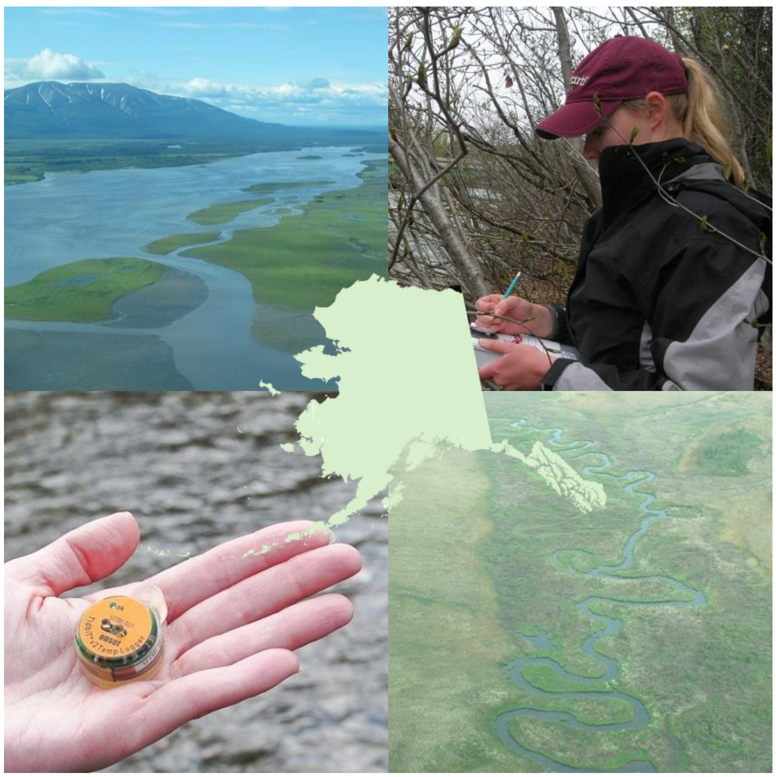
Stream Temperature Data Collection Standards and Protocol for Alaska:

Minimum Standards to Generate Data Useful for Regional-scale Analyses



Alaska Natural Heritage Program
UNIVERSITY of ALASKA ANCHORAGE

December 2014

ACKNOWLEDGEMENTS

The authors thank:

Greta Burkart, Laura Eldred, Jeff Falke, Steve Frenzel, Alan Peck, Chris Sergeant, Brock Tabor, Ryan Toohey, and John Trawicki for their guidance and service on the Technical Advisory Group; Joe Klein and Meg Perdue for review comments; and Joel Reynolds and Karen Murphy for assistance and coordination throughout the project and for their guidance in the preparation of this document.

Support for this effort was provided by the U.S. Fish and Wildlife Service on behalf of the Western Alaska Landscape Conservation Cooperative.

Western Alaska LCC

Stream Temperature Data Collection Standards and Protocol for Alaska:

Minimum Standards to Generate Data Useful for Regional-scale Analyses

Prepared by

Sue Mauger
Cook Inletkeeper

and

Rebecca Shaftel, Dr. E. Jamie Trammell, Marcus Geist, and Dan Bogan
Alaska Natural Heritage Program, UAA

December 2014

Please cite as:

Mauger, S., R. Shaftel, E.J. Trammell, M. Geist, and D. Bogan. 2014. Stream temperature data collection standards and protocol for Alaska: minimum standards to generate data useful for regional-scale analyses. Cook Inletkeeper, Homer, AK and Alaska Natural Heritage Program, UAA, Anchorage, AK. 53 pp.

Stream Temperature Data Collection Standards for Alaska

Table of Contents

Tables and Figures

Appendices

Glossary and Acronyms

Accuracy	The difference between a measurement and its true value
Active channel	Portion of channel wetted during and above winter base flows
CSV	Comma-separated value, a file format (.csv)
Downscaled climate predictions	Output from Global Climate Models which have been converted using regional-scale conditions
Drainage network	Streams and rivers that are connected within a single watershed
Duration	Overall length of time that temperature has been measured
Frequency	Amount of time between each temperature measurement
GIS	Geographic Information System
Heterogeneous	Not uniform in structure or composition
Inter-annual variability	Variation between multiple years
MWAT	Maximum Weekly Average Temperature, the highest annual 7-day moving average of daily mean temperatures
MWMT	Maximum Weekly Maximum Temperature, the highest annual 7-day moving average of daily maximum temperatures
Metadata	Data that describes other data
NIST	National Institute of Standards and Technology
Precision	The difference between repeated measurements of the same value
Quality assurance	Process used to check the precision and accuracy of the data
Quality control	Removal of erroneous data identified by the quality assurance process
R	A free software environment for statistical computing and graphics, http://www.r-project.org/
Reach	A section of a stream or river with similar physical characteristics (i.e. discharge, slope)
Regional-scale	Area that includes multiple moderate-sized watersheds
Resilience	The capacity to recover quickly from any changes
Resolution	The smallest detectable increment of measure
Riparian	Area immediately adjacent to rivers and streams
SNOTEL	National Resources Conservation Service climate and snowpack monitoring network (SNOwpack TELemetry)
Thermal maxima	Maximum temperature during a set time period
Thermal refugia	Localized patches of water with different temperatures than the surrounding habitats, often used by stream fishes to shelter from overly warm or cold stream temperatures
Thermal regime	Magnitude, variability, frequency, duration, and timing of stream temperatures

INTRODUCTION

Background

As Alaskans continue to feel the impacts of a changing climate, the need for resource managers to understand how these changes will alter aquatic systems and fisheries resources grows. Water temperature data collection has increased in recent years to begin to fill our gaps in knowledge about current thermal profiles; however, with Alaska's vast landscapes and ubiquitous freshwater habitats, the need for water temperature data is ongoing. Many entities are collecting temperature data for a variety of purposes to meet project or agency specific goals. Statewide interest in thermal patterns and increasing data collection efforts provides Alaska's scientific and resource managing community an opportunity to meet broader regional-scale data needs. Adopting minimum standards for data collection will ensure comparability of generated data.

The goal of this project is to define minimum ('base') standards for collecting freshwater temperature data in Alaska that must be met so that observations can support regional assessment of status and recent trends in freshwater temperatures and prediction of future patterns of change in these aquatic thermal regimes using downscaled climate projections. By identifying minimum data standards, our objective is to encourage rapid, but structured, growth in comparable stream temperature monitoring efforts in Alaska that will be used to understand current and future trends in thermal regimes. These trends will inform strategies for maintaining ecosystem resilience.

Summary of current standards and protocols for Alaska

Numerous agencies have produced national water temperature protocols including the U.S. Geological Survey (USGS, Wagner et al. 2006) and Environmental Protection Agency (U.S. EPA 2013). Additionally, organizations have generated protocols particular to Alaska, such as the National Park Service (Larsen et al. 2011, Shearer et al. in review, Sergeant et al. 2013), Cook Inletkeeper (Mauger 2008), and most recently the USGS in cooperation with U.S. Fish and Wildlife Service (Toohey et al. 2014). A summary inventory of current protocols can be found in Appendix A of this document. While these protocols provide excellent guidance regarding temperature monitoring, they are often focused on specific agency procedures and goals that are not applicable beyond their source entity. The national and broadly focused protocols present numerous issues that should be considered, but they do not direct the reader toward clear, minimum standards regarding sample frequency, sample duration, or data management. A basic set of stream temperature monitoring standards is still needed for Alaskans to begin building robust datasets suitable for regional analyses.

Simple, scientifically defensible standards will particularly benefit field staff whose primary tasks are not hydrology or monitoring as well as personnel at smaller organizations (e.g. tribal entities, watershed organizations, or local groups). Such basic guidance is also suitable for larger agencies' biologists whose primary tasks are not temperature monitoring. Establishing a set of minimum standards encourages additional groups to deploy temperature sensors while conducting other field tasks, thus leveraging field work occurring across the state, and increasing our ability to discern regional water temperature trends.

Standards versus Protocols

This document has two main components; a section describing the science behind identifying minimum stream temperature data standards and a section detailing the protocol we recommend for stream temperature data collection. Both sections have been designed to be standalone documents, but we recommend that data collection groups read both the data standards and data collection protocol.

Data standards are informed by *why* we want to collect temperature data. Standards identify the basic parameters of stream temperature that are most important to the goals of a project, in this case those parameters most important for monitoring trends to understand regional stream temperature change. However, we have done our best to identify standards that facilitate the maximum utility of the collected data. This means that data collected with these minimum standards should meet the needs of most research and monitoring questions asked at the regional scale.

Data collection protocols define the *how* of data collection. A protocol defines specific tasks associated with stream temperature monitoring, including selection, accuracy, placement, maintenance, and retrieval of stream temperature data loggers; in addition to data quality assurance, management, and sharing. Thus, a protocol is designed to meet the data standards identified at the beginning of a project.

Importance of regional-scale analyses

Climate-driven impacts to water temperature are likely to vary based on multiple local and landscape factors. However, given the current scale of future climatic forecasts, regional climate patterns provide the best available data on future conditions. Thus, we have focused on developing minimum standards for regional-scale analyses. We define regional scales as those areas that span multiple watersheds, such as 4^{th} level hydrologic units included in the USGS National Hydrography Dataset (NHD) that range in size from 5,000 to 25,000 square kilometers. In Alaska, examples of 4^{th} level hydrologic units include entire river drainages such as the Nenana, Mulchatna, or Alsek Rivers; or different basins within a larger system, such as the Upper and Lower Noatak River or North, South, and Middle Forks of the Kuskokwim River.

Regional stream temperature datasets can be analyzed to address many questions; examples are provided and discussed in more detail below.

- What is the current status of stream temperatures? How often and for how long are they above water quality standards designed to protect salmon and trout? (Kyle and Brabets 2001)
- What characteristics of streams and their watersheds are associated with different aspects of the stream thermal regime? (Isaak et al. 2010, Lisi et al. 2013)
- Are there trends in historic stream temperatures? Is there a coherent response across the region or are streams responding differently? (Isaak et al. 2011, Arismendi et al. 2012, Luce et al. 2014)
- Which components of the stream thermal regime are most responsive to climate change? (Arismendi et al. 2013)
- What are the projected stream temperatures under different climate scenarios? (Mantua et al. 2010)
- How will changing stream temperatures affect aquatic biota? (Mohseni et al. 2003, Haak et al. 2010)
- Are there management actions that can be taken to provide for habitat resiliency? (Rieman and Isaak 2010)

In Alaska, several regional analyses have been conducted to evaluate the most important watershed characteristics controlling summertime stream temperatures; important factors have included glacier cover (Kyle and Brabets 2001, Fellman et al. 2014), elevation (Mauger 2013, Lisi et al. 2013), wetlands (Mauger 2013), and lakes (Lisi et al. 2013). Due to the limited spatial and temporal coverage of stream temperature data in Alaska, there is much less information describing historic trends or generation of future projections, especially as they relate to salmonids.

Analysis of historic stream temperature trends in the Western U.S. indicate that some aspects of the thermal regime are coherent across regional scales, such as increasing summer temperatures (Isaak et al. 2011), while other aspects of the thermal regime are responding in complex ways, such as daily minimums advancing more rapidly than maximums, but not for all streams, and no consistent changes to stream temperature variability (Arismendi et al. 2012, 2013). Projected increases in the annual maximum weekly water temperatures by 2080 are on the order of 2-5˚C for Washington State (Mantua et al. 2010). Future projections of increasing stream temperatures across regional river networks indicate decreases in suitable habitat and fragmentation of existing habitat for salmonids in the Western U.S. (Rieman et al. 2007, Isaak et al. 2010, Ruesch et al. 2012, Jones et al. 2013). Management strategies to increase resiliency include improving riparian vegetation to shade streams, restoring stream flows in summertime to decrease stream sensitivity, and restoring fish passage to provide access to thermal refugia (Rieman and Isaak 2010, Isaak et al. 2010).

