


STREAM TEMPERATURE MONITORING NETWORK FOR COOK INLET SALMON STREAMS

FY 2010 REPORT
WORKING DRAFT

Prepared by

COOK INLETKEEPER

With assistance from

Aquatic Restoration and Research Institute
Kenai Watershed Forum
The Nature Conservancy of Alaska

ACKNOWLEDGEMENTS

We appreciate Chris Love, Nick Ettema, and Megan Cookingham with the Aquatic Restoration and Research Institute; Catherine Inman, Brianne Athearn, and Becky McNeil with the Wasilla Soil and Water Conservation District; Billy FitzGerald with Denali Trekking Company; Scott Wolfe with The Wildlifers; Larry and Judy Heilman in Beluga; Jessica Standifer in Tyonek; Tom Evans in Nanwalek; Tracie Merrill, Michael and Norman Opheim in Seldovia; Ken Gates and Jim Boersma with USFWS; Kevyn Jalone with Lake Clark National Park; Ted Otis, Tom Griffin, and Mike Parish with ADF&G; Eric Johansen with the US Forest Service; Laura Eldred with Alaska Department of Environmental Conservation; Kate Malloy, Holly Kent, and Greg Collins at Anchorage Waterways Council; Jennifer McCard and Michelle Martin at Kenai Watershed Forum; and Rachel Lord, Tala Woodward, and Liza Mitchell with Cook Inletkeeper for their assistance in collecting data; Jennifer McCard, Elizabeth Jones, Jim Czarnezki, and Samantha Fox with the Kenai Watershed Forum for database and analysis support; and Tom Kurkowski and Nancy Fresco at SNAP for climate projection mapping and data.

Stream Temperature Monitoring Network for Cook Inlet Salmon Streams is supported by a variety of funding sources for different sites across the basin. The overall project was made possible in part by an EPA Section 319 Clean Water Act grant from Alaska Department of Environmental Conservation, the U.S. Fish and Wildlife Service through the Alaska Coastal Program and Mat-Su Basin Salmon Habitat Partnership, and with funding from the Alaska Conservation Foundation, Bullitt Foundation, Wolfensohn Foundation, New-Land Foundation, True North Foundation, and Skaggs Foundation. Generous support was also provided by Cook Inletkeeper's members and business supporters.

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July 2010

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SUMMARY

The Cook Inlet basin in South-central Alaska encompasses 47,000 square miles and contains high quality freshwater and marine salmon habitat, some of which is at risk due to 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 in other regions, there is little consistent, long-term temperature data for salmon streams in Alaska. Through this multi-year project, we are implementing a Stream Temperature Monitoring Network to identify thermal impacts in coastal salmon habitat. Beginning in the summer of 2008, continuous water and air temperatures were taken in 48 non-glacial salmon streams. In 2008, stream temperatures exceeded Alaska's Water Temperature Criteria of 13ºC at 35 sites, 15ºC at 30 sites, and 20ºC at three sites. In 2009 stream temperatures exceeded 13ºC at 47 sites, 15ºC at 39 sites, and 20ºC at 17 sites. Maximum stream temperatures ranged broadly among sites: 9.2 – 22.0ºC (2008) and 13.1 – 24.5ºC (2009). The highest temperatures were recorded in streams that drain lakes or lowland areas west of the Susitna River. 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. To better understand how air temperatures are likely to change temporally, we used regional climate projections from Scenarios Network for Alaska Planning (SNAP). These projections tell us that air temperatures and, to a lesser degree, precipitation will increase across the landscape over the next 100 years. July air temperatures may increase as much as 5ºC in the Susitna River valley and increasing winter air temperatures may reduce snow accumulation, especially on the lower Kenai Peninsula and west side of Cook Inlet. 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. High water temperatures have been shown to induce physiological stress in salmon, which makes them more vulnerable to secondary stressors such as pollution, predation and disease[1]. However, water temperature can vary greatly across watersheds or even among tributaries within the same watershed, due to climatic drivers as well as structural factors like stream morphology, land cover, and groundwater influence.[2]

Cook Inlet encompasses 47,000 square miles and contains high quality freshwater and marine salmon habitat, some of which is at risk due to 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.[3]

All five species of wild Pacific salmon return to Alaska's Cook Inlet basin to spawn.

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[4]. Recent studies in upper Cook Inlet salmon streams show maximum temperatures in Montana Creek[5], a clear water tributary to the Susitna River, and Cottonwood Creek[6], a lake-dominated system, above state water quality standards. Yet despite the links between warm water temperatures and reduced salmonid survivorship in other regions[7], 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 identify thermal impacts in coastal salmon habitat. Stream temperature data will be used to identify watershed characteristics that buffer stream temperatures, thus making them less susceptible to climate and land-use changes. The main objectives are to: 1) collect consistent, comparable temperature data for non-glacial salmon streams; 2) generate GIS maps to illustrate temperature patterns, temperature exceedances, and potential thermal refugia; and in 2010, 3) generate maps of future scenarios of air temperature and precipitation conditions derived from climate projection data.

METHODS

The Stream Temperature Monitoring Network is the result of protocol development and monitoring design work which began in 2007. A technical advisory committee made up of state, federal, and private resource managers and scientists worked together to develop a standardized protocol for monitoring water temperature. This protocol[8] contains 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 coordinated with Data-collecting Partners, 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, with Aquatic Restoration and Research Institute during data analysis, and with The Nature Conservancy of Alaska to generate GIS maps to illustrate temperature patterns across the Cook Inlet basin.

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 (within 0.3°C) 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 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 rock was placed on the cable in the stream approximately 6 inches above the logger, securing the logger in place.

Water data logger is inside PVC housing and secured by cable to rebar.

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 in an effort to prevent water temperature from influencing 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. After removing the loggers from the sampling locations, they were checked a second time for sufficient battery power, and temperature accuracy at approximately 0 and 20°C using a NIST thermometer.

Table 1. Cook Inlet 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
Little 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 River	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. Cook Inlet Stream Temperature Monitoring Network data logger locations.

Temperature statistics calculated for each site included 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 7-day rolling maximum temperature; and maximum daily fluctuation. Regression equations were used to determine the relationship between daily and weekly average and maximum 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. Regression coefficients (slope of the linear relationship) quantify the response of water temperature to changes in air temperature.

Watershed metrics including watershed size, aspect, and percent land-cover types (% wetlands, % forested, % open water, % developed, and % 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 (5th level) HUC watersheds are 40,000 to 250,000 acres in size (62.5 to 390 square miles); 12-digit (6th level) HUC sub-watersheds are 10,000 to 40,000 acres in size (15.5 to 62.5 square miles). 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.

In 2010, the University of Alaska Fairbanks, Scenarios Network for Alaska Planning (SNAP) generated future scenarios of air temperature and precipitation conditions in the Cook Inlet basin. SNAP climate projections are based on the five best-performing Global Circulation Models (GCM's) used by the Intergovernmental Panel on Climate Change (IPCC), previously identified as a best fit for Alaska[9]. These models are scaled down to 2 km resolution using the PRISM model. The IPCC created a range of scenarios to explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting greenhouse gas emissions. The A2 scenario describes a very heterogeneous world with high population growth, slow economic development and slow technological change. The A1B scenario assumes a world of very rapid economic growth, a global population that peaks in mid-century, rapid introduction of new and more efficient technologies, and a balance between fossil fuels and other energy sources. Current trends indicate that the world may be headed somewhere between these two scenarios in terms of greenhouse gas emissions and global climate change. SNAP provided all data described below for both the A2 and A1B scenarios based on a composite (mean) of all five model outputs from 2000 to 2100. Cook Inlet maps and point data for each temperature monitoring site were generated of monthly averages for air temperature (degrees C) by decade; monthly averages for precipitation (cm) by decade; seasonal averages for air temperature and for precipitation by decade, where seasons are defined as follows: Spring (March - May) Summer (June-Aug) Autumn (Sept- Nov) Winter (Dec - Feb); and mean thaw date by decade.

2008 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. The water logger on Jim Creek is either buried deep in the soft sediment or was snagged by folks fishing. 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. 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.

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 2). 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.

