The Terrestrial Environmental Observation Network (TEON): Objectives and Implementation

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NOTE: The content of this document is identical to the version included in the Arctic Landscape Conservation Cooperative's Draft Strategic Science Plan.

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1. Summary

One of the greatest challenges facing arctic scientists and land managers is the establishment and maintenance of long-term environmental observation networks. Most networks are designed and implemented to support short-term, local objectives and are typically discontinued at the end of the project. Over the last decade, Arctic science plans and scoping documents have emphasized the need to establish and maintain a network of persistent observation sites (Brabets 1996, Vörösmarty et al. 2001, SEARCH 2005, Martin et al. 2009, AON 2010, Streever et al. 2011, IARPC 2012, UNEP, 2012). Ideal observation sites provide frequent, synchronous measurements of physical, chemical, and biological attributes that are uplinked to a central data portal. As of yet, very little progress has been made to organize observing activities in northern Alaska into a coherent, consistent network. For the first time, the Arctic Landscape Conservation Cooperative (Arctic LCC) has the collective interagency capacity to design, implement and support a Terrestrial Environmental Observation Network (TEON) that fills this longstanding gap. The Arctic LCC has the unique capacity to coordinate a broad array of science teams and unify the array of disparate of observation stations into one entity. In data-poor regions, new installations have become more feasible due to the decreasing cost and increasing rigor of environmental sensors and communication platforms. The proposed TEON network can remedy issues faced in previous attempts at creating a network by explicitly meeting the following criteria:

- The network of sites are responsive to the collective needs of a diverse suite of federal, state, academic and industrial stakeholders working in the Arctic LCC domain.
- Individual sites are broadly distributed, and characterize the spatial and temporal variability in bio-physical conditions. Replication within ecoregions supports inter-site comparisons.
- Site are selected which minimize the cost of installation, operation, access and maintenance while maximizing the representativeness of the network and continuance of existing data archives.
- Parameters measured and protocols used, are consistent among sites and include a common suite of variables relevant to diverse users (hydrology, meteorology, permafrost, etc.).
- Data streams are relevant and accessible to supporting agencies and partners for use in change detection, basic science, model calibration and verification and applied decision making.

Following the criteria defined above and the feedback from the Arctic LCC technical work groups and the Arctic LCC Steering Committee, we suggest that the Arctic LCC support the development and coordination of an observation network organized around 7 representative focal watersheds (Figure 1). These include the Kokolik River area, the Barrow/Meade River area, the Fish/Judy Creek area, the Kuparuk River area, the Hulahula/Jago River area, the Agashashok River area and the Upper Koyukuk area. Data will be collected by automated sensors at a suite of mainstem/tributary confluences within each watershed. Because these sites are stratified by ecoregion, terrestrial and tributary data will record local meteorological, hydrological and soil/permafrost conditions while mainstem measurements reflect the integrated upstream environment.