These types of regional analyses have relied on the compilation and synthesis of extensive amounts of data collected by a multitude of agencies and organizations with an interest in monitoring stream temperatures over the last few decades (e.g., Isaak et al. 2010). The adoption of minimum standards for stream temperature data collection in Alaska will enable analysis of stream thermal regimes in Alaska across larger spatial and temporal resolutions than is currently possible given the low density of stream temperature data across the state.

Lake temperature data collection

Although stream temperature assessments have burgeoned in the field and the literature over the last decade, regional lake assessments are lagging behind. Many of the minimum standards discussed here are relevant for both stream and lake temperature data collection, such as data logger accuracy, range and quality assurance measures as well as data management; however, site selection and deployment methods in the following protocol are only relevant for running water habitats.

Given the fundamental difference between moving water and lakes, we believe that it would be inappropriate to define universal temperature monitoring standards. Lakes are inherently different. Shallow lakes have very different thermal regimes than deep lakes which can have vertically stratified temperature profiles that may include seasonal mixing (Jones and Arp 2014). Glacial lakes have different regimes than disconnected permafrost-driven lakes. Thus, lakes are not an easily definable entity for establishing monitoring standards.

In addition, lake temperature monitoring is typically focused on different types of questions than river and stream monitoring. Specifically, most lake monitoring addresses vertical temperature profiles and aims to target specific events (i.e. mixing, freeze up). Fortunately, protocols for sampling in shallow Arctic lakes (Larsen et al. 2011) and the large lakes of Southwest Alaska (Shearer et al. in review) have been developed by the National Park Service that comprehensively address lake-specific issues. And with a preponderance of both large and remote lakes in Alaska, the emerging use of remote sensing data in conjunction with continuous data collection to characterize lake surface temperatures is encouraging (Arp et al. 2010).

The influence of lakes within a stream network on water temperature is significant and complex. Lakes increase residence time and solar absorption resulting in a positive relationship between stream temperature and percent lake cover (Moore et al. 2013, Fellman et al. 2014) and lake size (Garrett 2010, Lisi et al. 2013). And stream temperature generally declines as the distance from a lake outlet increases (Garrett 2010, Rosenfeld and Jones 2010); however, factors like lake depth, inlet and outlet position and wind patterns can be important drivers of temperature in an outlet stream (Rosenfeld and Jones 2010). Future research is needed in Alaska to understand the influence of lake temperature on stream temperature within a drainage network.

MINIMUM STANDARDS

In an effort to develop minimum standards for identifying regional trends in surface water temperature in Alaska, it is important to consider the various ways stream temperature trends have been modeled in other locations. Recent analyses of unregulated streams of the Western U.S. have documented significant warming trends for many stream systems, especially during the summer months (Isaak et al. 2011, Arismendi et al. 2012). Exploration of historic stream temperature data has also led to some unexpected results, such as daily minimums and means showed more significant warming trends than daily maximums (Arismendi et al. 2012, 2013), cooling trends during the spring and fall seasons (Isaak et al. 2011, Arismendi et al. 2012), and the necessity of having relatively long time series (~30 years) to document significant warming trends in minimum, maximum, and mean daily temperatures (Arismendi et al. 2012). As the network of stream temperature data collection in Alaska broadens and densifies, we are fortunate to be able to apply this knowledge and carefully maintain our data records for storing and sharing, continue to pursue year-round data collection, and set a goal of maintaining long-term monitoring sites (>30 years) so that informative regional scale trend analyses are feasible.

Below are our minimum data collection standards to generate data useful for regional-scale analyses of stream thermal regimes. The standards cover data logger accuracy and range; sampling frequency and duration; quality assurance steps including accuracy checks, site selection and data evaluation; and finally, metadata, data storage and sharing (Table 1). In some cases we have included recommendations beyond the minimum standards for the reader to consider. Guidance on how to implement these standards and recommendations is provided in the Stream Temperature Data Collection Protocol for Alaska.

Data logger

Minimum Standard: accuracy of ±0.25°C and range from -4° to 37°C.

The accuracy and range minimum standards are based on the best available technology for water temperature data loggers currently on the market. We set the minimum accuracy standard at ±0.25°C as opposed to 0.2°C to be clear that commonly used data loggers with accuracy specifications of 0.21°C are appropriate. There are additional brands with less accuracy that should not be used. Introduction of additional measurement error into stream temperature datasets can reduce our ability to detect trends. The range is set well beyond the expected values for stream temperature in Alaska.

Table 1. Minimum data collection standards for regional analysis of stream thermal regimes.

Minimum Standards		
Data Logger	Accuracy	±0.25°C
	Measurement range	-4° to 37°C (24° to 99°F)
Data Collection	Sampling frequency	1 hour interval
	Sampling period/duration	1 calendar month
Quality Assurance and Quality Control	Accuracy checks	water bath at two temperatures: 0°C and 20°C before and after field deployment to verify logger accuracy (varies ≤ 0.25°C compared with a NIST-certified thermometer)
	Site selection	five measurements across the stream width to verify that the site is well-mixed (i.e. varies ≤ 0.25°C)
	Data evaluation	remove erroneous data from the dataset
Data Storage	File formats	CSV format in 2 locations
	Metadata	unique site identifier agency/organization name and contact datum, latitude and longitude sample frequency stored with temperature data
	Sharing	quality-controlled hourly data

Data collection

Sampling frequency

Minimum Standard: 1 hour interval

The minimum standard for sample frequency was selected as the maximum interval that could be used while still effectively capturing the daily maximum and minimum temperatures. The probability of capturing the daily maximum or minimum given a specified sampling interval is affected by the daily range in water temperature. Dunham et al. (2005) compared several sampling intervals to their baseline of 30 minutes to estimate the probabilities of missing the maximum daily temperature by more than 1°C. Given a daily range of 12°C, there is less than a 2% probability of missing the true daily maximum by more than 1°C using a two-hour sampling interval (Figure 5, Dunham et al. 2005). These results are relevant for a dataset of 48 non-glacial salmon streams in Cook Inlet where the daily range among sites varied from 3.9°C to 11.6°C (Table 6, Mauger 2013).

However, a 1°C accuracy goal may not be sensitive enough for tracking maximum and minimum temperature trends during specific seasons important for aquatic organisms.

We resampled stream temperature data collected at 15 minute intervals for seven Cook Inlet streams whose daily ranges varied from 4.0° to 10.3°C. For each of the sampling intervals studied – 30 minutes, 1 hour, 2 hours, and 4 hours – we calculated the difference in daily maximum from the 15 minute interval dataset to determine the loss in accuracy from recording temperatures at longer time intervals (Figure 1). Error bars reflect the standard error of the mean differences based on 76 to 149 days of data within one year for each site. A 4 hour sampling interval results in a reduction to the maximum daily temperature of 0.3°C at the site with the largest daily range. This introduced bias is greater than the accuracy of the data loggers used. The 2 hour, 1 hour, and 30 minute sampling intervals resulted in only a minor loss of accuracy in measuring the daily maximum. We chose a 1 hour minimum standard for the sampling interval to reduce the possibility of introducing bias into the daily maximum and minimum values, which get compounded when calculating maximum weekly values, and as a realistic interval to synchronize with when performing quality assurance checks in the field.

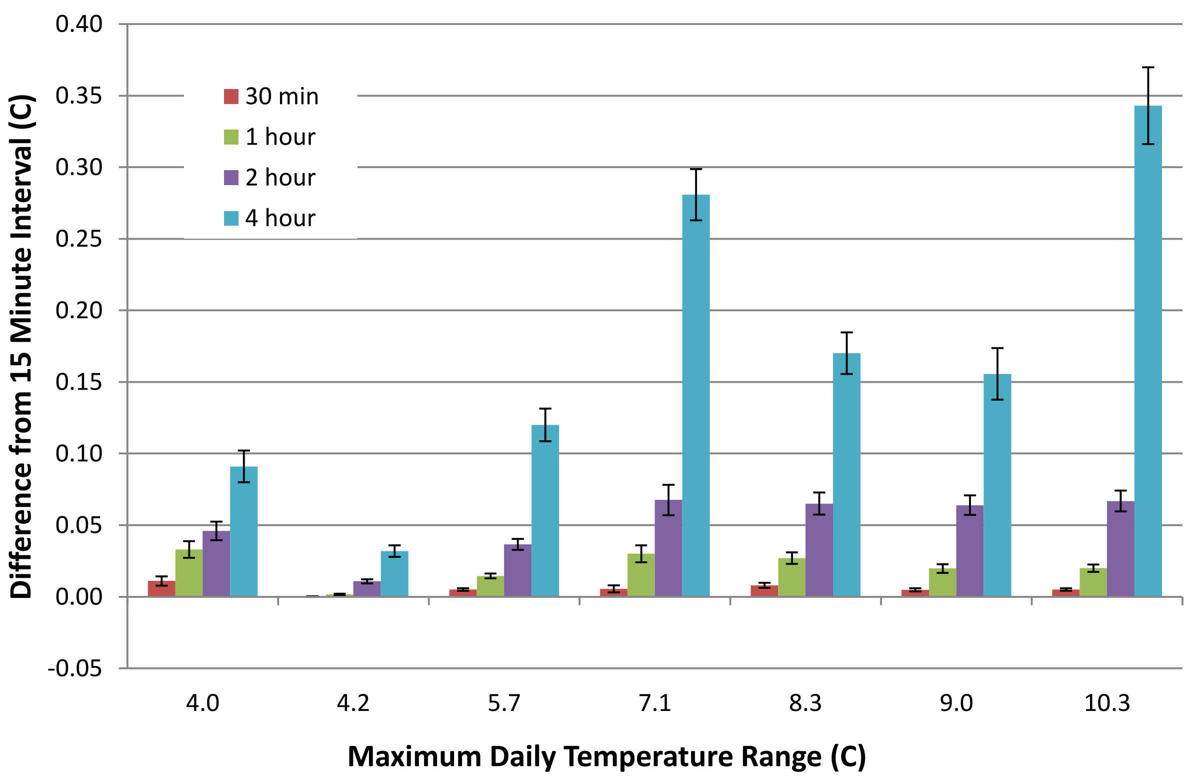


Figure 1. Difference in daily maximum for 30 minute, 1 hour, 2 hours, and 4 hours sampling intervals based on seven stream monitoring sites in Cook Inlet.

Sampling period/duration

Minimum Standard: one calendar month

Recommendations: year round data collection or as much of the open water season as possible and at least 3 years of data collection

The minimum standard for sample duration was set to one month after reviewing existing regional analyses for the shortest duration of data collection useful for understanding status and trends in stream thermal regimes. Several regional analyses developed statistical models for predicting monthly average temperatures (e.g. Wehrly et al. 2009, Hrachowitz et al. 2010, Mayer 2012, Fellman et al. 2014). The months most commonly modeled were July and August, but some studies also modeled other months of the year. We selected a one month (calendar month) minimum standard for sample duration because it was the shortest time interval useful for informing a regional analysis. But, we would like to emphasize that this is a minimum standard and there is an important need for year-round stream temperature data in Alaska in order to assess climate change impacts beyond the summer season.

Annual air temperatures have increased in Alaska by 1.7^{o}C (3^{o}F) over the last 60 years while winter temperatures have increased by 3.3^{o}C (6^{o}F; Chapin et al. 2014). In addition, dates of snowmelt and freeze-up have shifted so that the growing season is now 45% longer in Interior Alaska than it was at the beginning of the 20th century (Chapin et al. 2014). These trends highlight the need for monitoring stream temperatures during all seasons of the year as longer ice free seasons and increased warming in the wintertime may affect the vulnerability of aquatic taxa during the spring, fall, and winter.