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[10]. 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

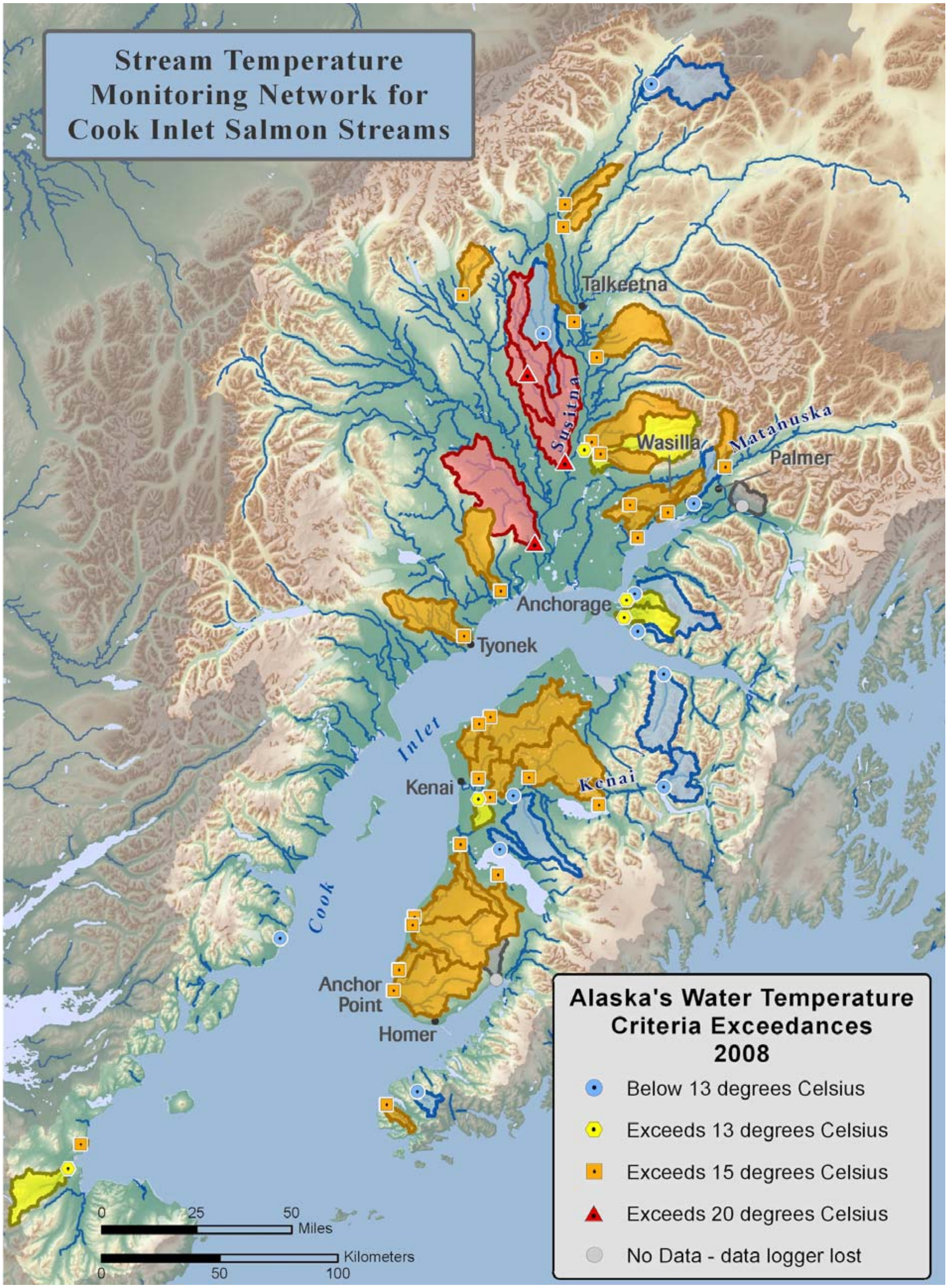
and may not exceed 20°C at any time.

Water temperatures above 13°C were recorded at 35 sites and above 15°C at 30 sites (Map 2, Table 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: Summary of water temperature statistics for May/June through September, 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 River	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

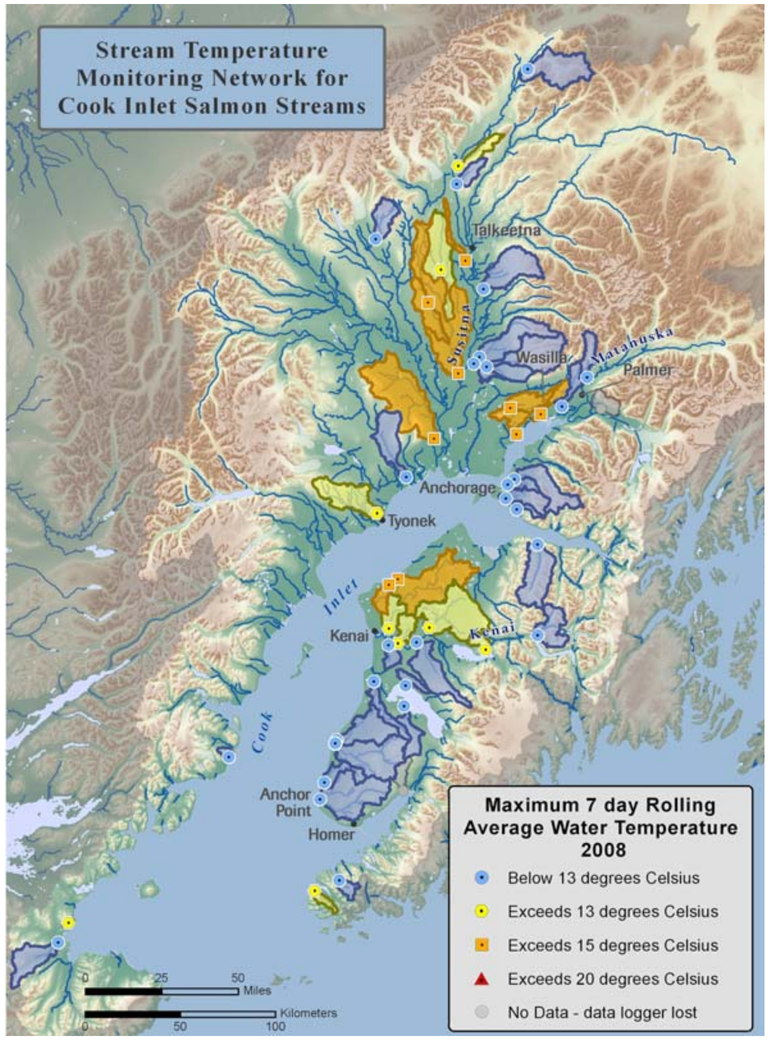


Map 2. Stream temperatures exceeded Alaska's Water Temperature Criteria of 13°C at 35 sites, 15°C at 30 sites, and 20°C at three sites.

Table 3. 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

Nine sites had maximum 7-day (or weekly) rolling averages (MWAT) above 15ºC (Map 3). MWAT is a metric being used to classify temperature sensitive streams in British Columbia, Canada[11], correlates well with various aspects of salmonid life history[12], and has been a useful predictor for fish species distributions in the United States[13]. 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 3. Maximum 7-day rolling averages (MWAT) or the maximum recorded value of daily average water temperature when averaged over 7 consecutive days.

<u>RELATIONSHIP TO AIR TEMPERATURE</u>

Average summer air temperatures measured at each site ranged from 9.1ºC (East Fork Chulitna River) to 12.2ºC (North Fork Campbell Creek) with over 80% of the sites between 10.0 – 11.9ºC. Generally, air temperatures varied along a latitudinal gradient with warmer temperatures recorded in Anchorage and the Mat-Su basin (Chart 1, Map 4). High elevation sites like East Fork Chulitna, 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.

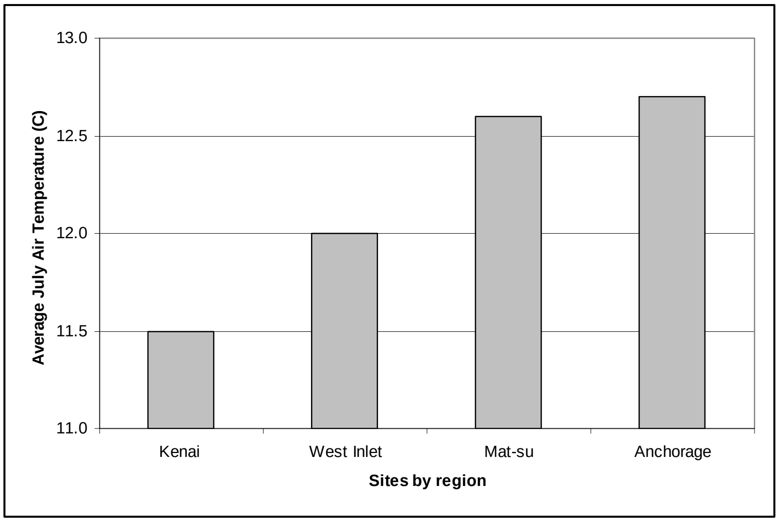
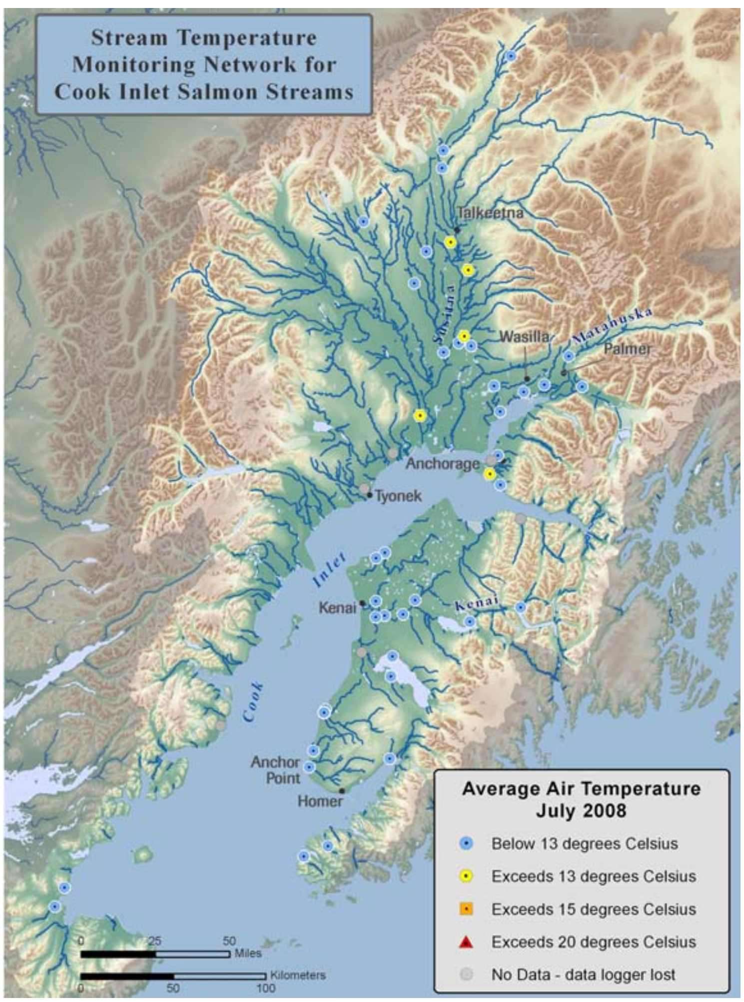


Chart 1. Average July air temperatures by region.