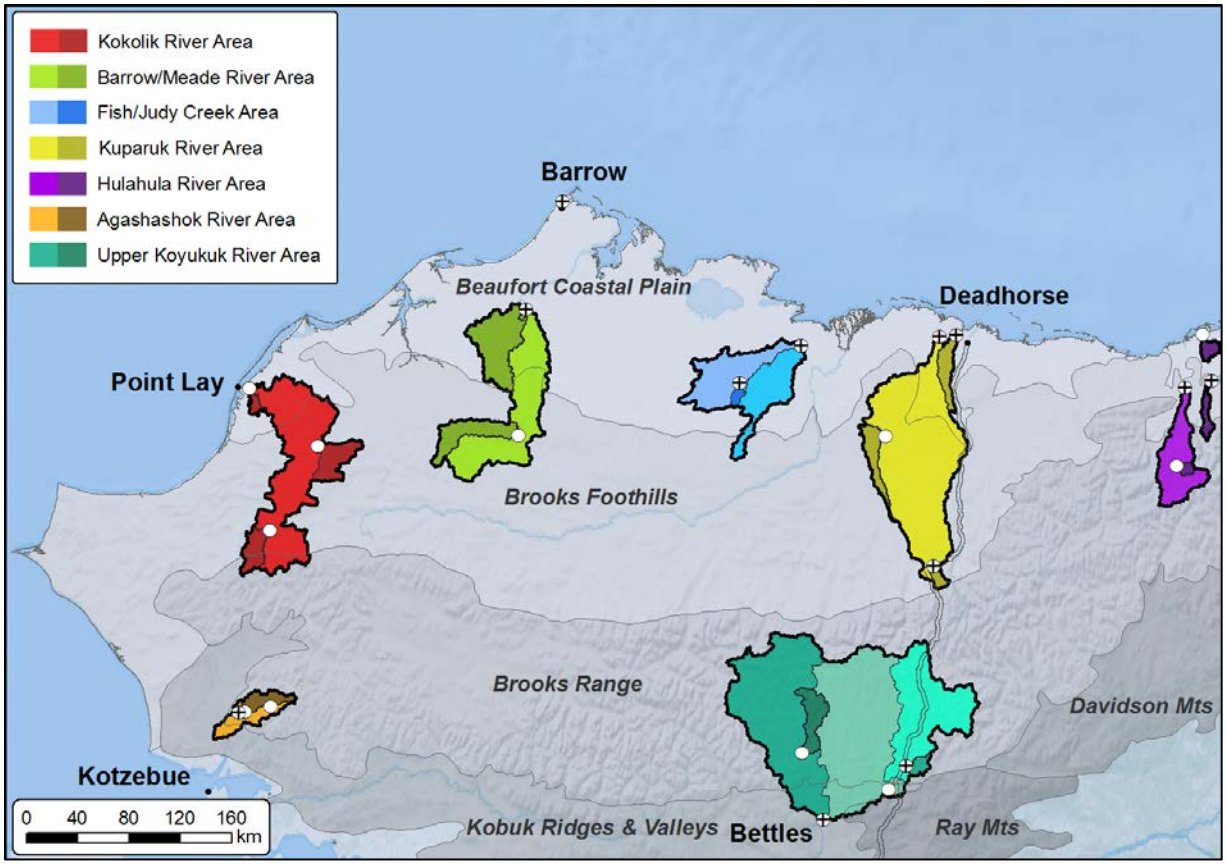


Figure 1: Regional map showing the locations of the 7 proposed focal watersheds (colored polygons). Note that watersheds cross multiple ecoregions (grey shading) and are located (when possible) near villages or along roads. Darker shading represents nested watersheds (see Figure 3). White circles denote the locations of proposed TEON stations; those with crosses indicate sites with existing infrastructure or data. The extent of the map roughly corresponds to the extent of the Arctic LCC domain.

2. Network Criteria

TEON sites are selected to satisfy a set of criteria, as discussed in summary above. The following section elaborates on the general rationale for site selection.

2.1 Network is Responsive to Stakeholder Needs

The development and maintenance of TEON requires the financial and intellectual commitment from a diverse array of benefiting agency and academic partners. This section briefly outlines how the network provides a valuable return on investment to a broad array of users.

Land Managers: Changing climate alters the timing and magnitude of biological and physical processes. These changes influence the abundance, distribution and behavior of managed species (and their habitat), such as caribou or waterfowl. These changes in environmental conditions specifically impact transportation (both roaded and unroaded) as well as the terrain stability required for

infrastructure such as pipelines. Though an individual agency may have a limited jurisdiction relative to the Arctic LCC as a whole, the distributed nature of TEON provides valuable insight into regional trends that impact local management activities. In particular, the hydrological concerns focus on changes to timing and amount of discharge, lake distribution, snowpack characteristics (amount and distribution), and water availability. The network also provides a framework for state, federal and academic scientists to work collaboratively at research sites with existing science infrastructure and established, predictable logistics. Change-detection cannot be done without a well-distributed network of consistent observation stations.

Physical and Biological Modelers: In order to simulate the behavior of a system, observational data are necessary to calibrate parameters and validate the results. This process typically requires long duration observational records from sites distributed across a domain of interest. The current density and duration of observational stations is insufficient to confidently construct models that either hindcast or forecast environmental conditions. Current records are short duration, collected with inconsistent instrumentation and insufficiently distributed to help ecophysical modelers distinguish trends from the noise and drive modern numerical simulations.

