The Central Alaska Network Flowing Waters Program: A Multi-tiered Approach to Ecological Monitoring in Alaskan National Parks

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This study is part of the National Park Service Inventory and Monitoring (Vital Signs) Program for the Central Alaska Network (CAKN). Climate change and other anthropogenic impacts can be expected to have a dramatic effect on CAKN freshwater ecosystems; the streams and rivers portion of the Vital Signs program is designed to detect trends in the status of important components of lotic (moving water) ecosystems. These include hydrologic regime, geomorphology, water quality, and the distribution and abundance of freshwater fish, benthic macroinvertebrate, and diatom species. Fundamentally, the goal is to develop a logistically feasible, repeatable, and scientifically robust monitoring program. To the extent possible, we intend to incorporate indicators, data and methods developed as part of the Denali Long Term Ecological Monitoring (LTEM) program.

The Central Alaska Network consists of 3 park units—Denali National Park and Preserve (DNPP), Wrangell-St. Elias National Park and Preserve (WSENPP) and Yukon-Charley Rivers National Preserve (YCRNP). Together these parks cover approximately 21.7 million acres (34,000 square miles) of land, which is about the size of the state of Indiana. In fact, if the CAKN were a state, it would be the 39th largest state in terms of area. This network constitutes 26% of land in the National Park Service (NPS) system, and is nearly 80% as large as all NPS land in the lower 48 states combined. Nearly 12 million acres of the network is designated wilderness, and a substantial portion of the rest is wilderness quality. There are an estimated 28,000 miles of streams and rivers flowing through the network. A lack of high-quality hydrologic data makes it difficult to obtain accurate numbers at this time. However, based on these estimates, the CAKN contains nearly one-third of all stream miles in the national park system. Based on an average sampling reach of 250 meters and a sampling frequency of 40 reaches per year, it would take approximately 4600 years to sample the entire system.

These inherent challenges are exacerbated by the remoteness of most of the network, and a paucity of data. There are fewer than 200 miles of roads in the network, meaning that the vast majority of sites can only be reached by helicopter. Currently, there are no active stream gages in the network, and almost no historical flow data. With some limited exceptions, there are few other extant data, either biological or physicochemical. For example, prior to the start of the CAKN Flowing Waters program, there were no data on the distribution of benthic diatoms, a key component of stream and river ecosystems.

Like streams everywhere, the characteristics and dynamics of stream ecosystems in the CAKN are influenced at a variety of spatial and temporal scales by physical, chemical, meteorological, and biological phenomena. Factors such as basin geology, topography, climate, and terrestrial vegetation community composition are nearly universal drivers of stream ecosystem structure and dynamics. Other determinants include flow regime (hydrology), habitat structure (geomorphology), temperature regime, and water chemistry. These in turn constrain ecosystem characteristics such as nutrient dynamics, primary productivity, organic matter decomposition, and ultimately biodiversity.

Due to the extreme climate that characterizes arctic and subarctic regions, the streams of the CAKN are substantially affected by extreme winters, glaciation, and permafrost. These differences present unique challenges, and an important opportunity to document the expected dramatic alterations in these systems in response to climate change. Melting permafrost can be expected to have a substantial effect on nutrient concentrations and transport, as well as on hydrologic regime, and connectivity between lakes and streams within catchments. The extent of glaciation within stream and river basins has a profound influence on all aspects of lotic ecosystems. Glacially-dominated streams tend to be highly dynamic and extensively braided, with a hydrograph that is characterized by extreme diurnal fluctuations in the summer months. Ongoing climate warming can be expected to alter these systems dramatically as glacial melting accelerates, the melting season increases in length, and glaciers continue to retreat. Another potentially damaging effect of climate warming is invasion by exotic species. To date, exotic species are not thought to be a problem for aquatic ecosystems in most of Alaska. However, we can expect northward migration of exotics to increase in the near future. Examples include whirling disease, and New Zealand mud snails. Furthermore, there is some evidence that nuisance blooms of the native diatom *Didymosphenia geminata* are increasing in scope and frequency already, a phenomenon that has been attributed (in other areas) to climate warming.

In addition to ecosystem perturbations related to climate change, other anthropogenic stressors are also expected to impact stream ecosystems in the CAKN. For example, atmospheric deposition of contaminants originating outside the parks is likely to become more important in coming years. Two airborne contaminants of special concern are nitrate, which can have substantial effects on stream nutrient dynamics, and mercury, which after methylation can bioaccumulate to very high levels in aquatic food webs.

Although they are currently less of an issue for Alaskan wilderness parks, local-scale stressors such as increased visitation, infrastructure development, resource extraction, and the accidental or purposeful introduction of exotic species (for example, Atlantic salmon). The CAKN flowing water monitoring program is designed to capture the effects of these and other potential changes on important aspects of stream ecosystem structure and function. More specifically, the overall goals of the program are to describe the current status of stream ecosystems in the CAKN and to detect decadal-scale trends in ecosystem condition, landscape context, instream biodiversity, hydrology (flow regime), channel characteristics (geomorphology), water chemistry, and temperature regime. A related goal is to provide a robust methodology for park management to use to evaluate water quality at specific sites of management concern.