The majority of regional analyses evaluating climate change effects on fish distributions have modeled one or more measures of the thermal maxima (e.g., Eaton et al. 1995, Isaak et al. 2010). In order to provide guidance on the recommended deployment period required to capture the thermal maxima in Southcentral Alaska, we reviewed five summers of stream temperature data collected in the Cook Inlet basin. We used the dates of maximum weekly average temperature (MWAT) and maximum weekly maximum temperature (MWMT) to evaluate the timing of the thermal maxima (Table 2). The MWMT occurs more frequently in July than MWAT, but warm events in June and August indicate the importance of measuring stream temperatures for all three summer months. For two sites in southern Cook Inlet, the MWMT was observed as late as September in 2010. We recommend a minimum deployment period of June 1 to August 31 to capture the thermal maxima for streams in Southcentral Alaska. The timing of thermal maxima may be different in other regions of Alaska. If the timing is not known, multiple years of data should be collected over the entire open water period before narrowing your sampling period to target the thermal maxima. In addition, climate change may be shifting the thermal maxima earlier in the summer due to decreasing snowpack and increasing temperatures.

Table 2. Frequencies of MWAT and MWMT by month for streams in Cook Inlet, 2008-2012.

Maximum weekly average temperature (MWAT)				
	June	July	August	September
2008	1	17	22	0
2009	0	42	0	0
2010	1	25	11	1
2011	2	38	2	0
2012	17	1	10	0
Maximum weekly maximum temperature (MWMT)				
2008	3	25	12	0
2009	0	42	0	0
2010	2	30	4	2
2011	3	38	1	0
2012	17	3	8	0

It is also important to consider inter-annual variability in stream temperature regimes when planning stream temperature data collection efforts. Values for MWAT and MWMT were highly variable over a five year monitoring period in Cook Inlet salmon streams. For streams with at least three summers of data (n=44), the difference between the lowest and highest MWAT ranged from 0.8^{o} to 6.4^{o}C and for MWMT ranged from 1.4^{o} to 7.3^{o}C. We recommend at least three years of data collection in order to accurately capture the effect of inter-annual variability on a stream's thermal regime. If you are unable to collect data year round, it is important to consider sampling the same month (or set of months) year after year for consistency. A data logger can be used to record measurements for several years as the battery life for a typical logger is 5 years at a 1 minute or greater interval. But, due to limitations in storage capacity and recommended steps for quality assurance, loggers should be retrieved annually so that accuracy checks can be performed and data can be downloaded before redeploying.

Quality assurance and quality control

Accuracy checks

Minimum Standard: Water bath at two temperatures, 0^{o}C and 20^{o}C, before and after field deployment to verify logger accuracy

The minimum standards for quality assurance and quality control were selected to ensure that each logger meets data quality objectives, data are representative of temperatures in the stream reach, and erroneous data are removed. The accuracy checks required for pre- and post-deployment are needed to verify that each logger meets its technical specifications throughout the deployment period and that no drift of measurements has occurred over time. These accuracy checks are not used to calibrate or modify values recorded by the data logger, but instead were established to ensure that data can be confidently shared with other users.

Site selection

Minimum Standard: Five measurements across the stream width to verify that the site is well-mixed

Recommendation: Deploy a backup logger at your site in the event that one logger fails or is lost during deployment

Site selection at the reach scale includes two components: identifying a stable location within the reach and deploying the logger in a well-mixed section of the stream channel. Due to the diversity in stream and river ecosystems within Alaska, we can only provide general guidance for site selection within the reach. High velocity habitats, such as those found along the outside bank of a bend, should be avoided to reduce the likelihood of losing a logger during high flow events. Low velocity habitats, like those along the inside of a bend or in eddies or pools, should be avoided because sediment deposition may bury a logger. Logger should be deployed within the active channel to prevent exposure to air temperatures during low flows. We recommend deploying two loggers at a site to help reduce the impact of losing data from placing a logger in an unstable location within a reach.

Temperature loggers should be placed in a well-mixed section of the main stream channel if the data are to be useful for regional-scale analysis of stream temperatures (the purpose of this document). Stream thermal regimes can be highly variable at the reach scale depending upon the diversity of habitat types present. Thermal imaging of the Anchor River in Southcentral Alaska indicates that sloughs and side channels may be warmer or colder than the main channel by as much as 4°C (Table 5, Watershed Sciences 2010). Stream reach features with unique temperature characteristics, such as off-channel habitat, groundwater upwelling areas, or anthropogenic features (e.g. dam or point discharge), should be avoided. The minimum standard for site selection is a quality assurance step to ensure that the logger is deployed in a location within the stream channel that is well-mixed.

Site selection also includes the location of a monitoring site within the stream network, which is typically related to project objectives and may not be based on regional analysis of stream temperatures. For individual groups or collaborative efforts initiating regional stream temperature data networks in Alaska, Isaak provides general guidance for site selection (Isaak n.d.). Probabilistic designs, such as those used for EPA's National Aquatic Resource Surveys (Stevens and Olsen 2004), can be used to locate random sampling sites that are spatially balanced across a stream network, but they are logistically challenging to apply in remote locations when sites cannot be sampled for various reasons. For predictive modeling of stream temperatures across a network, sites may be strategically placed to capture the full range of the dominant environmental gradients driving stream temperatures (Isaak et al. 2010). Depending upon the region, important environmental gradients to consider include elevation, slope, stream size, wetlands, and lakes. Spatial data for the region can be assembled in GIS and used to attribute the stream network with the necessary stream or watershed information required for site selection. An example can be found here: http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temp/multregression/methods.shtml).

Other suggestions for site selection include utilizing confluences and targeting unique features in your stream network. Confluences provide an opportunity to gather information about three distinct stream reaches by deploying loggers in the two incoming tributaries and also within the downstream reach below where the two source waters have become well-mixed. Discrete features in your region that may affect stream temperatures, such as a large lake or wildfire, can be bracketed to better capture their effect. Recent guidance on sampling designs for stream networks recommends placing multiple samples in clusters at confluences and also single samples at outlet and headwater reaches (Som et al. 2014).

Data evaluation

Minimum Standard: Remove erroneous data from the dataset

It is extremely important that data are reviewed by the data collection agency and all erroneous data are removed. Data evaluation steps can only be performed with confidence by the field staff familiar with the sampling events and site conditions and should occur immediately after returning from the field to prevent any loss of information sharing needed to diagnose erroneous data. Data evaluation steps include removing air temperature measurements before deployment and after retrieval and screening for anomalous readings caused by dewatering or burial of the logger. Sowder and Steel (2012) provide additional examples of visual checks for anomalous data.

Data storage

File format

Minimum Standard: CSV format in 2 locations

The minimum standards for data storage were selected in order to facilitate sharing of datasets among users. We specified that the file format for the minimum standard be software neutral, comma separated values (.csv), so that it is easily imported into a variety of database and analysis programs, such as Excel, Access, and R. Additionally, data and associated metadata (see below) need to be stored in at least two locations, with one of those locations being publicly accessible.

Metadata

Minimum Standard: unique site identifier, data source agency/organization name and contact, datum, latitude and longitude, sample frequency; and stored with temperature data

Regional scale assessments of stream temperatures will require scientists to use data from numerous sensors sourced from many agencies. The minimum standard requires that metadata information be stored with the temperature data files so that future users can easily use the data. The creation, maintenance, and distribution of metadata are critical. As the number of temperature monitoring datasets increases rapidly, our ability to discern which datasets are useful to a given research interest will be related to our capacity to sort through metadata which have common fields. Using consistent fields and formats will improve comparisons between datasets collected by different groups and at different times.

The Western Alaska and Northwest Boreal Landscape Conservation Cooperatives along with the USGS Alaska Climate Science Center convened a two day workshop in Anchorage in November 2012 assembling scientists interested in Alaska's water temperature monitoring. Lacking common attributes, workshop organizers were unable to catalog and map water temperature monitoring sites at the workshop due to inconsistent formatting among agencies and a lack of digital metadata. Workshop organizers and participants prioritized a need for a more comprehensive inventory of project metadata and attributes for current and past stream and lake temperature monitoring efforts.

The Alaska Online Aquatic Temperature Site (AKOATS) and the IMIQ Hydroclimate Database and Data Portal (IMIQ 2014) are examples of standardization of metadata attributes across dozens of data sources. At a minimum, metadata shall include the following attributes: unique site identifier, data source agency or organization name and contact information, datum, latitude, longitude, and sample frequency (1 hour, 30 minutes, 15 minutes). We strongly encourage investigators to submit project metadata to AK-OATS (http://aknhp.uaa.alaska.edu/aquatic-ecology/akoats/).

Sharing

Minimum Standard: Quality-controlled hourly data

Recommendation: daily summaries of minimums, maximums, and means

The minimum standard for sharing data is quality-controlled hourly data, which provides the information needed to characterize all aspects of a stream's thermal regime (Dunham et al. 2005, Nelitz et al. 2007, Arismendi et al. 2013). Although many regional analyses have focused on stream temperature responses associated with the summertime thermal maxima (e.g. mean July temperature or MWMT), there are many other components to the stream thermal regime: magnitude (minimums), variability (daily range), frequency (number of events that exceed a threshold), duration (length of a temperature event), and timing (day of year, Poole et al. 2001). We also recommend providing daily summaries of minimum, maximum, and mean stream temperatures. Calculating these daily summary statistics serves as an important quality assurance step by forcing the data collector to review the data soon after data retrieval so that erroneous measurements can be identified and deleted. Daily summary statistics should only be calculated for quality controlled data with at least 90% of daily measurements (e.g. 22 hourly measurements).

This document was developed to help the reader understand our justification for selecting and motivation for establishing minimum standards for stream temperature data collection. The protocol that follows provides detailed instructions on implementing these minimum standards. We hope that this project will encourage data collection efforts that will be useful for understanding current and future temperature trends in Alaska's freshwater systems.

LITERATURE CITED

Arismendi, I., S. Johnson, and J. Dunham. 2012. The paradox of cooling streams in a warming world: regional climate trends do not parallel variable local trends in stream temperature in the Pacific continental. Geophysical Research Letters 39:L10401.

Arismendi, I., S. L. Johnson, J. B. Dunham, and R. Haggerty. 2013. Descriptors of natural thermal regimes in streams and their responsiveness to change in the Pacific Northwest of North America. Freshwater Biology 58:880–894.

Arp, C. D., B. M. Jones, M. Whitman, A. Larsen, and F. E. Urban. 2010. Lake temperature and ice cover regimes in the Alaskan Subarctic and Arctic: integrated monitoring, remote sensing, and modeling. Journal of the American Water Resources Association 46:777–791.

Chapin, F.S., III, S.F. Trainor, P. Cochran, H. Huntington, C. Markon, M. McCammon, A.D. McGuire, and M. Serreze. 2014. Chapter 22: Alaska. Climate Change Impacts in the United States: The *Third National Climate Assessment*. J.M. Melillo, T.C. Richmond, and G.W. Yohe (editors), U.S. Global Change Research Program, pp. 514-536. doi:10.7930/J00Z7150.

Dunham, J., G. Chandler, B. Rieman, and D. Martin. 2005. Measuring stream temperature with digital data loggers: A user's guide. Page 15. Fort Collins, CO.

Eaton, J., J. McCormick, B. Goodno, D. O'Brien, H. Stefan, M. Hondzo, and R. Scheller. 1995. A field information-based system for estimating fish temperature tolerances. Fisheries 20:10–18.

Fellman, J. B., S. Nagorski, S. Pyare, A. W. Vermilyea, D. Scott, and E. Hood. 2014. Stream temperature response to variable glacier coverage in coastal watersheds of Southeast Alaska. Hydrological Processes 28:2062–2073.

Garrett, J. D. 2010. Pervasive thermal consequences of stream-lake interactions in small Rocky Mountain watersheds, USA. Utah State University.