Field Scientists: Baseline data are hard to come by in remote locations in Northern Alaska. Barrow and Toolik field station attract researchers as a consequence of having well maintained records of physical and biological parameters, but these two hot-spots of scientific inquiry are not very representative of the region. The proposed TEON sites provide a formalized network with baseline data and established logistics that spans the hydrological, meteorological and ecological variability in the Arctic LCC region. These sites will function as long term natural laboratories where new investigations can take advantage of the foundational Arctic LCC data to accomplish projects that extend beyond the scope of TEON. We hope that TEON sites will become an integral component within the NSF-supported Arctic Observing Network (AON) effort as well as other programs such as CALM and GTN-P.

Industry Stakeholders: The oil and gas industry works closely with state and federal land managers to assure that their current operations conform to regulatory requirements and that their future plans are both logistically and legally viable. The TEON network will provide valuable, well-distributed data to these uses for a variety of applications including road construction (ice and gravel pad) and pipeline stability (present and proposed). In a larger context, the TEON data will drive modeling efforts that will be useful for generating short term forecasts as well as distinguishing whether current conditions are the consequence of long term environmental change (natural variability) or the consequence of anthropogenic activities. Some sites within the network are near to existing or planned industrial activities.

2.2 Sites Must Capture the Spatial and Temporal Variability

The Arctic LCC domain is a vast and complex region characterized by extremes; high relief, glacially sculpted mountains are contrasted against expansive coastal plains dotted with thermokarst lakes. Superimposed onto this topographic gradient are patterns in climate driven not only by elevation but by high interannual variability in sea ice extent thus affecting proximity to moisture sources and the paths of storm tracks. Much of what we know about climate in northern Alaska is based on models calibrated

using extremely sparse and incomplete instrumental data (Fleming et al. 2000, Shiklomanov and Nelson 2002, Serreze et al. 2003 Simpson et al. 2005). Weather, climate, and hydrologic information in this vast geographic area are relatively sparse and particularly in regards to long-term records. For example, Alaska has one stream gauge per 4,600 sq miles compared to an average of 1 gauge/470 sq miles in the Western US, excluding Alaska (Klein 2011). These calibration data come largely from Barrow and the Toolik/Kuparuk/Dalton Highway areas and many have argued that they are not necessarily representative of the larger Arctic LCC domain. Modeled conditions suggest that liquid precipitation and snow accumulation are highest in the mountains while annual air temperatures are lowest in the mountains and coastal plains but warmest in the foothills (SNAP website, 2012). Casual observations made by travelers in the region support the assertion that that large spatial and temporal gradients in climate exist in the region but these remain unconfirmed by real data. Many key species (caribou, fish, birds) migrate annually along these gradients in climate and terrestrial ecosystems are shown to be adapted to local conditions (Walker et al., 2008, Jorgenson, 2012).

As a consequence of this spatial variability, biologically relevant environmental parameters such as timing of snowmelt, peak runoff or maximum active layer depth are asynchronous across the Arctic LCC domain (Smith, 2010; Romanovsky, and Osterkamp, 1995). In order to capture this variability, we built upon the efforts of previous workers (e.g. Brabets, 1996) who designed (but were unable to implement) observation networks intended to capture this heterogeneity. Anticipated shifts in seasonality are also expected to have a significant impact on the timing and magnitude of these events (McNamara et al., 2008), potentially conflicting with the life histories of species in the region. In order to quantify the true variability in the region and demonstrate shifts in the location and timing of environmental processes, we propose that a network of observation stations will improve not only our records of change but also our ability to interpret and predict it.

Though the above suggests the need for a well distributed array of independent stations, we assert that the sensor network should also provide an opportunity for inter-comparison between sites. After considering numerous categorizations of the arctic landscape, we propose that the most robust framework for stratifying TEON sites uses the ecoregional framework proposed by Gallant et al. (1995) and further refined by Nowacki et al (2011) and Jorgenson (2012). Gallant et al. (1995) described how the ecoregional framework was derived for Alaska.