Regressions were run with average 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 4. Average July air temperatures at each site.

Table 4. R-square values of the regression equation between average 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

2009 RESULTS

We deployed air and water loggers at 48 sites and ended up with 47 air temperature datasets (missing Meadow Creek) and 47 water temperature datasets (missing Silver Salmon Creek), which is a 97.9% retrieval rate. However, we discovered that the water temperature logger on the Chuitna River, which was deployed on June 11th, was missing during a QA site visit in late July. In early August, a consulting firm doing stream research for PacRim Coal, returned the data logger to our local partner and explained that field personnel inadvertently removed the logger on June 30th. We decided not to redeploy the logger since we had lost 6 weeks of data.

RANGE OF VARIABILITY

The summer of 2009 was notably warmer than the summer of 2008. Maximum stream temperatures varied broadly among sites: 13.1 – 24.5°C, with the highest temperatures recorded in upper Cook Inlet streams. Average summer temperatures ranged from 8.4-15.0°C (Table 5). Average temperatures across all sites were 10.3 – 18.9°C in July and 8.1 – 16.1°C in August; July and August cumulative degree days ranged from 318 - 586 and 252 - 467, respectively. The maximum daily fluctuation was greatest at Fox Creek at 11.6°C and smallest at English Bay River at 3.0°C.

TEMPERATURE EXCEEDANCES

In the summer of 2009, water temperatures above 13°C were recorded at all 47 sites and above 15°C at 39 sites (Map 5, Table 6). Temperatures exceeded 20°C at 17 sites: six sites on the Kenai Peninsula and 11 sites in the Mat-Su basin. Loggers at 5 sites were deployed after June 21st (Moose Creek, Talkeetna) or pulled out early (Chenik Creek, Chuitna River, McNeil River and Jim Creek) so the number of days of exceedances may be under reported. Fourteen sites had a maximum 7-day rolling maximum above 20°C (Map 6). Two sites (Kroto (Deshka) Creek and Jim Creek) had a maximum 7-day (or weekly) rolling average (MWAT) above 20°C (Map 7).

RELATIONSHIP TO AIR TEMPERATURE

Average summer air temperatures measured at each site ranged from 10.0°C (Stariski Creek) to 13.5°C (Deception Creek) with 47% of the sites between 10.0 - 11.9°C. Generally, air temperatures varied along a latitudinal gradient with warmer temperatures recorded in Anchorage and the Mat-Su basin (Chart 2, Map 8).

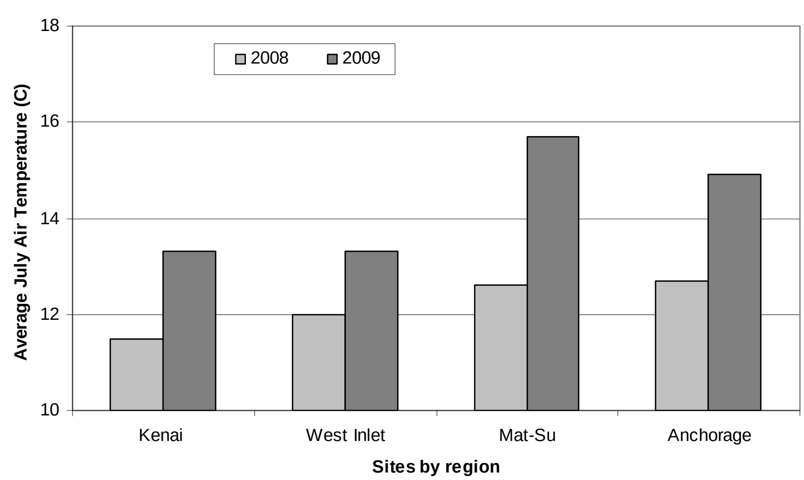
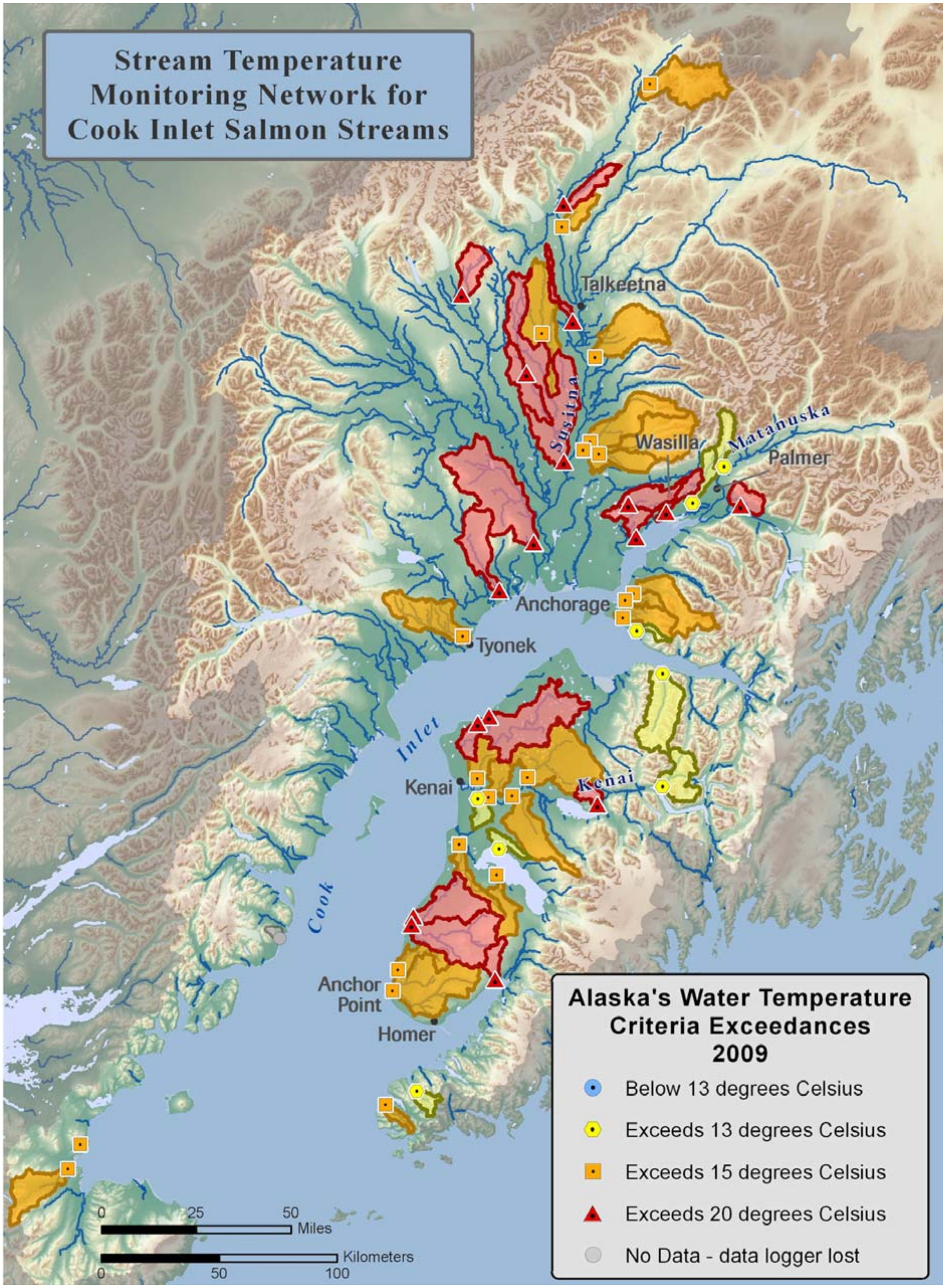


Chart 2. Average July air temperatures by region.