Haak, A. L., J. E. Williams, D. J. Isaak, A. S. Todd, C. C. Muhlfeld, J. L. Kershner, R. E. Gresswell, S. W. Hostetler, and H. M. Neville. 2010. The potential influence of changing climate on the persistence of salmonids of the Inland West. USGS 2010-1236.

Hrachowitz, M., C. Soulsby, C. Imholt, I. A. Malcolm, and D. Tetzlaff. 2010. Thermal regimes in a large upland salmon river: a simple model to identify the influence of landscape controls and climate change on maximum temperatures. Hydrological Processes 24:3374–3391.

IMIQ. 2014. Imiq Hydroclimate Database & Data Portal, Arctic Landscape Conservation Cooperative, Fairbanks, AK. http://arcticlcc.org/projects/imiq/

Isaak, D. J. (n.d.). Climate-Aquatics Blog Post #8: Thoughts on monitoring designs for temperature sensor networks across river and streams basins. http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temp/blogs/08ThoughtsOnTemperatureMonitoringDesignsForRiverNetworks.pdf.

Isaak, D. J., C. H. Luce, B. E. Rieman, D. E. Nagel, E. E. Peterson, D. L. Horan, S. Parkes, and G. L. Chandler. 2010. Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological applications 20:1350–71.

Isaak, D. J., S. Wollrab, D. Horan, and G. L. Chandler. 2011. Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. Climatic Change 113:499–524.

Jones, B. M. and C. D. Arp. 2014. Past, present, and future thermal regimes of lakes in Western Alaska, Western Alaska Landscape Conservation Cooperative Final Report, WA2011_03, https://westernalaskalcc.org/projects/Lists/Project%20Products/Attachments/85/WAKLCC_Lake_Surface_Temperature_Final_Report%202014%20Oct%2027.pdf.

Jones, L., C. Muhlfeld, L. Marshall, B. Mcglynn, and J. Kershner. 2013. Estimating thermal regimes of bull trout and assessing the potential effects of climate warming on critical habitats. River Research and Applications 30:204–216.

Kyle, R. E., and T. P. Brabets. 2001. Water temperature of streams in the Cook Inlet basin, Alaska, and implications of climate change. Page 32 WRI 01-4109. Anchorage, AK.

Larsen, A., J. Houghton, J. Black, D. Verbyla, C. Ruedebusch, R. McGinnis, and H. Kristenson. 2011. Shallow lake limnology monitoring protocol: Central Alaska Network (CAKN) and Arctic Network (ARCN) Version 2.0. Page 656. Fort Collins, CO.

Lisi, P. J., D. E. Schindler, K. T. Bentley, and G. R. Pess. 2013. Association between geomorphic attributes of watersheds, water temperature, and salmon spawn timing in Alaskan streams. Geomorphology 185:78–86.

Luce, C., B. Staab, M. Kramer, S. Wenger, D. Isaak, and C. McConnell. 2014. Sensitivity of summer stream temperatures to climate variability in the Pacific Northwest. Water Resources Research.

Mantua, N., I. Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102:187–223.

Mauger, S. 2008. Water temperature data logger protocol for Cook Inlet salmon streams. Page 10. Homer, AK.

Mauger, S. 2013. Stream temperature monitoring network for Cook Inlet salmon streams 2008 - 2012. Page 33. Homer, AK.

Mayer, T. D. 2012. Controls of summer stream temperature in the Pacific Northwest. Journal of Hydrology 475:323–335.

Mohseni, O., H. G. Stefan, and J. G. Eaton. 2003. Global warming and potential changes in fish habitat in U.S. streams. Climatic Change 59:389–409.

Moore, R. D., M. Nelitz, and E. Parkinson. 2013. Empirical modelling of maximum weekly average stream temperature in British Columbia, Canada, to support assessment of fish habitat suitability. Canadian Water Resources Journal 38:135–147.

Nelitz, M. A., E. A. MacIsaac, and R. M. Peterman. 2007. A science-based approach for identifying temperature-sensitive streams for rainbow trout. North American Journal of Fisheries Management 27:405–424.

Poole, G. C., J. Risley, and M. Hicks. 2001. Issue Paper 3 Spatial and temporal patterns of stream temperature (revised). Page 35.

Rieman, B. E., D. Isaak, S. Adams, D. Horan, D. Nagel, C. Luce, and D. Myers. 2007. Anticipated climate warming effects on bull trout habitats and populations across the Interior Columbia River Basin. Transactions of the American Fisheries Society 136:1552–1565.

Rieman, B. E., and D. J. Isaak. 2010. Climate change, aquatic ecosystems, and fishes in the Rocky Mountain West: implications and alternatives for management. Page 53. Fort Collins, CO.

Rosenfeld, J., and N. E. Jones. 2010. Incorporating lakes within the river discontinuum: longitudinal changes in ecological characteristics in stream–lake networks. Canadian Journal of Fisheries and Aquatic Sciences 67:1350–1362.

Ruesch, A. S., C. E. Torgersen, J. J. Lawler, J. D. Olden, E. E. Peterson, C. J. Volk, and D. J. Lawrence. 2012. Projected climate-induced habitat loss for salmonids in the John Day River network, Oregon, U.S.A. Conservation Biology 26:873–882.

Sergeant, C. J., W. F. Johnson, and S. Nagorski. 2013. Freshwater water quality monitoring protocol: version FQ-2013.1. Page 232. Fort Collins, CO.

Shearer, J., C. Moore, K.K. Bartz, E. Booher, and J. Nelson. In review. Southwest Alaska Freshwater Flow System Monitoring Protocol Standard Operating Procedures, Southwest Alaska Network. Natural Resource Report NPS/AKR/SWAN/NRR—2011/XXX. National Park Service, Fort Collins, Colorado.

Som, N. a., P. Monestiez, J. M. Ver Hoef, D. L. Zimmerman, and E. E. Peterson. 2014. Spatial sampling on streams: principles for inference on aquatic networks. Environmetrics 25:306–323.

Sowder, C., and E. A. Steel. 2012. A note on the collection and cleaning of water temperature data. Water 4:597–606.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262–278.

Toohey, R. C., E. G. Neal, and G. L. Solin. 2014. Guidelines for the collection of continuous stream water-temperature data in Alaska. Page 37. Reston, Virginia.

U.S. EPA. 2013. Best practice for continuous monitoring of temperature and flow in wadeable streams. Page 123. Washington DC.

Wagner, R. J., R. W. Boulger, C. J. Oblinger, and B. A. Smith. 2006. Guidelines and standard procedures for continuous water-quality monitors: station operation, record computation, and data reporting. Page 96. Reston, Virginia.

Watershed Sciences. 2010. Airborne thermal infrared remote sensing Anchor River basin, Alaska. Page 21. Corvallis, OR.

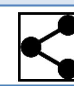
Wehrly, K. E., T. O. Brenden, and L. Wang. 2009. A comparison of statistical approaches for predicting stream temperatures across heterogeneous landscapes. Journal of the American Water Resources Association 45:986–997.

APPENDIX A
Summary of stream and lake water temperature monitoring protocols currently used in Alaska

Background

Through the Alaska Online Aquatic Temperature Site (AKOATS) project, Alaska Natural Heritage Program staff began cataloging water temperature monitoring protocols from many resource management and science monitoring organizations across the state. The protocols provide an overview of the data attributes being collected at monitoring sites. We have subsequently added more protocols to our collection and produced this summary chronicling the current state of water temperature monitoring guidance in Alaska. The full report, available upon request, includes a synopsis describing each protocol along with a simple, tabular dashboard to summarize the presence or absence of particular key elements.

Dashboard Key:

Data Logger	**Data Collection**	**Quality Assurance**			**Data Storage**		
Accuracy Range	Sample Frequency Duration	Accuracy Checks	Site Selection	Data Evaluation	File Format	Metadata	Sharing
							
Minimum sensor accuracy and operating range	Minimum sample frequency (XX minutes) and minimum duration to collect data	Are there sensor accuracy check procedures, ice bath, field testing?	Is there guidance for sensor placement within stream or lake?	How are the data checked? Are the data corrected?	How are the data stored? Which format? Can they be exported in simple files?	Does each site have distinct metadata regarding identifier, lat/long coordinates, etc.?	Can the data be shared? Have the raw data been summarized into daily stats (mean, max, min)?

			Data Logger	**Data Collection**	**Quality Assurance**			**Data Storage**		
Source	Title		Accuracy	Sample Frequency	Accuracy Checks	Site Selection	Data Evaluation	File Format	Metadata	Sharing
	Date	Pages	Range	Duration						
CIK UAA	Stream Temp. Data Collection Standards and Protocol for Alaska		+/- 0.25°C	60 minutes	checks at 0°C & 20°C pre and post deployment, field checks	5 cross sectional stream temps	remove data errors	.csv format in 2 locations	unique ID, source agency, contact info, lat/long, datum, freq.	quality-controlled hourly data; compiled daily max, mean, min
	2014	53 pp.	- 4°C to +37°C	minimum 1 month data						
USGS w/ FWS	Guidelines for the Collection of Continuous Stream Water-Temperature Data in Alaska		+/- 0.2°C	recommend 30 minutes, 60 minute max	checks at 0°C and 20°C pre and post deployment	detailed instructions for cross sectional stream temps	excellent instructions for error checking, uses graphic examples	simple suggestion to create a project specific data mngt. plan, no details	no specific attributes are listed, included in data mngt. plan suggestion	recommends data process -ing, daily summary stats, graphs for error checks
	2014	34 pp.		no minimum duration						
NPS SEAN	Southeast Alaska Freshwater WQ Monitoring Protocol		+/- 0.2°C	60 minutes	pre & post season calibration, monthly field checks	sites and sensor placement were carefully selected	data are error checked and cleaned	data stored in .csv form, locally and on IRMA website	thorough metadata standards in IRMA	excellent data access (raw & stats) via SE Network Inv. & Mon. site
	2013	36 pp., +196 pp. SOPs		ice free May-Oct						
NPS ARCN	Shallow Lake Monitoring Protocol Central AK and Arctic Network		+/- 0.2°C	variable frequencies, including 60 minutes	pre & post field season calibration	different siting criteria for lakes: bottom, surface, limnetic zone	data are checked and cleaned, detailed data mngt. plan	data stored SQL/Access but can be exported to .csv format	thorough metadata includes all base attributes	summary stats are compiled for each site
	2011	52 pp. +600 pp. SOPs		ice free May-Sept						

			Data Logger	Data Collection	Quality Assurance			Data Storage		
Agency	Title		Accuracy	Sample Frequency	Accuracy Checks	Site Selection	Data Evaluation	File Format	Metadata	Sharing
	Date	Pages	Range	Duration						
NPS SWAN	Southwest Alaska Freshwater Flow System Monitoring Protocol		+/- 0.2°C	variable frequencies, including 60 minutes	pre & post season calibration	cross sectional channel profiles during high & low flow	data are checked and cleaned, Aquarius time series software	data stored as .csv format and SQL – Aquarius database	thorough metadata includes base attributes, FGDC standards	summary stats are compiled for each site
	2011	74 pp.	–5° to +45°C	ice free May-Sept						
Cook Inlet-keeper	Water Temp Data Logger Protocol for Cook Inlet Salmon Streams		+/- 0.2°C	15 minutes	checks at 0°C & 20°C pre and post deployment	10 cross sectional temps considering high & low flows	data are checked and cleaned by graphing data annually	data are .csv files: entered into EPA's STORET Data Warehouse	basic site metadata attributes are stored for each sensor	daily summary stats are compiled annually for each site
	2008	13 pp.	- 4°C to +37°C	ice free May-Sept						
USGS	Guidelines and Standard Procedures for Continuous Water Quality Monitors		+/- 0.2°C	variable frequencies	pre & post deployment calibration checks plus 3 in-season checks	10-20 cross sectional profiles during high & low flow periods	data are checked and cleaned	data can be exported as .csv format from NWIS database	thorough metadata includes base attributes, FGDC standards	annual and monthly summary stats are compiled for each site
	2006	74 pp.	0°C to +40°C							
USFS	Measuring stream temperature with digital data loggers: a user's guide		Range of accuracy listed	recommend 60 minutes	checks at 0°C & 20°C pre and post deployment	general guidance - re: spatial hetero-geneity	instructions for graphical error screening	database for archiving large set of records	list of attributes: unique ID, source agency, contact info, lat/long, freq.	daily statistical summaries are compiled and weekly stats
	2005	18 pp.	- 4°C to +37°C	minimum 1 month data						

Stream Temperature Data Collection Protocol for Alaska

Table of Contents

Figures

Appendices

BACKGROUND

Water temperature is one of the most significant factors in the health of freshwater ecosystems. Temperature affects primary production, invertebrates, and fish in running waters (Hynes 1970). For salmon specifically, temperature affects survivorship of eggs and fry, rate of respiration and metabolism, timing of migration, resistance to disease and pollution, and availability of oxygen and nutrients (Richter and Kolmes 2005). Due to the critical role that water temperature plays in the function of aquatic ecosystems and because of growing concern about climate and land-use impacts on Alaska's freshwater systems, water temperature data collection has increased in recent years.