> *The map of Alaskan ecoregions was derived by synthesizing information on the geographic distribution of environmental factors such as climate, terrain (including information on physiography, geology, glaciation, permafrost, and hydrologic features), soils, and vegetation. This synthesis was a qualitative assessment of the distributional patterns and relative importance of these factors for influencing the character of the landscape from place to place.*

The ecoregional concept partitions the Arctic LCC region into roughly three domains based on physical characteristics that support distinct ecosystems. These include the Beaufort Coastal Plain, the Brooks Foothills and the Brooks Range (Figure 1). Small portions of the Davidson Mountains and Kobuk Ridges and Valleys lie along the southern fringe of the Arctic LCC area. Though more highly resolved maps of ecological domains have been generated for the Arctic LCC region (Jorgenson 2004, 2012 and

Jorgenson et al., 2009), we found that our sites were representative of both the coarser ecoregions and the finer, more nuanced classifications.

Based on the "Ecological Landscape" units delineated by Jorgenson (2012), we compared the categorical composition of the 7 TEON focal watersheds (in aggregate) to the bulk composition of the Alaska portion of the Arctic LCC. Ecological Landscape units (Figure 2) integrate climate, surficial geology, and lithology. This classification delineated 31 landscape units in northern Alaska, 27 of which occur within the boundaries of the terrestrial portion of the Arctic LCC within Alaska. Of these, 22 are represented within the 7 TEON watersheds (Table 1). The "missing" Ecological Landscape units are all aquatic, e.g. marine, or freshwater (Teshekpuk Lake). The only landscape unit under-represented (difference > 5%) is Arctic Rocky Alkaline Alpine, which occurs mostly in the eastern Brooks Mountains.