Table 5: Summary of water temperature statistics for May/June through September, 2009. 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	22.61	15.03		18.12	14.60	9.97		561.65	452.54	289.19	17.94	25.21	10.15
Anchor River	19.98	11.45	10.50	13.44	11.68	8.09	314.92	416.54	362.10	242.61	15.86	18.90	8.08
Beaver Creek	16.48	11.49	11.41	13.20	11.52	8.16	342.22	409.24	357.22	236.64	14.60	16.10	4.34
Bishop Creek	22.21	14.78	14.98	17.24	14.71	10.13	449.28	534.51	455.91	303.88	19.49	21.42	6.07
Byers Creek	22.80	14.25	11.90	17.14	13.87	10.23	357.03	531.35	430.04	306.86	19.11	22.23	7.84
Cache Creek	20.65	10.80	8.26	13.90	10.36	6.71	247.92	430.98	321.21	201.30	16.27	19.94	9.03
Chenik Creek	17.70		6.58	11.36			190.96	352.28			14.34	15.55	5.73
Chester Creek	16.44	11.64	11.23	13.06	11.68	9.03	336.93	404.80	361.97	271.04	13.91	15.75	4.98
Chijuk Creek	24.26	14.15	13.99	17.80	13.13		419.78	551.71	406.90		19.94	23.66	8.11
Chuitna River	17.87										14.41	17.75	7.28
Cottonwood Creek	22.01	14.32	14.62	16.63	14.07	10.08	438.49	515.67	436.06	302.35	19.10	20.98	6.58
Crooked Creek	18.03	10.54	10.42	12.46	10.52	7.11	312.70	386.37	326.03	213.23	14.80	17.30	6.54
Deception Creek	18.79	11.99	10.95	14.09	11.44		328.58	436.75	354.49		16.44	18.56	5.64
Deep Creek	20.63	11.68	10.60	13.87	11.89	8.05	318.05	429.87	368.72	241.47	16.48	19.44	7.75
East Fork Chulitna River	15.46	8.39	6.82	10.48	8.14	5.47	204.56	324.80	252.45	164.20	11.75	14.72	7.05
English Bay River	19.56	13.76		15.60	13.46	11.58		483.49	417.32	347.28	17.61	18.80	2.95
Fish Creek	22.73	14.66	15.31	17.45	14.33	9.71	459.30	541.04	444.22	291.17	19.90	21.76	6.41
Fox Creek	22.03	12.60	11.78	14.78	12.51	8.88	353.45	458.22	387.87	266.53	16.71	21.28	11.63
Funny River	16.05	9.87	9.64	11.73	9.90	6.75	289.29	363.77	306.96	202.61	13.51	15.30	4.99
Hidden Creek	22.84	14.46	12.45	16.51	14.43	11.66	373.44	511.67	447.44	326.50	19.12	21.98	7.49
Jim Creek	23.87		15.97	18.90	16.13		479.11	585.80	467.85		21.83	23.39	4.72
Kroto (Deshka) Creek	24.53	14.83	15.61	18.69	13.71	9.52	468.42	579.51	425.04	285.47	21.87	23.42	5.29
Little Willow Creek	19.51	11.91	10.66	14.65	11.65	7.89	319.83	454.09	361.19	236.74	17.19	19.14	4.74

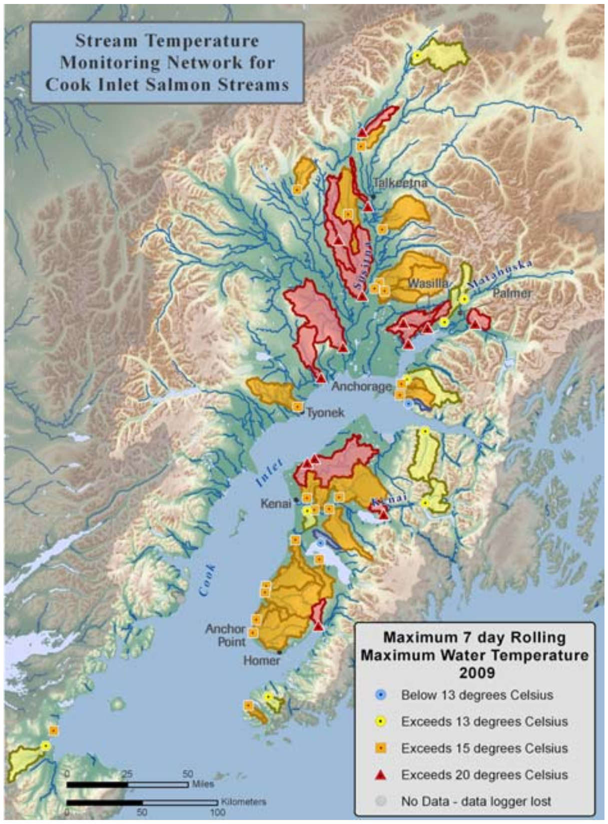
Stream Name	Highest temperature in dataset	Average summer temperature	June average temperature	July average temperature	August average temperature	September average temperature	June degree days	July degree days	August degree days	September degree days	Maximum 7-day rolling average temperature	Maximum 7-day rolling maximum temperature	Maximum Daily Difference
McNeil River	15.34			10.32				320.03			11.45	14.65	7.18
Meadow Creek	22.68	13.70	13.95	16.48	13.37	9.02	418.40	510.90	414.33	270.61	19.01	21.65	7.37
Montana Creek	18.84	11.90	10.16	14.22	11.76	8.42	304.81	440.70	364.67	252.56	15.87	18.56	5.92
Moose Creek, (Palmer)	14.77	8.85		10.26	8.75	6.72		318.10	271.38	201.73	11.64	14.07	6.40
Moose Creek (Talkeetna)	18.13				12.58				390.10		15.47	16.72	8.63
Moose River	19.27	13.08	13.01	15.45	13.17	8.76	390.32	479.03	408.20	262.78	17.78	18.76	4.98
NF Campbell Creek	17.58	11.45	10.17	13.36	11.54	8.09	305.21	414.23	357.60	242.74	15.27	17.16	4.91
Nikolai Creek	18.15	9.74		11.67	9.63	6.63		361.82	298.39	198.93	14.07	17.20	8.47
Ninilchik River	20.22	11.28	10.51	13.45	11.42	7.72	315.33	416.94	353.93	231.53	16.12	18.87	7.22
Quartz Creek	14.37	9.20	7.38	10.36	9.42	7.42	221.36	321.16	292.07	207.87	11.79	14.08	6.36
Rabbit Creek	13.14	8.96	6.90	10.25	9.08	6.80	206.95	317.80	281.56	204.09	11.34	12.95	5.17
Resurrection Creek	13.86	9.21	7.16	10.32	9.45	7.25	214.93	320.05	292.93	217.41	11.39	13.49	5.48
Seldovia River	14.12	9.49	7.52	10.43	9.58	8.05	218.14	323.27	296.95	241.41	11.90	13.36	4.61
Shantatalik Creek	13.59	9.23		10.32	9.32	7.00		319.92	289.06	210.08	11.59	12.95	4.94
Ship Creek	15.13	9.84	8.51	11.30	10.00	7.29	255.35	350.40	309.99	218.82	12.63	14.46	5.60
Silver Salmon Creek													
Slikok Creek	14.52	8.96	9.48	10.25	8.84	6.41	284.37	317.72	273.89	185.86	11.81	14.10	6.65
Soldotna Creek	19.01	11.74	11.87	13.60	11.67	8.33	356.18	421.53	361.78	241.71	15.40	18.34	7.11
Stariski Creek	19.53	11.32	10.52	13.34	11.48	7.93	315.48	413.57	355.85	237.89	15.92	18.39	7.09
Swanson River	21.67	14.11	14.35	16.70	14.12	9.33	430.49	517.58	437.63	279.84	18.98	20.79	6.33
Theodore Creek	20.75	13.09		15.55	12.93	8.66		482.01	400.88	259.68	17.83	20.20	5.45
Trapper Creek	22.23	14.13	13.79	17.30	13.68	9.38	413.83	536.43	424.00	281.45	19.64	21.84	5.01
Troublesome Creek	19.94	11.86	10.11	14.78	11.40	7.75	303.40	458.19	353.43	232.61	16.65	19.56	6.37
Wasilla Creek	14.98	9.74	9.66	11.43	9.55	6.95	289.81	354.20	296.08	208.54	12.97	14.18	3.26
Willow Creek	18.79	11.86		14.27	11.80	8.20		442.48	365.72	245.86	16.47	18.29	5.17

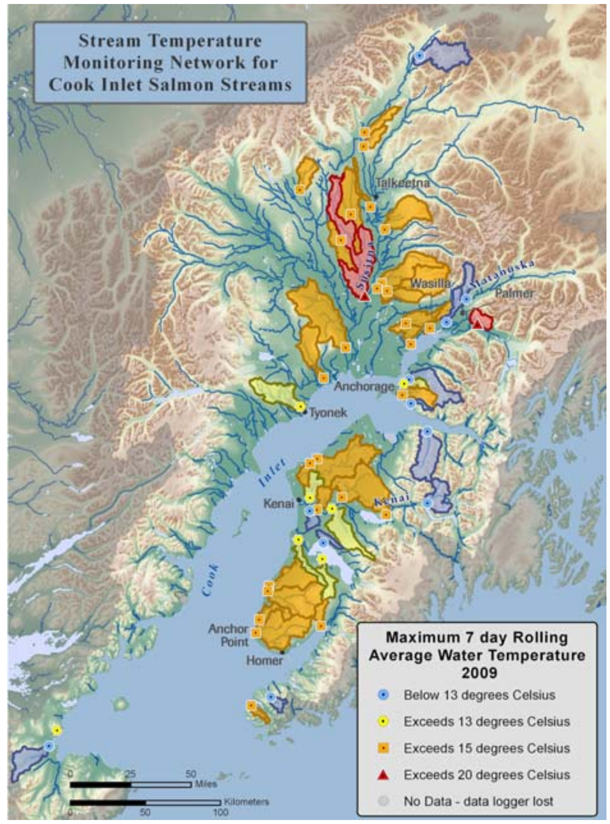


Map 5. Summer temperatures exceeded Alaska's Water Temperature Criteria of 13°C at 47 sites, 15°C at 39 sites, and 20°C at seventeen sites.