Stream temperature data collection is relatively easy with the availability of low cost data loggers with good accuracy and reliability. Continuous data loggers can be deployed across a range of habitat types, programmed to collect data at a variety of intervals, and require little maintenance. As a result, stream temperature data are often collected as part of research and monitoring programs to meet various project-specific objectives. This provides a valuable opportunity to compile and synthesize datasets across agencies and organizations in Alaska to understand broader regional patterns; however, minimum data standards need to be established to ensure data quality and comparability.

This protocol was developed specifically to establish the minimum requirements necessary to make stream temperature data collected across Alaska useful for understanding regional scale patterns and climate related trends. By meeting the minimum standards discussed within, investigators can collect data potentially useful for both project-specific needs and other resources managers and decision makers, now and in the future, thus gaining a greater return on their monitoring investment.

We hope that investigators will consider these minimum standards when developing a monitoring or study plan, and collect comparable stream temperature data that can be useful for other analyses whenever possible. In some cases, more rigorous quality assurance methods or shorter sampling intervals may be necessary. Fortunately, these decisions will not preclude the usefulness of these data for regional analysis as these are only minimum standards. We realize that some project-specific needs, particularly related to sampling location, may not be compatible with these standards and will not result in useful data at a regional scale. Nevertheless, in Alaska, where travel costs can eat up field budgets quickly, voluntary adoption of minimum standards when reasonable will go a long way to help stretch limited research dollars and, most importantly, to generate valuable datasets for understanding thermal patterns across Alaska's vast freshwater ecosystems.

SCOPE

The goals for developing this protocol are to facilitate more stream temperature data collection; reduce the variability of data quality due to disparate sampling methods; and ultimately, to generate more robust datasets to assess regional patterns and climate-related trends in Alaska's freshwater systems. The protocol describes recommendations and minimum standards for the selection, accuracy, placement, maintenance, and retrieval of water temperature data loggers; quality assurance procedures and data management. This information is written for a general audience to encourage broad participation among agencies and organizations throughout Alaska in collecting stream temperature data.

This protocol is not meant to supersede existing agency-specific protocols but instead to provide guidance for entities with an interest in making their data as broadly useful as possible. Tips and recommendations are offered to address Alaska's uniquely challenging conditions including ice movement, high flow events, wildlife tampering and remote access which all need to be considered when establishing a sampling site.

PRE-PLACEMENT PROCEDURES

Developing a Monitoring or Study Plan

It is important to develop a monitoring or study plan before heading to the field. In general, this plan should document:

1. your objectives for collecting data,
2. what specific types of data you will collect,
3. how you will manage and analyze the data,
4. what instruments and other equipment you will use,
5. where, when and how often you will collect data,
6. who will be responsible for collecting the data,
7. how you will assure the quality of the data, and
8. how and with whom you will share the data.

Through the process of answering these questions, you should gain a clear understanding of all that is required of a well-conceived data collection program. The time you invest in the office developing a plan will pay off when you head to the field. You will be able to make more confident decisions about site selection, logger placement and the type of information you should document on site if you have done your homework. And proper planning yields further dividends years after collection when high quality data are available for regional analysis.

Selecting a Data Logger

Temperature data loggers are necessary for collecting continuous temperature data records. The price of temperature data loggers continues to decline while their reliability and ease of use continues to improve. There are many manufacturers and models of data loggers from which to choose (see Appendix A for examples). You need to consider a few factors when selecting a data logger. The following specifications are recommended:

1. submersible, waterproof logger
2. accuracy ±0.25^{o}C ⇐ **MINIMUM STANDARD**

   Accuracy is a measure of confidence that describes how close a measurement is to its "true" value.
3. measurement range -4^{o} to 37^{o}C (24^{o} to 99^{o}F) ⇐ **MINIMUM STANDARD**
4. resolution <0.25^{o}C

   Resolution refers to the smallest detectable increment of measure of a logger and needs to be less than the accuracy range.
5. programmable start time/date
6. user-selectable sampling frequency/interval
7. memory/storage capacity

   A logger's storage capacity must allow you to collect data at your desired sampling interval (i.e. 30 minutes, 1 hour) for as long as you expect to deploy it (i.e. 1 month, 1 year).
8. battery life

   Some loggers have factory replaceable batteries and others have non-replaceable batteries which should last 5 years with typical use. If the logger does not track battery power, be sure to document the logger's use so you know when to take it out of circulation. See Appendix E for an example of a sensor deployment history log.

In addition to the data logger, you will need to purchase the appropriate software and a connector cable from your computer to the data logger. If it is an option, you also may want to buy a shuttle which allows you to download the data in the field. By downloading your data periodically, rather than at the end of the entire sampling period, you reduce the risk of losing significant amounts of data. This is particularly useful if you are concerned about vandalism, high flow events or ice conditions.

***Note: Discrete measurements taken at one moment in time during a site visit with a hand held thermometer or probe are not useful to understand regional trends, although they may be useful for other objectives, including as a quality assurance check on a continuous logger.

Accuracy Checks

It is important to check and document the accuracy of the data logger(s) before and after field deployment. This is a relatively simple procedure and will give you and future users greater confidence in the quality of your data and help prevent the collection of erroneous data. We recommend that loggers go through an accuracy check at least once a year. If you are collecting data for multiple years at a site, you should swap loggers out once a year if possible. Logbooks, data sheets or electronic spreadsheets are highly recommended to keep data logger information organized and easily retrievable. See Appendix E for an example of sensor accuracy check log.

MINIMUM STANDARD ⇒ The accuracy of a temperature data logger must be checked in a water bath at two temperatures: 0^{o}C and 20^{o}C before and after field deployment using a NIST (National Institute of Standards and Technology) traceable (calibrated and maintained) thermometer accurate to ±0.25^{o}C.

***NOTE: NIST-certified thermometers can be liquid-in-glass thermometers or they can be a data logger which has been NIST-certified. In either case it is important to confirm the accuracy of the NIST-certified thermometer is at least ±0.25^{o}C with a resolution of <0.25^{o}C. We recommend a 4-point (0, 10, 20, 30^{o}C) calibration. It is good practice to send your NIST-certified thermometer/logger back to the manufacturer for re-calibration every two years.

To perform an accuracy check, connect the logger to your computer with the appropriate data logger software installed. Program the logger to record data at a short recording interval (1 or 5 minutes work well). Be sure the clock on the computer used to launch the logger and the clock used during the accuracy check procedure are synchronized. For efficiency, we recommend calibrating a group of loggers at the same time.

Once a batch of loggers has been launched (i.e. programmed and started), submerge them in a water bath held at room temperature (approximately 20^{o}C). A second bath should be cooled with ice or cold-packs in a large cooler or other covered and insulated container to get the temperature down to as close to 0^{o}C as possible. Verify that each bath is uniform temperature (mixing may be required). Place the launched loggers in one of the baths long enough to equilibrate to the temperature of the bath (approximately 30 minutes). Make sure each logger's sensor is fully submerged.

After the equilibration period, measure and record water bath temperatures with the NIST-certified thermometer as close to the time the logger is recording a measurement value as possible. If you have a data logger that is NIST-certified, launch this logger at the same short recording interval and place it in the water bath with the loggers you are checking. Take at least 3 measurements. Once the water bath temperature measurements have been recorded, place the loggers in the second bath, allow them to equilibrate, and repeat the process. If your monitoring or study plan requires particular accuracy in a smaller temperature range, you may want to add additional water bath checks at different temperatures.

Once the loggers have been exposed to both temperatures, remove the loggers from the second water bath, connect to your computer and display or download the data. Compare the logger data to the NIST-certified thermometer/logger reading and record both values in your logbook or datasheet. If a reading from a data logger is more than 0.25°C from the NIST-certified thermometer/logger, set this logger aside**. If a logger fails an accuracy check a second time, do not deploy this logger in the field** and contact the manufacturer about returning the logger if it is still under warranty.

Sampling Frequency/Interval

After you have completed the accuracy check procedure, re-launch the logger in preparation for going into the field. Program the logger to collect data at a 1 hour sampling frequency. A 1-hour sampling frequency will ensure you capture the daily range of variability between daily maximum and minimum temperatures at a resolution useful for regional analysis. Set the 1 hour interval to begin on the hour (1:00, 2:00, etc) so you can easily synchronize future quality assurance field measurements with the logger's recording time. You may also set a shorter interval (15 minutes, 30 minutes) if your project-specific objectives warrant it.

MINIMUM STANDARD ⇒ Collect data at a 1 hour sampling frequency.

Sampling Period

We recommend collecting water temperature data year-round as the annual thermal minima may be changing faster than the annual maxima. If your project objectives are to capture the highest annual temperature, loggers should be deployed from June 1 – August 31. If you plan to leave the logger in during the winter, you should give additional consideration to the deployment method and how it will respond to ice conditions. We recommend deploying multiple loggers at a site to increase your chances of recovering year-round data. Loggers can be swapped out mid-year if there are concerns about battery life or storage capacity.

MINIMUM STANDARD ⇒ Collect at least one month (calendar) of data.

PLACEMENT PROCEDURES

Site Selection

The specific stream and reach selected for logger placement are determined by the goals and objectives laid out in your monitoring or study plan. We encourage you to consult the Alaska Online Aquatic Temperature Site (AKOATS, http://aknhp.uaa.alaska.edu/aquatic-ecology/akoats) to determine if your sampling efforts could fill data gaps or if historical datasets exist in your area of interest. This may provide some guidance for sites with reasonable access and point you to a contact person to discuss logistics or potential collaboration. Ease of access should be a major consideration when selecting a site. You will be able to do more quality assurance checks and retrieve data more frequently if you can reach the site without excessive travel costs or safety concerns.

Logger Placement

Once on site, you need to identify a stable location within the reach. Look for a location with uniform depth across the stream channel to reduce the risk of dewatering at different water levels. High velocity habitats, such as those found along the outside bank of a bend or in the deepest part of the active channel, should be avoided to reduce the likelihood of losing a logger during high flow events. Low velocity habitats, like those along the inside of a bend or in backwater pools, should be avoided because sediment deposition may bury the logger. Also avoid areas with evidence of slumping banks or beaver activity. Consider the extent of tidal influence during the highest tides of the year if your reach is near an estuary or the confluence with a large tidally-influenced river. Additional consideration should be given to human activity in the area. If you are near a well-used fishing spot or there is notable foot traffic in the area, you should consider finding a spot that is not obvious to reduce vandalism and accidental snagging. Our recommendation is to deploy two loggers at a site to help reduce the impact of losing data from placing a logger in an unstable location within a reach.

