration from coastal watersheds to estuarine and marine habitats and then back to natal streams. Our ability to discern population impacts during one phase of the salmon life cycle is extremely limited. In many Alaska streams we use weirs and sonar to monitor adult migration back into the watershed, but rarely are they used to count how many juveniles actually leave a stream. As a result, when unexpectedly low returns occur, unfavorable marine conditions are often blamed. Until we can better account for outmigrating fish we will likely underestimate thermal impacts to salmon populations occurring in the freshwater environment. This project may help focus attention on the need for more watershed-based research and identify which streams are good candidates for these new research efforts.

During this first year of the Stream Temperature Monitoring Network, a significant effort was made to develop a STORET-compatible stream temperature database that was flexible enough to generate temperature metrics as well export data to STORET (EPA's STOrage and RETrieval system for water quality data). Our goal was to develop something that could be expanded into a state-wide temperature database. In the end we reverted to using Visual Basic Language in Microsoft Excel to generate temperature metrics and are still working with EPA tech support to move the temperature data into STORET, which has a long history of being difficult to use. To achieve our goal of developing long-term comparable temperature datasets, this data-management hurdle will have to be resolved.

In the second year of the Stream Temperature Monitoring Network, we plan to refine the stream-type classification by incorporating additional parameters like stream slope, aspect, width and velocity. Temperature loggers were re-deployed at all sites during May and June 2009. With continued data-collection to capture annual variation, this project will play an important role in helping state resource managers prioritize streams with the greatest potential to buffer stream temperatures for research, restoration and protection efforts to ensure Alaska wild salmon endure as thermal change continues.

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