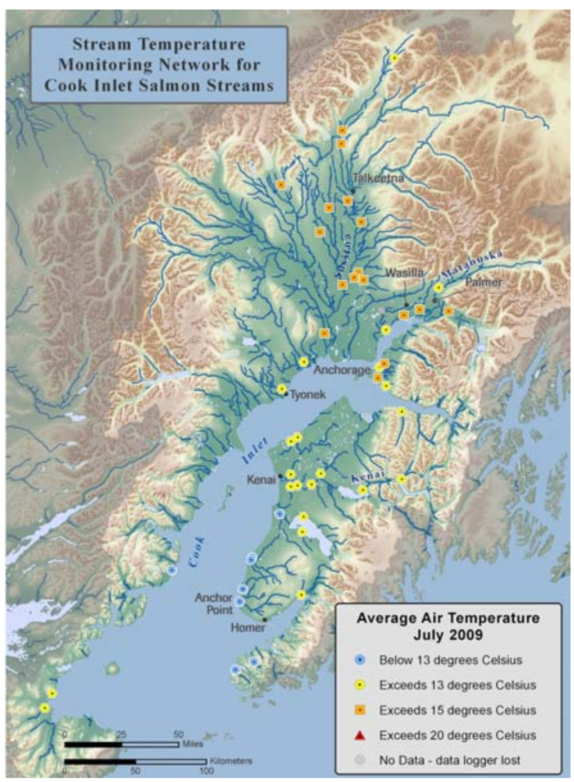
Table 5. Temperature exceedances for the summer season (June 21- September 22, 94 days total) and dates of logger deployment in 2009. At a minimum, loggers were deployed by 6/21 and pulled out after 9/22 unless otherwise noted with an asterisk.

Temperature Logger Site	# Days Exceeds 13°C	# Days Exceeds 15°C	# Days Exceeds 20°C	Deployment Dates
Alexander Creek	88	81	31	6/18
Anchor River	49	22	0	5/20
Beaver Creek	35	15	0	5/15
Bishop Creek	82	60	11	5/14
Byers Creek	78	54	13	5/29
Cache Creek	40	26	3	5/30
Chenik Creek	14	5	0	*6/02 – 8/19
Chester Creek	40	14	0	6/01
Chijuk Creek	67	47	16	*5/12 – 9/21
Chuitna River	7	6	0	*6/11-6/29
Cottonwood Creek	82	50	7	5/27
Crooked Creek	31	17	0	5/26
Deception Creek	42	20	0	*5/07 – 9/15
Deep Creek	50	33	3	5/14
East Fork Chulitna River	18	4	0	5/29
English Bay River	69	24	0	6/12
Fish Creek	79	59	13	5/18
Fox Creek	77	50	15	5/22
Funny River	18	7	0	5/13
Hidden Creek	86	62	14	5/19
Jim Creek	70	60	23	*5/29 – 8/29
Kroto (Deshka) Creek	63	50	18	5/21
Little Willow Creek	46	22	0	5/28
McNeil River	16	3	0	*6/18 – 8/08
Meadow Creek	74	46	12	5/07
Montana Creek	49	29	0	5/07
Moose Creek, (Palmer)	9	0	0	6/08
Moose Creek (Talkeetna)	37	22	0	*7/17 – 9/27
Moose River	56	25	0	5/28
NF Campbell Creek	39	16	0	5/28
Nikolai Creek	24	13	0	6/08
Ninilchik River	48	21	1	5/14
Quartz Creek	12	0	0	5/19
Rabbit Creek	4	0	0	5/26
Resurrection Creek	11	0	0	5/31
Seldovia River	7	0	0	6/02
Shantatalik Creek	4	0	0	6/08
Ship Creek	22	1	0	5/26
Silver Salmon Creek	No data	No data	No data	6/15
Slikok Creek	17	0	0	5/11
Soldotna Creek	51	25	0	5/11
Stariski Creek	45	19	0	5/14
Swanson River	75	51	7	5/14
Theodore River	65	37	5	6/11
Trapper Creek	68	45	10	5/06
Troublesome Creek	46	34	0	5/29
Wasilla Creek	11	0	0	5/27
Willow Creek	43	25	0	6/09





Maps 6 and 7. Maximum 7-day rolling maximums (MWMT) and maximum 7-day rolling averages (MWAT) or the maximum recorded value of daily maximum/average water temperature when averaged over 7 consecutive days.



Map 8. Average July air temperatures at each site.

R-square values of regression equations between average air temperature and water temperature at each site ranged from 0.34 - 0.93 (daily) and 0.45 – 0.98 (weekly). The weekly average air-water relationship was weakest at Chenik Creek, McNeil River and strongest at Cottonwood Creek (Table 7). R-square values of regression equations between maximum air temperature and water temperature at each site ranged from 0.13 - 0.83 (daily) and 0.23 – 0.91 (weekly). The weekly maximum air-water relationship was weakest at Chenik Creek, McNeil River and strongest at Nikolai and Bishop Creeks. Weekly air and water temperatures have a stronger relationship than daily temperatures; average air and water temperatures have a stronger relationship than maximum temperatures.

Regression coefficients for average and maximum weekly temperatures provide a measure of the response of water temperature to air temperature. Twelve streams had coefficients >1.0 for average weekly regressions and two sites had coefficients >1.0 for maximum weekly regressions (Table 7). Water temperatures in these streams increase more than a degree Celsius for every degree of air temperature increase. Swanson River is the only stream that has a coefficient greater than 1.0 for both average and maximum weekly regressions. Alexander Creek is the only stream with a coefficient greater than 1.0 for maximum but not average weekly regressions. Four lower Kenai Peninsula streams (Anchor River, Stariski Creek, Deep Creek and Ninilchik River) have the highest average weekly regression coefficients, which suggest that these streams are particularly vulnerable to rising air temperatures.

Table 7. R-square values and regression coefficients (slope) of weekly average/maximum air temperature and water temperature. Coefficients >1.0 are highlighted. Chuitna River and Moose Creek (Talkeetna) were removed due to their short datasets.

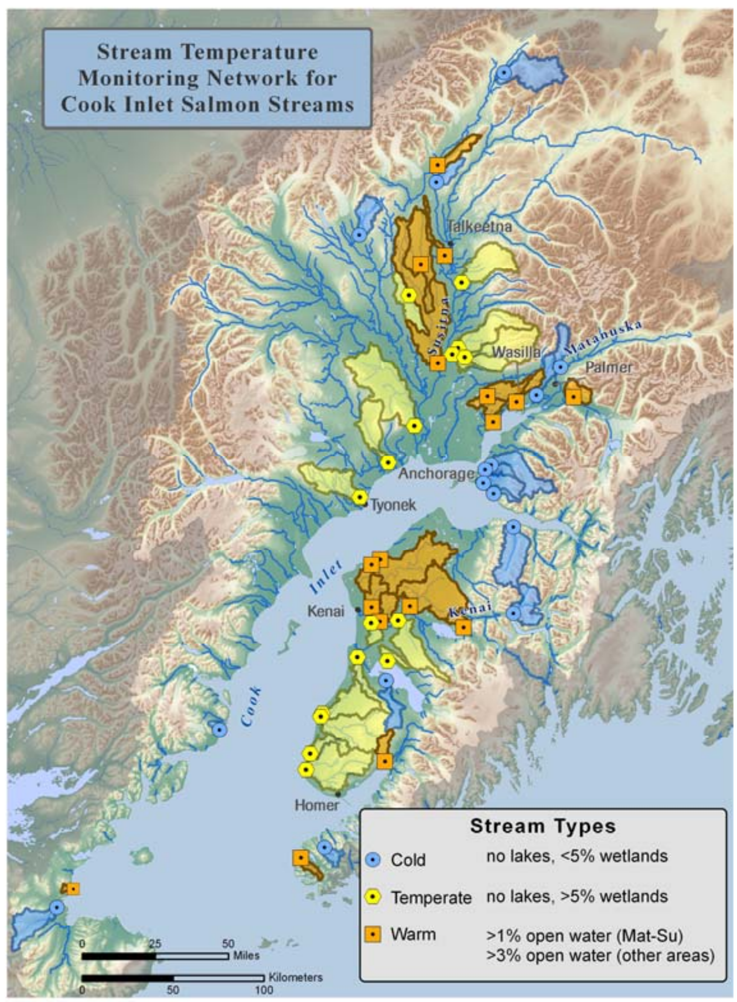
Stream Name	R^2 of average weekly	Coefficient of average weekly	R^2 of maximum weekly	Coefficient of maximum weekly
Alexander Creek	0.93	0.79	0.63	1.02
Anchor River	0.84	1.23	0.27	0.65
Beaver Creek	0.88	0.86	0.51	0.43
Bishop Creek	0.94	1.04	0.90	0.89
Byers Creek	0.76	0.71	0.70	0.65
Cache Creek	0.78	0.73	0.71	0.72
Chenik Creek	0.52	0.76	0.23	0.33
Chester Creek	0.96	0.65	0.87	0.66
Chijuk Creek	0.83	1.05	0.37	0.62
Cottonwood Creek	0.98	0.96	0.88	0.81
Crooked Creek	0.80	1.04	0.54	0.75
Deception Creek	0.86	0.86	0.70	0.71
Deep Creek	0.88	1.30	0.45	0.96
EF Chulitna River	0.81	0.50	0.84	0.52
English Bay River	0.69	0.79	0.61	0.70
Fish Creek	0.96	1.08	0.80	0.81
Fox Creek	0.84	1.18	0.41	0.96
Funny River	0.94	0.80	0.66	0.55
Hidden Creek	0.71	0.83	0.63	0.63
Jim Creek	0.59	0.96	0.64	0.72
Kroto (Deshka) Creek	0.92	1.06	0.85	0.96
Little Willow Creek	0.93	0.71	0.84	0.63
McNeil River	0.45	0.52	0.49	0.27
Montana Creek	0.61	0.74	0.36	0.52
Moose Creek (Palmer)	0.93	0.57	0.89	0.63
Moose River	0.91	0.95	0.77	0.59
NF Campbell Creek	0.94	0.75	0.72	0.56
Nikolai Creek	0.95	0.84	0.91	0.91
Ninilchik River	0.85	1.21	0.52	0.84
Quartz Creek	0.69	0.47	0.50	0.28
Rabbit Creek	0.81	0.57	0.70	0.46
Resurrection Creek	0.79	0.56	0.72	0.45
Seldovia River	0.81	0.61	0.85	0.53
Shantatalik Creek	0.95	0.64	0.71	0.58
Ship Creek	0.91	0.60	0.72	0.55
Slikok Creek	0.76	0.64	0.59	0.47
Soldotna Creek	0.96	0.81	0.72	0.41
Stariski Creek	0.84	1.15	0.52	0.81
Swanson River	0.88	1.15	0.80	1.02
Theodore River	0.95	1.05	0.81	0.98
Trapper Creek	0.87	0.91	0.59	0.67
Troublesome Creek	0.85	0.80	0.62	0.72
Wasilla Creek	0.98	0.63	0.90	0.55
Willow Creek	0.91	0.70	0.76	0.67