Once you have found a stable location, you need to deploy the logger in a well-mixed section of the stream channel. Places with unique temperature characteristics, such as off-channel habitat, groundwater upwelling areas, or anthropogenic features (e.g. dam or point discharge), should be avoided. Well-mixed waters can often be found in the active channel or the leading edge of a river bend (Figure 1). Shaded sites with moderately turbulent flows tend to make good logger placement spots.

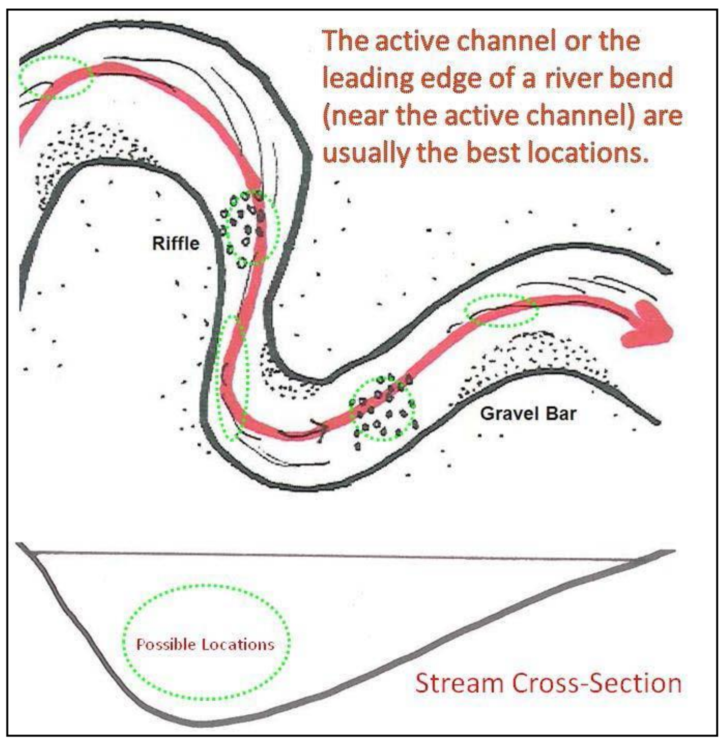


Figure 1. Dashed green circles represent examples of the best locations to place a logger (Ward 2011). The active channel is wetted during and above winter base flows.

MINIMUM STANDARD ⇒ Take five measurements across the stream width with a hand-held thermometer or temperature probe, which has been checked in the lab/office with a NIST-certified thermometer, to verify that the site is well-mixed (i.e. varies ≤ 0.25^{o}C) horizontally and vertically before you deploy the logger.

If a transect is not well-mixed, select another location. Consider moving downstream if you are below a tributary or lake outlet to find more homogenous temperatures. If you are on a large, slow moving river, there may be differences in the surface water temperature and the bottom temperature. The presence of fine sediments creating a mucky bottom is evidence that the water column may be stratified and a significant temperature difference may exist. If you think this may be the case at your site, extra care must be taken to document the vertical stratification of your stream reach. Toohey et al. (2014) and Wagner et al. (2006) provide additional guidance for this situation.

Once you find a location that is well mixed, record these temperature readings on your field data sheet (see documentation section below). We recommend that you take these transect measurements during all your site visits to confirm the site is well-mixed at a variety of flow levels.

***Note: Hand-held thermometers or probes can be purchased from a variety of suppliers (see Appendix A). It may be most cost efficient to buy a multi-probe model that will meet a variety of water quality monitoring needs. For example, a good conductivity probe will also have a temperature probe that may be adequate to do the field checks.

Deployment

If the logger does not come with a protective case, it should be placed in a housing to protect the equipment from natural, wildlife or human disturbance. Housings are simple to make, inexpensive, provide shade for the logger, protect the logger from moving debris, and allow for secure attachment with a cable. Make sure the housing allows for good water circulation past the logger and that the housing and logger's sensor are not in direct contact as the housing may absorb heat. An example of a housing design and the equipment needed to construct one are described in Appendix B.

The choices you make to secure a logger at the site will have the greatest influence on your success in collecting stream temperature data. When selecting your deployment method, be sure to consider how it will work at high and low flows, how much streambed movement there is at the site, and how to prevent people from tripping over rebar, sand bags or cables. If you intend to leave a logger in stream over the winter, you need to consider how ice movement might destabilize the anchoring method. If you are working in a new location and do not have a good understanding of how much the stream bed moves in high flows or what the ice movement is in the spring, consider deploying two loggers using different anchoring methods to see what works best. Methods for securing a data logger are described in Appendix C.

Considering the high cost of travel and logistics compared to the relatively low cost of equipment, we recommend deploying at least two data loggers at a site. It is possible that you might lose both loggers due to high flows or ice movement, but less likely that you would end up with no data due to tampering, logger failure, or poor deployment placement. In addition, the second logger provides an excellent source of data quality assurance.

Documentation

In a write-in-the-rain field notebook or deployment data sheet, record a thorough description for each site to help ensure the logger(s) can be relocated and to account for factors that influence water temperature. The site description should, at a minimum, include water body name, latitude and longitude, datum, a site map, photographs of the site (upstream, downstream, and across the channel), instantaneous water temperature, date and time of the actual placement, and logger(s) serial number. Directions to the site from relatively permanent landmarks should be recorded. See Appendix E for an example of a deployment data sheet.

Depending on the objectives of your data collection effort, additional measurements or observations may be useful for interpreting stream temperature data. Parameters that can influence temperature measurements include, but are not limited to, water depth, water velocity, stream discharge, channel width, solar input, distance from the stream bank, overhead cover, and air temperature. You should consider measuring these parameters if they are relevant to your monitoring objectives.

***Note: Air temperature data collection is beyond the scope of this protocol; however, investigators often utilize the relationship between water temperature and air temperature to predict future changes in stream temperature. Consequently, if and where to collect air temperature data are common concerns. Airport weather stations and SNOTEL sites are good places to start to see if air temperature data are being collected near your water temperature site. Air temperature data collected from coastal locations may be strongly influenced by coastal processes and thus not be a good data source for watershed patterns. If understanding the relationship between air and water temperatures is important for your project-specific objectives, we recommend collecting a year of air data near your water logger to compare with other data sources. This will help you determine if you should continue to collect air temperature data in conjunction with your water temperature data collection. Air temperature can be collected with the same loggers used to collect water temperature; however they must be secured within a solar shield. The solar shield and logger should be attached to a post or suspended from vegetation at least 6 feet off of the ground and 50 - 100 feet away from the stream so that air cooled by the stream does not influence your air temperature data.

Maintenance of Logger Installation

Whenever feasible, it is recommended to visit the site monthly to make a quality assurance check and any needed maintenance to the housing or deployment equipment. A field visit is especially important if high flow conditions have occurred since deployment. When a visit is made, record the date, time, and instantaneous water temperature. Take the water temperature measurement within a few minutes of an expected logger temperature reading as a logger validation check. Use a hand-held thermometer or temperature probe that has been checked in the lab/office with a NIST thermometer. Verify the site is still well mixed by recording 5 measurements across the stream channel. Check the security of the housing and deployment equipment and adjust if necessary. Remove debris or sediment buildup. Record and photograph any land-use or habitat changes that are relevant. See Appendix E for an example of a quality assurance and maintenance check data sheet.

RETRIEVAL PROCEDURES

When you arrive at the site to retrieve the logger(s), document the condition of the site and the logger. Record whether each logger is still in the water and any signs of vandalism or disturbance. Also, perform one more quality assurance check and record the date, time, and instantaneous water temperature at the time of retrieval. If you are swapping out a logger with a new one and time allows, get at least one overlapping reading with both loggers in the stream. If you are not deploying another logger at this location, remove all equipment from the site including rebar, cables or sandbags from the stream channel.

DATA HANDLING PROCEDURES

Download Data

Depending on the type of logger used, data may be downloaded periodically in the field with a shuttle or you may need to remove the data logger from the site and connect it to your office computer. The temperature data logger should be gently wiped to remove any biofilm or sediment that may affect its ability to communicate. The logger should then be connected and downloaded using the manufacturer's procedures for the data logger type.

Once the data have been downloaded by the data logger software package, we recommend you export the data into a spreadsheet file format (e.g., Microsoft Excel). This will allow for greater data evaluation, management, and sharing. You should also save the file in a universal (i.e. non-software specific) format such as a .csv file as a backup to avoid future software upgrades preventing you from opening older spreadsheet file versions.

Quality Control

It is important to verify and document the accuracy of a data logger after field deployment. Follow the same procedures described in the 'Accuracy Checks' section above. If a temperature logger fails a post-deployment accuracy check (i.e. water bath reading is greater than 0.25°C from the NIST), then another accuracy check must be performed. **If the logger fails an accuracy check a second time, do not re-deploy this logger.** Field data collected using this logger needs to be carefully evaluated. The raw data should be checked against the instantaneous temperature measurements taken during maintenance site visits to see if there is any evidence that the logger accuracy drifted since the pre-deployment accuracy check. If site visit measurements do not meet the accuracy goal of ±0.25°C, these data do not meet the minimum standards for regional analysis. Document this accuracy failure prominently.

Data Evaluation

After you have successfully completed the post-deployment accuracy check on a logger, you need to further evaluate the field collected temperature data. The following steps will give you and future users' confidence in the validity of the data and prevent erroneous data from being summarized and reported.

- Delete temperature data collected before or after the deployment period since the data logger is recording air temperature data (Figure 2). Field notes from the deployment and retrieval events will provide the dates and times necessary to identify the deployment period.
- Compare instantaneous temperature measurements collected during maintenance checks to the data logger measurements to confirm you have met the accuracy goal of ±0.25°C.
- Graph the data to identify anomalous data that might result from the data logger not being submerged (Figure 3) or being buried in soft sediment (Figure 4).

Sowder and Steel (2012) and Toohey et al. (2014) provide additional examples of visual checks for anomalous data, including when a logger becomes encased in ice.

MINIMUM STANDARD ⇒ Remove erroneous data from dataset.

Once you have documented and removed erroneous data, your 'final', cleaned dataset needs to be packaged for sharing and storage.

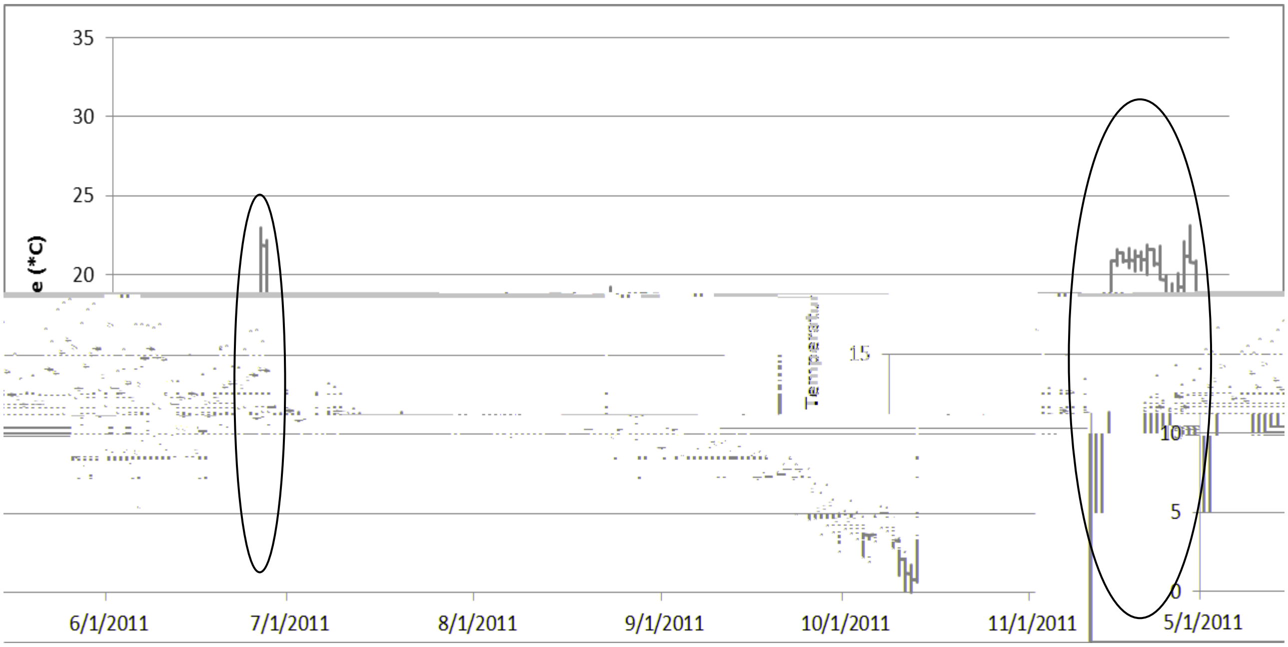


Figure 2. Example of raw water temperature dataset with air temperature data collected before and after the deployment period (circled).