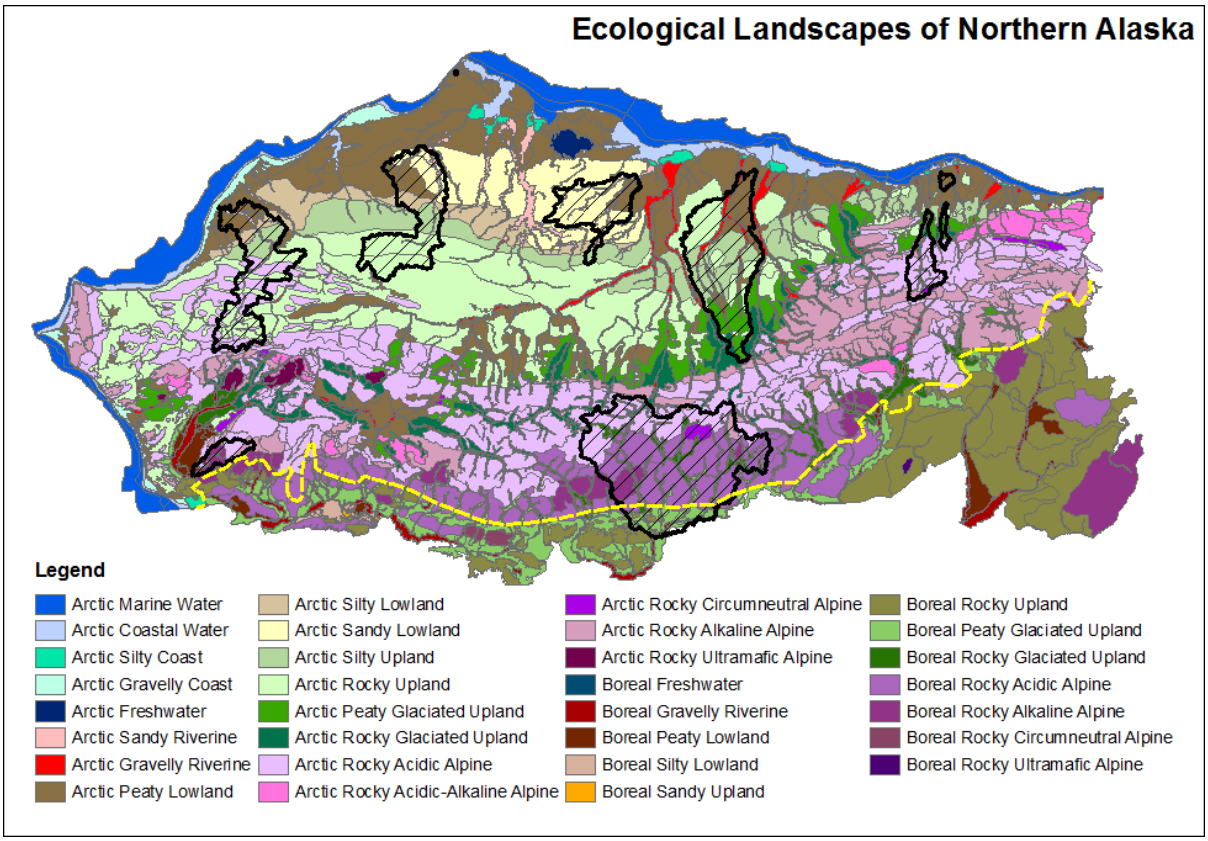


Figure 2: Map of 'Ecological Landscapes' in northern Alaska (Jorgenson, 2012). Arctic LCC boundary is represented by the dashed yellow line, and proposed TEON watersheds are shown in black cross-hatch.

Ecological Landscape Units	% of AK Arctic LCC	% of TEON	Difference in %
Arctic Rocky Alkaline Alpine	8.00	1.52	-6.48
Arctic Rocky Acidic Alpine	20.82	16.18	-4.64
Arctic Peaty Lowland	14.45	10.18	-4.26
Arctic Rocky Glaciated Upland	4.63	1.63	-3.00
Arctic Rocky Acidic-Alkaline Alpine	1.58	0.07	-1.52
Arctic Rocky Upland	16.92	15.71	-1.21
Arctic Gravelly Riverine	3.20	2.04	-1.16
Arctic Silty Coast	0.47	0.00	-0.47
Arctic Gravelly Coast	0.44	0.03	-0.41
Arctic Peaty Glaciated Upland	3.76	3.44	-0.33
Boreal Rocky Upland	0.35	0.02	-0.32
Boreal Peaty Lowland	0.36	0.05	-0.31
Arctic Rocky Ultramafic Alpine	0.41	0.10	-0.30
Arctic Coastal Water	0.29	0.00	-0.29
Arctic Freshwater	0.28	0.00	-0.28
Arctic Marine Water	0.03	0.00	-0.03
Boreal Freshwater	0.02	0.00	-0.02
Boreal Peaty Glaciated Upland	0.71	0.86	0.15
Arctic Silty Lowland	2.11	2.33	0.22
Boreal Gravelly Riverine	0.58	0.91	0.33
Arctic Sandy Riverine	1.18	1.56	0.38
Arctic Rocky Circumneutral Alpine	0.39	1.03	0.63
Boreal Rocky Alkaline Alpine	1.50	2.98	1.48
Boreal Rocky Glaciated Upland	1.89	3.95	2.06
Arctic Silty Upland	5.54	9.63	4.09
Arctic Sandy Lowland	4.46	8.98	4.51
Boreal Rocky Acidic Alpine	5.61	16.81	11.20

Table 1. Coverage of Ecological Landscapes (Jorgenson, 2012) within the Alaska portion of the Arctic LCC, compared to the aggregate area of the proposed 7 TEON watersheds. Landscape units in gray are not represented within TEON watersheds. The "Difference in %" shows those units that are present but significantly under-represented (pink) and those that are significantly over-represented (green).