A major focus of the program will be on the use of biological indicators to estimate ecosystem condition, and to detect changes in that condition over time. Biological indicators of ecosystem condition generally consist of various metrics that singly or together describe important aspects of biological communities. Biological indicators for streams typically are derived from metrics that describe either aquatic macroinvertebrate, benthic diatom, or freshwater fish communities, either singly or in combination. For example, indicator metrics may describe overall species composition, trophic structure, physiological condition, or the presence of sensitive taxa. The primary advantage of biological indicators is that they integrate the effects of ecosystem stressors over both space and time. Stream ecosystems typically exhibit a great deal of spatial and temporal variability, making them difficult to describe accurately based on physical or chemical data collected in a single visit. The biota, however, respond to and integrate the effects of these changes because resident organisms are exposed to them continuously over the course of their lifetimes. Moreover, different communities respond at different spatial and temporal scales. For example, benthic diatoms turn over rapidly and hence tend to respond to relatively short-term effects, whereas aquatic macroinvertebrate larvae may live for months to years and hence respond over longer time scales. In recent years, biological indicators have become commonly as tools for water quality assessment. Such biological assessment methods are thought to more accurately reflect overall water quality than traditional approaches that rely on water chemistry. A major goal of the CAKN streams program, therefore, will be to use biological indicators not only to assess overall status and trends in stream ecosystem condition, but also to develop robust bioassessment tools that park managers can use to address specific water quality issues.

Currently, we are evaluating a variety of physical, chemical, and biological metrics to detect ecosystem change in CAKN streams. These include the following: remotely sensed imagery; instantaneous discharge measurements; spherical panoramic photography; detailed habitat surveys; water chemistry sampling (field and lab); fish presence, physiological condition, and tissue contamination; macroinvertebrate species composition and abundance; and benthic diatom species composition, chlorophyll content, and abundance. In addition, we hope to institute a program of continuous data collection of stage height, temperature, and water chemistry at a subset of sampled sites.

Perhaps the most critical aspect of the program is determining where and when we will sample. In order to detect "real" trends, we need to account for natural variability of what we are measuring. This variability may be spatial, temporal, or more commonly, both. This is particularly the case for streams, which are exceptionally variable and dynamic ecosystems in both space and time. Survey design can help to account for some of this variation. For example, the use of a small number of sentinel sites (that are sampled frequently) can eliminate the effects of spatial variability, and result in increased power to detect trends. However, this approach sacrifices inference to unsampled sites, both because of the small number of sites sampled and, more importantly, because sentinel sites are typically chosen for accessibility (i.e., they constitute a judgment sample). Conversely, we obtain maximal spatial inference with a probabilistic survey of many sites. However, given the cost of accessing remote locations, there will typically be a relatively small number of sites sampled each year, and hence a long return interval for each site. This results in a greatly reduced ability to quantify temporal variability and hence to detect trends. In an area the size of the CAKN, it might easily take many decades to begin to detect trends with any degree of confidence.

To address these challenges, the CAKN program is combining these approaches into a multi-tiered survey design. The survey design consists of three types of sites. We will sample a moderate number of sentinel sites. These will be selected by accessibility (a judgment sample), and will be sampled annually for an increased sensitivity to trends. We will also sample a large number of "synoptic" sites. These will be sampled on a long return interval (a relatively small number will be sampled each year). The synoptic sites will be selected using a probabilistic approach (using the generalized random tessellation stratified, or GRTS, algorithm) to increase inference to unsampled sites. The GRTS algorithm generates a probabilistic sample of potential study sites that is spatially balanced. In addition, any consecutive subset of sites on the resulting list is also a spatially balanced sample. This has obvious advantages when the costs of site access are high. The GRTS sample can also be stratified and weighted by relevant criteria. For the CAKN program, the GRTS sample was stratified by accessibility (based on a GIS layer representing cost of access), and unequally weighted by stream size to maximize the proportion of streams in the final sample that would be wadeable.

Finally, we will designate a very small number of intensively monitored sites. These sites, a subset of the sentinel sites, will be sampled multiple times each year. At these sites we will collect many types of data continuously (e.g., temperature, discharge, precipitation, water chemistry) to provide more insight into diel (daily) and seasonal dynamics. We will also collect more types of data at these sites (e.g., permafrost active layer depth, precipitation) to provide a more robust platform for the development of both explanatory and predictive ecosystem models. These models will facilitate the interpretation of data collected at the synoptic and sentinel sites and provide a basis for the development of predictive hypotheses that may allow more focused data collection. The data collected at the synoptic and sentinel sites will, in turn, allow us to both calibrate and evaluate the models that we construct.

We are currently in the early stages of implementing this approach. To date we have established 19 sentinel sites in 2 park units (DNPP and WSENPP). We have also generated a GRTS sample for WSENPP that is in the process of being evaluated. The initial GRTS sample consisted of 400 potential study sites, 200 in each of the 2 accessibility strata. Although the goal was a final list of 100 sites, we selected 300 oversample sites to account for the likelihood that many sites would not be sampleable. Accessibility was defined largely by the probability that a helicopter would be required to access the site. Each sample was weighted to ensure overrepresentation of second- and third-order streams; stream order is an imperfect surrogate for stream size, but is much more easily extracted from spatial data for large numbers of sites than better surrogates, such as upstream contributing area. Of these 400 sites, 23% were eliminated as unsampleable using remotely sensed data. 115 of the remaining 307 sites were evaluated by helicopter overflights in 2008. Of these 115 sites, 66% were determined to be unsampleable or probably unsampleable, leaving a maximum of 34% that we expect to be able to sampleable. Based on these numbers, we should be able to generate a final list of 100 sites. In 2009, we will be attempting to formally implement the GRTS survey in WSENPP. We hope to expand the program to include a GRTS sample of DNPP in 2010 and YCRNP in 2011.