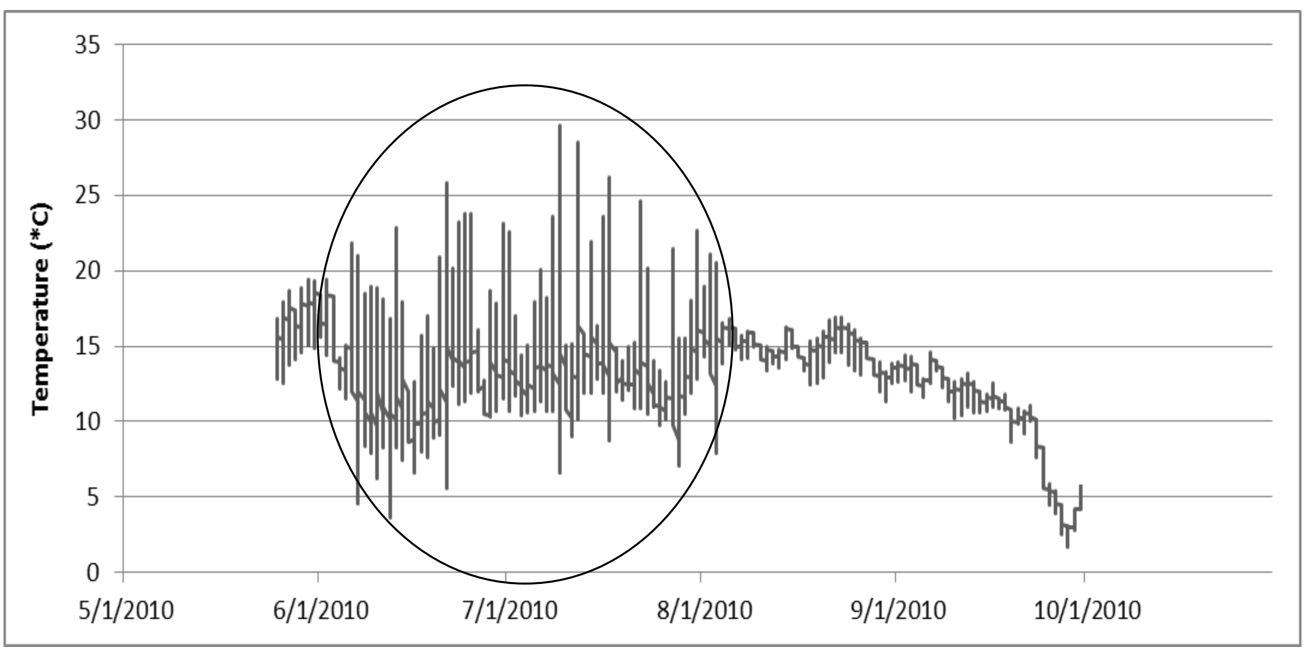


Figure 3. Example of raw water temperature dataset with air temperature collected due to the logger getting caught up on a stream bank for a good period of time (circled).

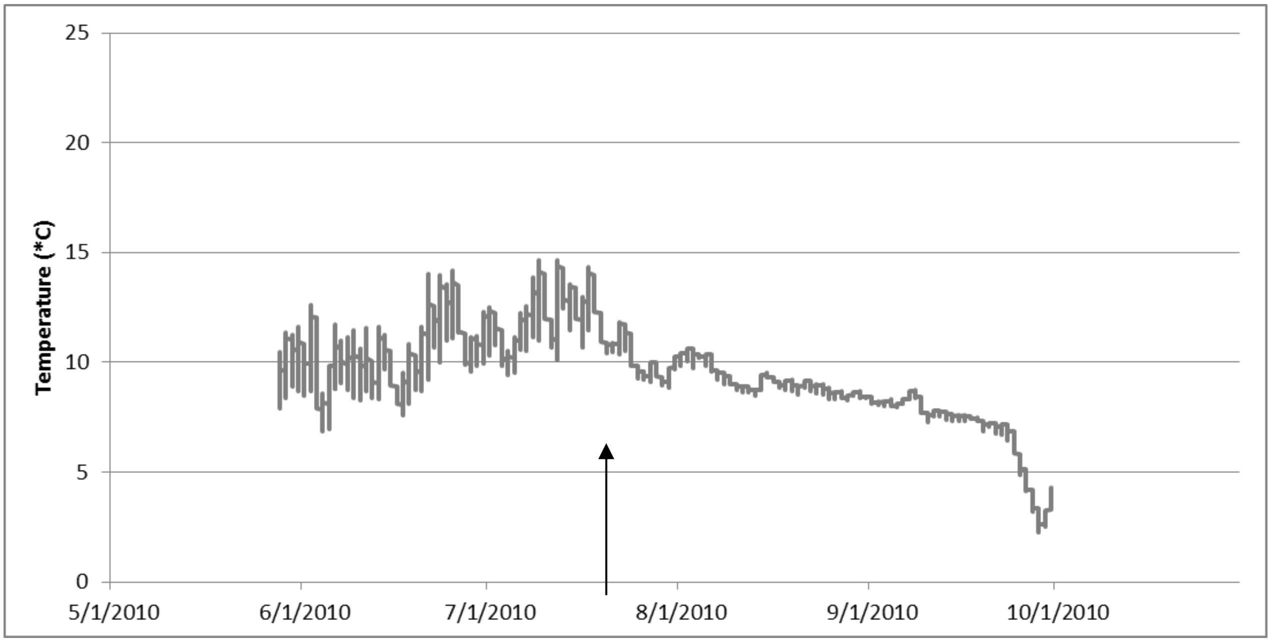


Figure 4. Example of raw water temperature dataset with a noticeable change in the daily temperature range due to burial of the logger in soft sediments.

Data Sharing

The minimum standard for sharing data is quality-controlled hourly data, which provides the information needed to characterize all aspects of a stream's thermal regime. We do recommend summarizing your data into daily maximum, mean and minimum values even if this is not a project-specific need. Taking this additional data handling step may reveal anomalous data not found during data evaluation, and from these values a wide variety of other metrics can be calculated depending on future users' needs. Additionally, having the daily values available will make data requests a welcome opportunity for data sharing and not an untimely, onerous future request. Daily summary statistics should only be calculated for quality controlled data with at least 90% of daily measurements (e.g. 22 hourly measurements).

MINIMUM STANDARD ⇒ Make water temperature data available as quality-controlled hourly data.

Data Storage

The investment of resources to purchase, deploy and retrieve loggers, and then process the data deserves reasonable measures to insure against inadvertent losses. Water temperature data should be stored in a digital table format that is software neutral, such as comma separated values (.csv) file format. Data managers should make backup copies of the 'final' and daily data and store this information on a separate computer, preferably at an alternate physical location. Additionally, data and associated metadata (see below) need to be stored in at least two locations, with one of those locations being publicly accessible. Data files should be named so that their content is recognizable such as with a unique site number or name coupled with year(s) of the dataset (e.g., Site047_2014.csv or AnchorRiver_2012_2013_daily.csv).

In addition, metadata must be stored with the temperature data files. Metadata is the 'data about the data' or the how, when, and by whom a particular set of data was collected. Metadata can be a single table describing all of your temperature monitoring locations which could be linked to the data files via a unique site identifier or you can keep separate metadata files for each site. See Appendix D for metadata guidelines. We strongly encourage investigators to submit project metadata to AK-OATS (http://aknhp.uaa.alaska.edu/aquatic-ecology/akoats/).

MINIMUM STANDARD ⇒ Store temperature data and associated metadata in .csv format in two locations. Metadata shall include the following attributes: unique site identifier, data source agency or organization name and contact information, datum, latitude, longitude, and sampling frequency.

LITERATURE CITED

Hynes, H.B.N. 1970. The Ecology of Running Waters. University of Toronto Press. 555 p.

Richter A. and S.A Kolmes. 2005. Maximum temperature limits for chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science, 13:23-49.

Sowder, C., and E. A. Steel. 2012. A note on the collection and cleaning of water temperature data. Water 4:597–606.

Toohey, R. C., E. G. Neal, and G. L. Solin. 2014. Guidelines for the collection of continuous stream water-temperature data in Alaska. Page 37. Reston, Virginia.

U.S. EPA. 2013. Best practice for continuous monitoring of temperature and flow in wadeable streams. Page 123. Washington DC.

Wagner, R. J., R. W. Boulger, C. J. Oblinger, and B. A. Smith. 2006. Guidelines and standard procedures for continuous water-quality monitors: station operation, record computation, and data reporting. Page 96. Reston, Virginia.

Ward, W. 2011. Standard operating procedures for continuous temperature monitoring of fresh water rivers and streams. Washington State Department of Ecology.

APPENDIX A
Additional Resources

1. Examples of data logger models that meet minimum standards:
   TidbiT v2, HOBO Pro v2
      Onset Computer Corporation, 800.LOGGERS, www.onsetcomp.com
   YSI 6920 V2 sonde
      YSI Incorporated, 800.765.4974, www.ysi.com
   Levelogger Edge
      Solinst Canada Ltd., 800.561.9081, www.solinst.com

2. Learn more about National Institute of Standards and Technology (NIST): www.nist.gov

3. Examples of NIST-certified thermometer/logger and hand-held field thermometer suppliers:
   Thomas Scientific, 800.345.2100, www.thomassci.com
   Cole-Parmer, 800.323.4340, www.coleparmer.com
   Onset Computer Corporation, 800.LOGGERS, www.onsetcomp.com
   Hanna Instruments, 800.426.6287, www.hannainst.com
   HACH Company, 800.227.4224, www.hach.com

4. Natural Resources Conservation Service's SNOTEL sites
   NRCS installs, operates and maintains an extensive, automated system call SNOTEL (short for Snow Telemetry). SNOTEL is designed to collect snowpack and related climatic data in the Western U.S. and Alaska.
   http://www.wcc.nrcs.usda.gov/snow/about.html

5. NOAA's National Climate Data Center
   NCDC is responsible for preserving, monitoring, assessing, and providing public access to the Nation's treasure of climate and historical weather data and information.
   http://www.ncdc.noaa.gov/

6. Scenarios Network for Alaska & Arctic Planning
   SNAP develops plausible scenarios of future conditions through a diverse and varied network of people and organizations, which allow better planning for the uncertain future of Alaska and the Arctic.
   http://www.snap.uaf.edu/

APPENDIX B

Housing Construction

PVC housings are very simple to make, inexpensive ($10-15), provide shade for the logger, protect the logger from moving debris, and provide for secure attachment with a cable.

The data logger is suspended in a PVC pipe that allows stream water to flow through but prevents solar radiation to penetrate. Black PVC provides more camouflage than white PVC for sites where vandalism is a concern. In clear water streams heat absorption by the dark surface may be an issue; if there is no shading from the stream-side vegetation, we recommend white PVC.