WATERSHED CHARACTERISTICS

Relative stream 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. Sites were classified as large, clear (n=11); large, brown (n=7); small, clear (n=20); small, brown (n=10). Relative stream size generally reflected watershed size (based on HUC classification) with the exception of Chijuk Creek and Cache Creek. Chijuk Creek was classified as a small stream but as a large watershed; Cache Creek is a large stream with a small watershed. Brown water vs clear water was determined by local knowledge rather than by DOC or color measurements. However, there was no significant difference between means of these apriori groups for any of the temperature metrics in 2008.

Through the land-cover analysis, we were able to quantify wetland and lake extent in each watershed, which have been identified as important drivers in previous research in the Mat-Su basin[xiv]. By grouping streams first by those with open water, and then by percent of wetlands, streams fall into 3 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 9, Table 8). 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 2009 regression coefficients based on these grouping, we find that cold-water streams have the lowest values for average weekly regression slopes (group average = 0.63). Warm and temperate groups have higher slope values but are not significantly different from each other (group averages = 0.94, 0.93).



Map 9. Stream-type classifications were developed using land- cover data.

Table 8. 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 (Deshka) 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

SNAP Results

Scenarios Network for Alaska Planning (SNAP) generated future scenarios of air temperature and precipitation conditions derived from climate projection data. We selected two scenarios to provide a range of potential future conditions based on greenhouse gas emissions. All of the SNAP maps have the following text (which is included here because it might be too small to read in the following pages):

> **The Intergovernmental Panel on Climate Change (IPCC) created a range of scenarios to explore how different patterns of population growth, energy use, and technological advances may affect future climate.**
>
> **"A1B" is a mid-range scenario. It assumes a world of very rapid economic growth, a global population that peaks in mid-century and then levels out, rapid introduction of more efficient technologies, and a balance between fossil fuels and other energy sources.**
>
> **"A2" is a more pessimistic scenario. It assumes a world with high population growth, slow economic development, and slow technological change.**
>
> **Current trends indicate that the world may be headed somewhere between these two scenarios in terms of greenhouse gas emissions and global climate change.**
>
> **This map shows average values from projections from five global climate models used by the Intergovernmental Panel on Climate Change. Due to variability among models and among years in a natural climate system, such maps are useful for examining trends over time, rather than for precisely predicting monthly or yearly values. For more information on the SNAP program, including derivation, reliability, applicability, and variability among these projection, please visit www.snap.uaf.edu.**

Air Temperatures

Decadal averages of July air temperature show a strong upward trend throughout the entire Cook Inlet watershed for both the A1B (Map 10) and A2 (Map 11) scenarios. Air temperatures will continue to be warmer in the Mat-Su basin than on the southern Kenai Peninsula. By 2090-2099, average July air temperatures in the Susitna River valley are predicted to be over 19^{o}C, which would be a 5 ^{o}C (9 ^{o}F) increase from 2008-2009.

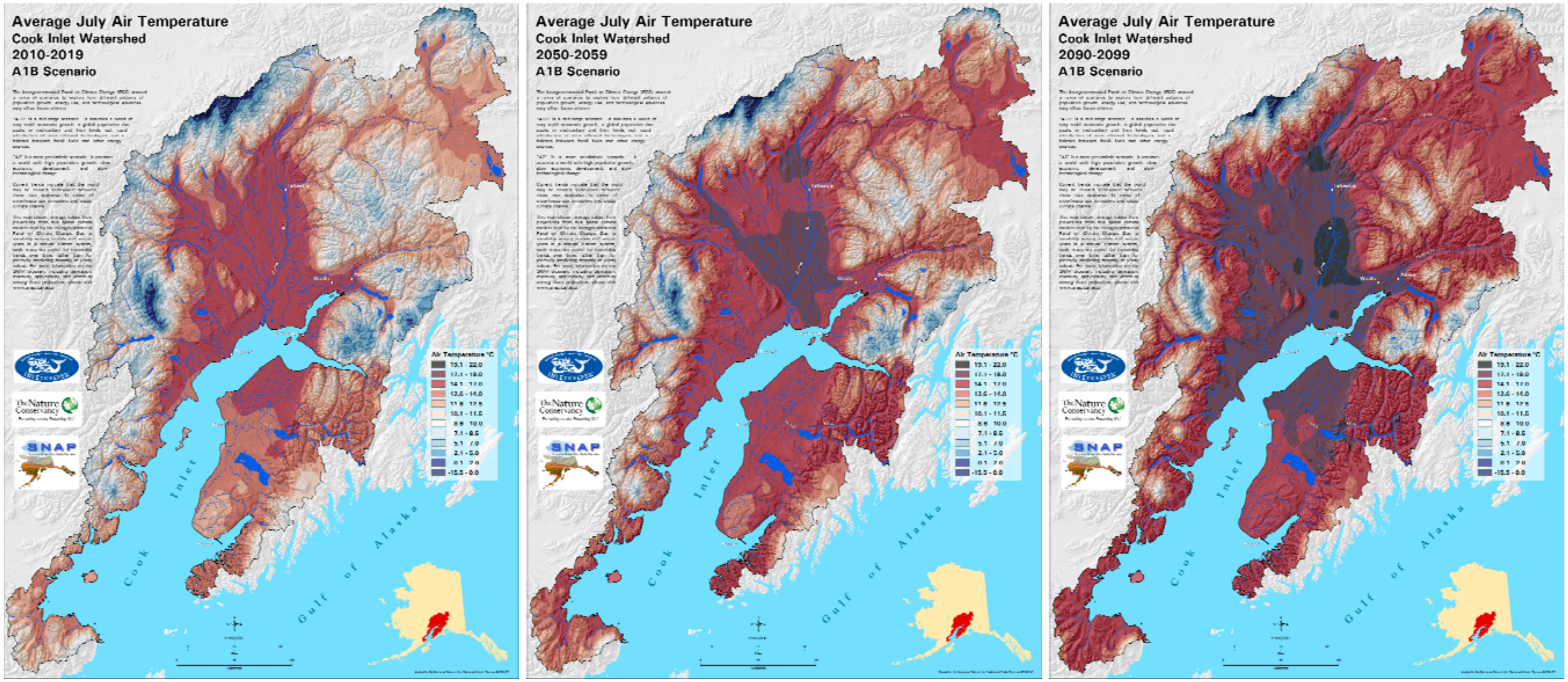
Increases in air temperature are predicted for all seasons, but the most dramatic change will likely be in the winter (Map 12). By 2090-2099, average winter temperatures on the lower Kenai Peninsula and the west side of Cook Inlet will be above freezing, which could result in significant reductions in snow accumulation.

Precipitation

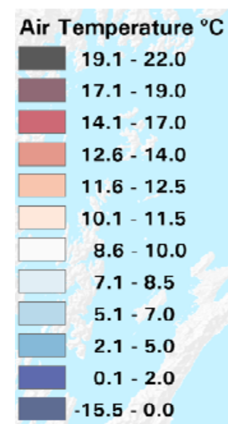
Generally, precipitation will increase during all seasons of the year with the greatest increase occurring in autumn (Map 13) and the smallest increase in spring. Seasonal increases will be relatively small (less than 5 cm).