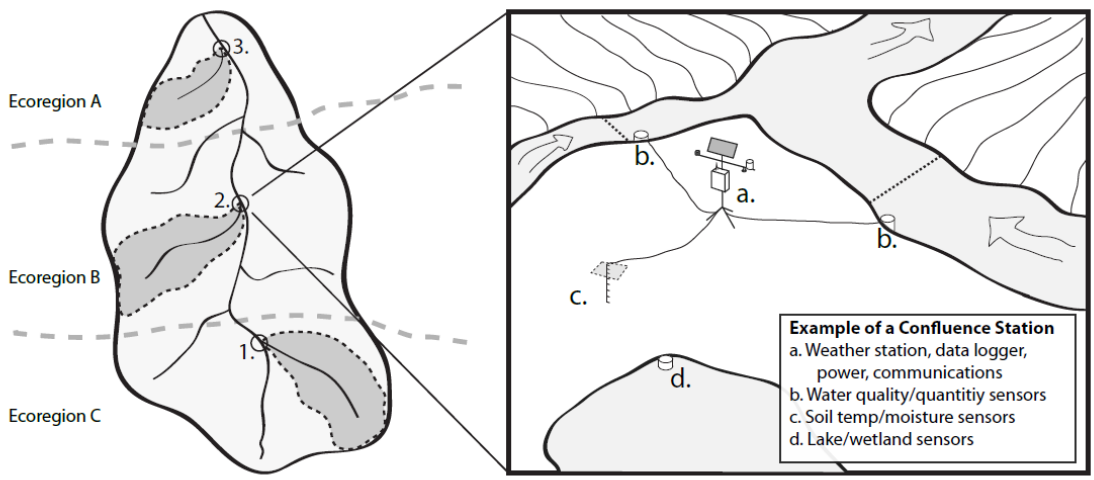
We also used Jorgenson and Heiner's (2004) ecotype map of northern Alaska as the basis for comparing vegetation/cover types represented within TEON watersheds. Because this dataset does not include the 2 southern focal watersheds, our analysis only considers the 5 northern watersheds. For most ecotypes, the composition within TEON watersheds is within a few percentage points of that for the Alaska portion of the Arctic LCC area (Table 2). Exceptions are Lowland Moist Sedge-Shrub Tundra and Upland Tussock Tundra, which are both over-represented, and Alpine Noncarbonate Dwarf Shrub

Tundra, which is under-represented. All 12 ecotypes that represent at least 1% of the region are present within TEON watersheds. Several rare ecotypes are missing however, including two coastal types, four alpine types, and spruce forest. Many of these omissions are covered by the 2 southern watersheds which were excluded from this analysis.

Ecotype	% of AK Arctic LCC	% of TEON	Difference in %
Coastal Barrens	0.23	0	-0.23
Coastal Wet Sedge Tundra	0.63	0	-0.63
Coastal Grass and Dwarf Shrub Tundra	0.68	0.03	-0.64
Riverine Barrens	0.83	0.54	-0.29
Riverine Willow Shrub Tundra	0.56	0.57	0
Riverine Moist Sedge-Shrub Tundra	2.41	2.97	0.56
Riverine Wet Sedge Tundra	0.98	0.96	-0.03
Riverine Waters	0.64	0.43	-0.2
Riverine Dryas Dwarf Shrub Tundra	0.13	0.05	-0.08
Lowland Wet Sedge Tundra	7.56	8.06	0.5
Lowland Lake	4.86	5.38	0.52
Lowland Moist Sedge-Shrub Tundra	9.63	14.37	4.74
Lowland Low Birch-Willow Shrub	1.12	1.38	0.26
Upland Tussock Tundra	8.43	12.47	4.04
Upland Dryas Dwarf Shrub Tundra	1.24	1.08	-0.16
Upland Shrubby Tussock Tundra	21.59	22.36	0.77
Upland Low Shrub Birch-Willow Tundra	17.85	15.36	-2.5
Upland Moist Sedge-Shrub Tundra	6.64	8.49	1.85
Upland Tall Alder Shrub	0.1	0.06	-0.04
Upland Spruce Forest	0.02	0	-0.02
Alpine Glaciers	0.1	0.12	0.02
Alpine Noncarbonate Barrens	4.02	1.94	-2.09
Alpine Carbonate Barrens	0.05	0	-0.05
Alpine Mafic Barrens	0.05	0	-0.05
Alpine Noncarbonate Dwarf Shrub Tundra	7.91	3.19	-4.71
Alpine Carbonate Dwarf Shrub Tundra	0.06	0	-0.06
Alpine Mafic Dwarf Shrub Tundra	0.09	0	-0.09