Here's a supply list to make the housings:

2” Sch 40 ABS pipe (1' length)
2” DWV clean out plug (2)
2” DWV female adaptor (2)
3/8”x 4” ZC eye bolt (1)
8” cable ties
Multi-purpose cement
Assorted nuts and bolts
Drill and 3/8” and 1/4” drill bit

Glue the female adapters to each end of the PVC pipe. Drill a 3/8” hole through one clean out plug for the eyebolt to go through. Secure the eye bolt through the clean out plug with appropriate-sized nuts and bolts. Drill at least 20, 1/4” holes in the PVC to allow water flow. Use a cable tie through drilled holes to suspend the data logger in the housing. Additional cable ties can be used to secure rocks in the bottom of the housing to weigh it down. Screw the clean out plugs into the female adapters.

APPENDIX C
Deployment Methods

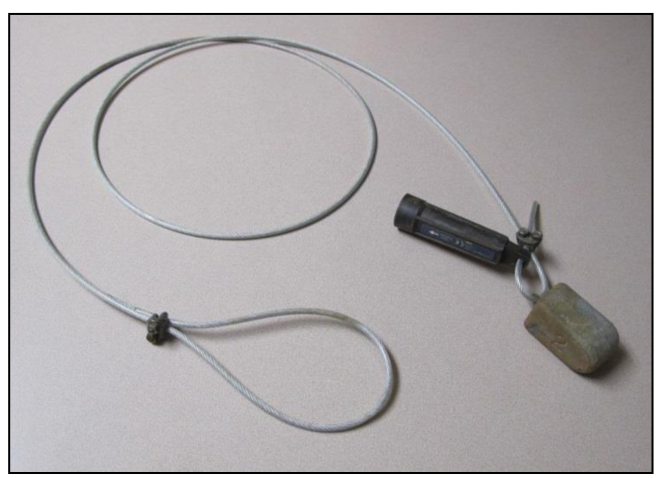
Rebar or Duckbill Method

This method is preferred for streams with moderate movement of the streambed during high flows. The protective case or PVC housing is attached by a cable to a rebar or to a duckbill earth anchor. Use a stake pounder to sink the rebar down about 3 feet or to drive the duckbill into the stream bottom near a large rock or other landmark.

Stream Bank-Secured Cable Method

This method is preferred for streams with significant movement of the streambed during high flows. In this method the logger in its protective case or PVC housing is secured to the stream bank vegetation using plastic-coated wire rope.

The logger and something like a 2-pound halibut weight are secured to the wire rope using a wire rope clip. Upon deployment the cable is wrapped around a large tree, rocks, bridge supports, or other secure object within or on the stream bank. The logger is then placed within the stream channel. The cable should be hidden under bank vegetation to avoid vandalism or accidental disturbance. Try to avoid locations where the cable will cross active fishing or wildlife trails.



Sand Bag Method

This method is preferred <u>only</u> for streams with minimal movement of the streambed during high flow events. Sturdy sand bags can be purchased at most hardware stores. Fill the bag on site with any mineral material (large rocks, cobbles or sand). Avoid organic material which is often buoyant. The logger, in its protective case or PVC housing, can be attached to the bag by weaving a cable tie through the mesh. The bag can be tied off with a rope to the stream bank for extra security. The rope should be hidden under bank vegetation to avoid vandalism or accidental disturbance. Try to avoid locations where the rope will cross active fishing or wildlife trails.

Epoxy Method

This method requires the presence of a large rock or bridge support on site to attach the epoxy. See http://www.fs.fed.us/rm/pubs/rmrs_gtr314.pdf for a complete description.

Isaak, Daniel J.; Horan, Dona L.; and Wollrab, Sherry P. 2013. A simple protocol using underwa-ter epoxy to install annual temperature monitoring sites in rivers and streams. Gen. Tech. Rep. RMRS-GTR-314. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 21 p.

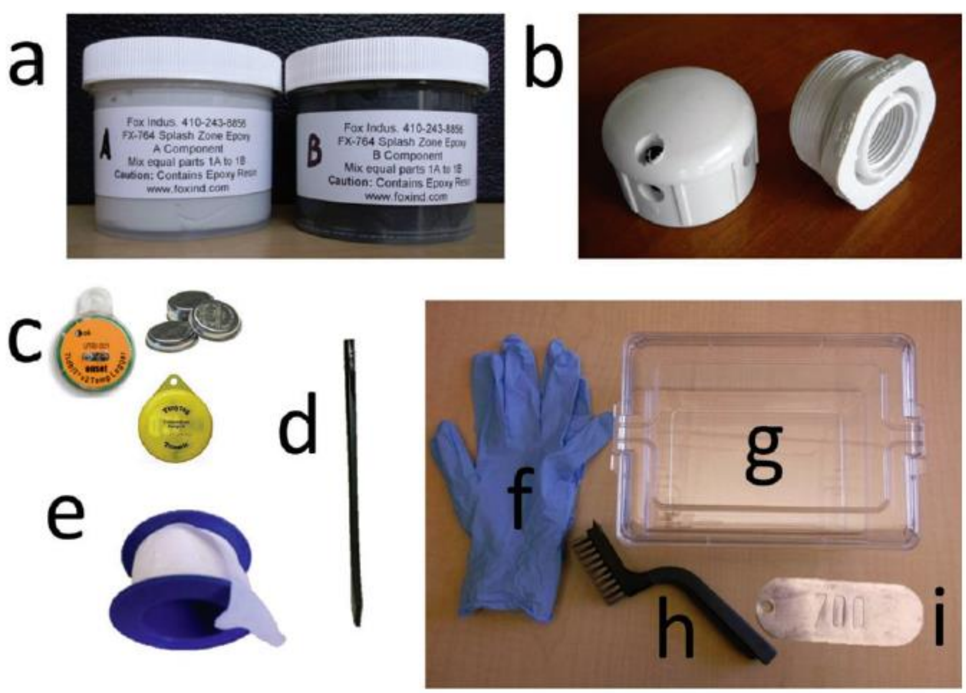


Figure 2—Equipment needed to install annual stream temperature monitoring sites includes: (a) two-part FX-764 epoxy from Fox Industries, (b) PVC canister solar shield, (c) temperature sensors, (d) cable tie, (e) plumber's tape, (f) rubber gloves, (g) plastic viewing box, (h) wire brush, and (i) metal forestry tag.

APPENDIX D
Metadata Guidelines

Using common metadata will allow researchers to quickly assess monitoring data from various sources to determine which might be appropriate for a given project. Regional scale water temperature analyses will require scientists to use data from numerous sensors sourced from many agencies. The researchers' understanding of data sources will be based upon sensors sharing common metadata attributes and formats.

Here is an example of the data fields and formats that serve as the core AKOATS metadata elements.

WHO			**WHERE**			**WHAT**	**WHEN**			
Site ID	**Source Name**[1]	**Contact**	**Datum**	**Lat**	**Long**	**Type**	**Start Date**[3]	**End Date**	**Status**	**Sample frequency**
Unique site identifier from source agency	Data Source agency or organization using ADIwg[2] list and naming conventions of organizations (n=105 groups)	Name of key contact person for data source agency	Horizontal reference point for various coordinate systems	Sensor Latitude (decimal degrees)	Sensor Longitude (decimal degrees)	Water-body type: S = stream L= lake	Initial date of data collection	Final date of data collection	Sensor operational status using ADIwg domain list[4]	Time (minutes) between temperature recordings
Anchor River	CIK	Sue Mauger	WGS84	59.77300	-151.83400	S	06/01/2008	09/30/2014	On-Going	15
mutsk02	uaaAKNHP	Dan Bogan	WGS84	59.81700	-155.76492	S	06/15/2013	09/25/2014	On-Going	60
kdk_karlk01	fwsakKodiakNWR	Bill Pyle	NAD83	57.35424	-154.03836	L	09/10/2011	09/30/2014	On-Going	60

[1] Note: complete set of agency source names available via the AKOATS project website
[2] ADIwg – Alaska Data Integration Working Group
[3] DD/MM/YYYY format
[4] Completed, On-Going, Planned

APPENDIX E
Data Sheet Templates

Sensor Accuracy Check Log
Sensor Deployment History Log
Deployment Data Sheet
Quality Assurance/Maintenance Check

Sensor Accuracy Check Log

Serial # ______________________ Logger Manufacturer/Type______________________

Pre-Deployment Accuracy Check							Post-Deployment Accuracy Check						
Date	Time	Logger Temp Reading	NIST Temp Reading	Difference (Logger – NIST)	Pass? < ±0.25°C from NIST	Performed by:	Date	Time	Logger Temp Reading	NIST Temp Reading	Difference (Logger – NIST)	Pass? < ±0.25°C from NIST	Performed by:

Sensor Deployment History Log

Serial # ________________________ Logger Manufacturer/Type_________________________ Purchase Date _____________________

Pre-deployment accuracy check (Y/N)	Launch date	Battery level	Deployment		Location/ Site ID	Retrieval		Data download date	Battery Level:	Post-deployment accuracy check (Y/N)	Data evaluation completed	
			Date	Time		Date	Time				Date	By

WATER TEMPERATURE DATA COLLECTION

Deployment Data Sheet

Stream Information

Stream Name: ____Site ID:_______________________

Field Crew: ____

Agency/Organization: ____

Directions to Site: ____

____

____

Water Logger Information

Sampling frequency: ______________________

Logger Type: ________________________________

Date placed in stream: _____________________

Serial #: ________________________________

Time placed in stream: _____________________

Instantaneous water temperature: _______________

Time of measurement: _____________________

Air Logger Information (if applicable)

Logger Type: ________________________________

Date placed in riparian zone: ________________

Serial #: ________________________________

Time placed in riparian zone: ________________

Instantaneous air temperature: __________________

Time of measurement: _____________________

Site/Reach Information

Verified site is well mixed? yes/no Instrument used: ______________________________________

Transect Measurements (left to right): ________ ________ ________ ________ ________

Site represents: channel upwelling tributary lake outlet point source

Habitat type of water logger placement: riffle pool run other ____________

Deployment method: rebar in stream bank-secured cable sandbag epoxy other ____________

Channel depth (m): _________ Channel width (m): __________ Elevation (m): _________________

Channel flow status: 100 – 90% filled 90-75% filled 75-50% filled <50% filled

GPS: Datum: ___________ N _____________________Latitude W ________________________Longitude

Stream name____ Date: ______________________________

Photo Documentation

Camera used: __________________________ Total # of photos taken: ____________________________

Description of photos:

Detailed sketch of site should include stream aspect, landmarks like large boulders or other markers to help locate the loggers, trails or other access points.

Other Comments/Observations:

____

____

____

____

____

WATER TEMPERATURE DATA COLLECTION

Quality Assurance/Maintenance Check Data Sheet

Tip: Bring a COPY of the original deployment data sheet and photos with you to locate the logger.

Stream Information

Stream Name: ____ Site ID:_______________________

Field Crew: ____

Agency/Organization: ____

Quality Assurance Check:

Verified site is well mixed? yes/no Instrument used: ______________________________________

Transect Measurements (left to right): ________ ________ ________ ________ ________

Water Logger

Serial #: ______________________________ Sampling frequency: _____________________________

Date: ___________________ Time: ________________ QA water temperature: ________________

Instrument used to take measurements: _______________________ Checked against a NIST?: yes/no

Logger retrieved? Yes/no If yes, Time: ________________

New logger deployed? Yes/no If yes, Time: ________________ Serial #: _______________________

Air Logger (if applicable)

Serial #: ______________________________ Sampling frequency: _____________________________

Date: ___________________ Time: ________________ QA water temperature: ________________

Instrument used to take measurements: _______________________ Checked against a NIST?: yes/no

Maintenance Check:

Remove any debris from the rebar or cable; rinse out any accumulated sediment in the housing, check the cable or wire for signs of wear. Note any sensor fouling, burial or exposure that may have affected temperature readings; signs of vandalism, describe photographs taken or other relevant comments:

____

____

____