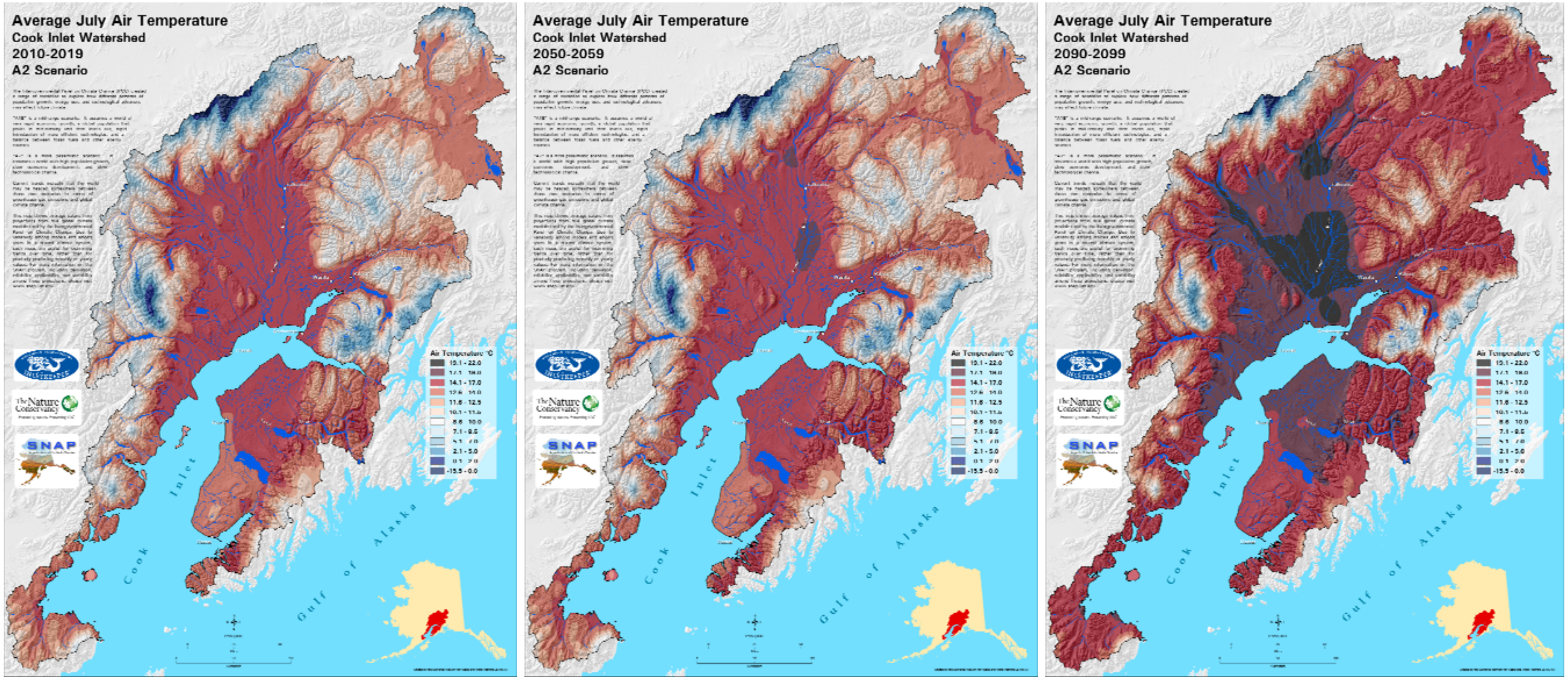
Thaw date

The thaw date (date when average temperature >0^{o}C) is predicted to shift earlier in the year until the majority of the Cook Inlet basin thaws before March 26th (Map 14).

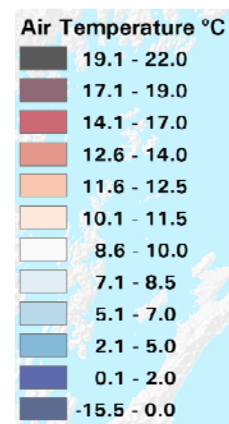


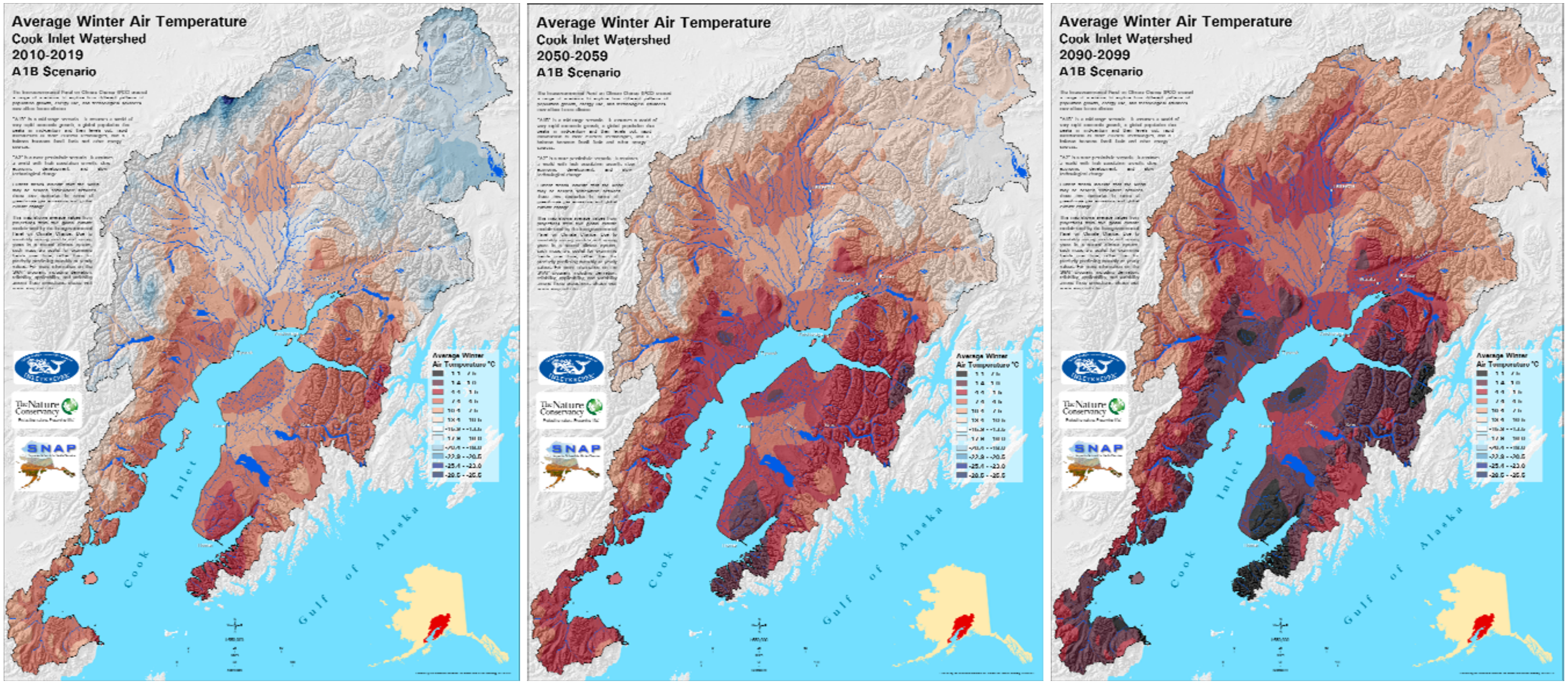
Map 10. Average July air temperature for 2010-2019; 2050-2059; 2090-2099 for the A1B Scenario



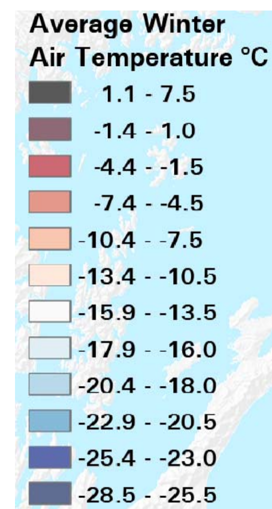


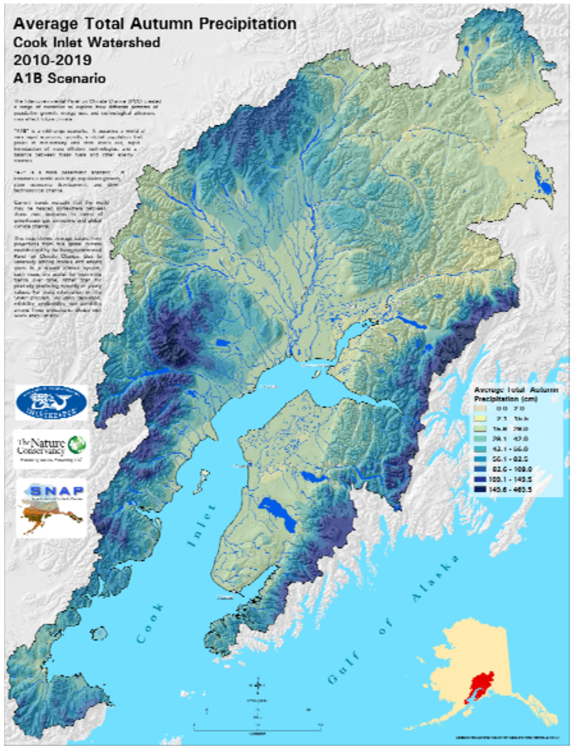
Map 11. Average July air temperature for 2010-2019; 2050-2059; 2090-2099 for the A2 Scenario.

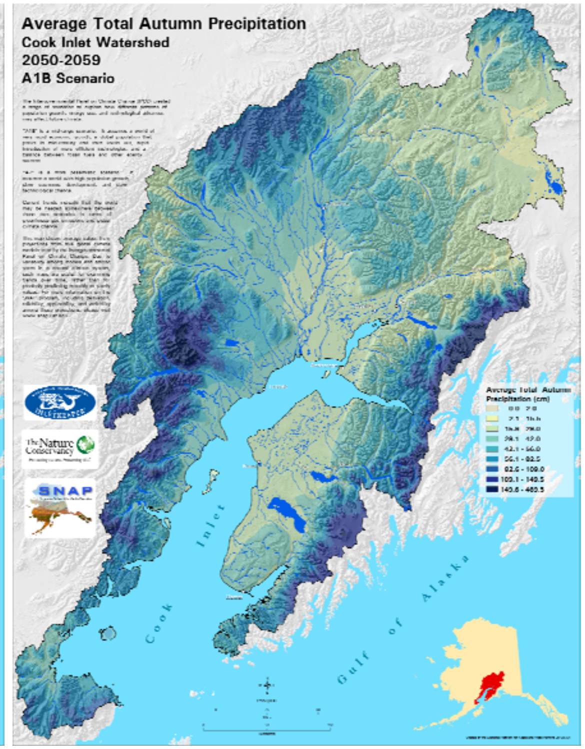


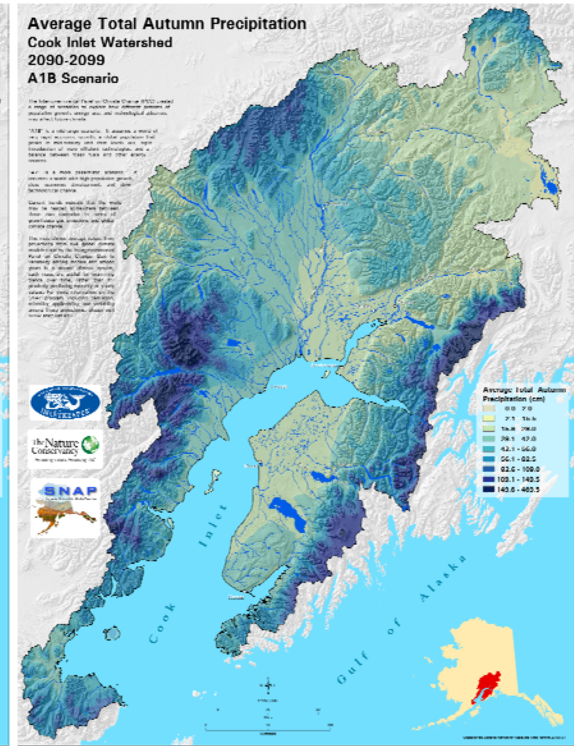


Map 12. Average winter air temperature for 2010-2019; 2050-2059; 2090-2099 for the A1B Scenario.

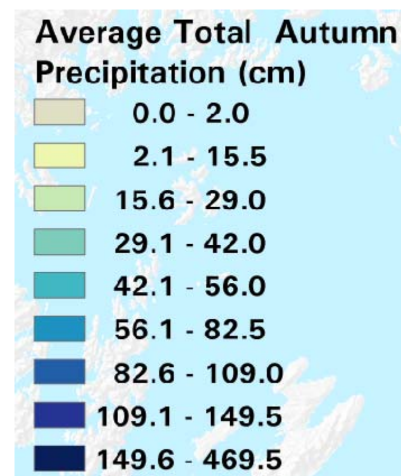


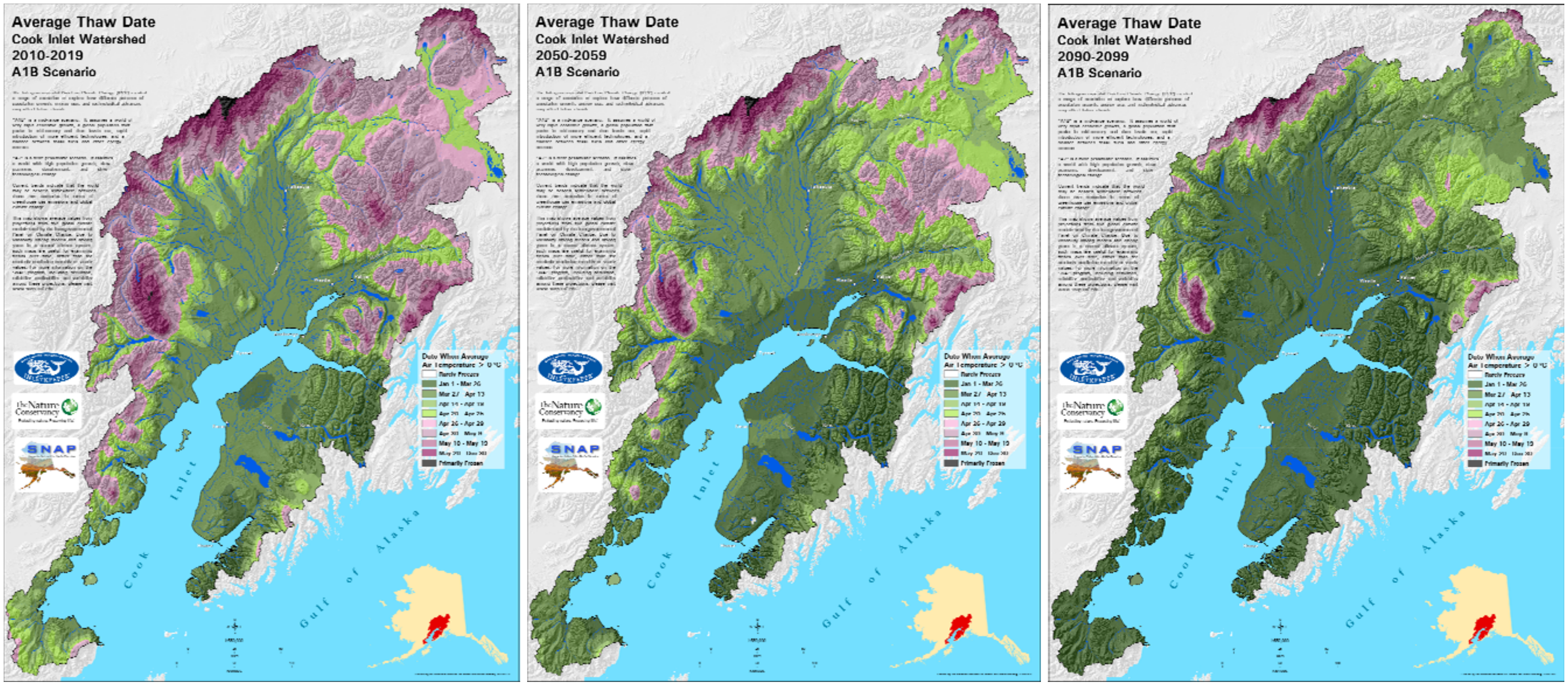






Map 13. Average autumn precipitation for 2010-2019; 2050-2059; 2090-2099 for the A1B Scenario.





Map 14. Average thaw date for 2010-2019; 2050-2059; 2090-2099 for the A1B Scenario.

DISCUSSION

Non-glacial salmon streams in the Cook Inlet watershed consistently exceed Alaska's numeric water quality standards set for the protection of fish, even during a relatively cool, wet summer as in 2008. The warmer summer of 2009 provided a valuable contrast to capture a realistic range of variability in current weather conditions. Through the Stream Temperature Monitoring Network, we can use these 48 "reference" streams to establish a baseline relationship between air and water temperature in a variety of stream types. This regional perspective, incorporating spatiotemporal variability as described in Poole[15], can serve as a tool for identifying thermal impacts in a time of changing climate.

Based on 2008-2009 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.

The relationship between air and water temperature typically differs from stream to stream due to varying degrees of shading, differences in water sources (groundwater, surface runoff) and elevation[16]. 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.[17] Presently, development does not appear to be driving the thermal response in these streams, which have comparable regression coefficients to less developed systems of the same stream type.

In 2008-2009, air temperatures varied across the basin spatially relative to latitude and elevation. To better understand how air temperatures are likely to change temporally, we used regional climate projections from Scenarios Network for Alaska Planning (SNAP). These projections tell us that air temperatures and, to a lesser degree, precipitation will increase across the landscape over the next 100 years. July air temperatures may increase as much as 5°C in the Susitna River valley and increasing winter air temperatures may reduce snow accumulation, especially on the lower Kenai Peninsula and west side of Cook Inlet. This combination of warmer summers and less snow to support summer baseflows has the potential to create thermal conditions that are stressful or unsuitable for salmon in certain stream types and geographic locations.

Alaska's instantaneous temperature criteria and threshold values for the protection of fish 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.

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 out-migrating 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.

In the third year of the Stream Temperature Monitoring Network, we will 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 2010. 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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