Table 2. Representation of ecotypes (Jorgenson and Heiner, 2004) within the Alaska portion of the Arctic LCC, compared with the 5 northern proposed TEON watersheds. Ecotypes missing within TEON watersheds are shaded in gray. Ecotypes that are significantly over-represented in TEON watersheds are shaded in green; those that are significantly under-represented are shaded in pink

Because a random, stratified sampling design would preclude prioritization of watersheds with legacy data, we suggest organizing sites along transects that follow rivers that progressively cross (and sample) the three main ecoregions (Figure 1). If located at tributary junctions, individual sites can support both local measurements (climate, vegetation, ground temperatures and hydrology) that characterize a particular ecoregion while also supporting measurements of mainstem river fluxes (water, nutrients and sediment) that integrate the diversity of all upstream environments (Figure 3). By selecting observation sites nested along watersheds, we gain both breadth in landscape characteristics while also supporting studies that examine additive interactions between ecoregions. For example, a series of tributary and mainstem stations in a given watershed supports not only the investigation of how the timing and magnitude of local (tributary) peak discharge varies across the Arctic LCC but how contributions integrate to generate the oft-measured mainstem signal. In the event that an observation site for a particular ecoregion cannot be established inside a particular focal watershed, we suggest that a site be selected in an adjacent watershed that shares similar characteristics.



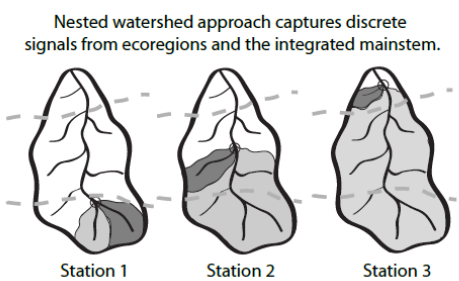


Figure 3. Idealized TEON watershed spanning multiple ecoregions (A, B, C) with nested watersheds (dark gray shading) and observation stations positioned at tributary confluences (1, 2, 3). A nested watershed approach allows characterization of ecoregion-specific conditions and an integrated signal from the mainstem. Information on water quality/quantity, weather, soil/permafrost, and vegetation is collected at confluence stations (inset).

2.3 Sites Minimize Costs While Maximizing Legacy Data Preservation

The cost of installation, operation and maintenance of complex observation networks is often prohibitive. Numerous committees and synthesis reports have expounded upon the dire need for an improved environmental observation network in northern Alaska (references above), yet because of the

cost and effort required to access most of this remote region, this burden has been too great for one agency or entity to sustain independently. The cooperative structure of the LCC makes this task attainable. To increase the affordability of the network, we suggest taking advantage of existing installations with legacy data and agency or academic investment or interest. Because the Arctic is characterized by large interannual variability, change detection requires long duration records to detect trends in a noisy signal. Sustaining an existing data stream is always more valuable than initiating a new one because a significant baseline already exists from which to detect change. Working with existing installations also reduces costs because of the preexisting infrastructure and reduces uncertainty because these sites have already proven to be stable, accessible and desirable. Incorporating existing sites within the larger TEON framework reduces the burden on field crews and data managers because they become supported by a larger, more robust and consistent infrastructure.

Regions within the Arctic LCC domain that lack observing networks will require installation of new observation stations. These new sites are selected to minimize access and installation costs while also assuring the completeness of the network and serving stakeholder needs. New sites were not selected to support particular entities, but rather be responsive to the needs and concerns of multiple agencies while producing data that are relevant to a broad, interdisciplinary audience. Where possible, new sites are located near roads, rivers or villages or where year-round access is relatively easy and inexpensive (near airstrips). For sites that are more difficult or expensive to access by air, we have considered using inflatable boats to float between sites along a given drainage. By positioning sites near tributary junctions, multiple useful measurements can be made within walking distance from the landing zone. Though not all sites can offer the following attributes, an ideal site provides safety, power, and communications, access to tools and materials, and/or shelter for technicians.

2.4 Observed Variables are Relevant and Consistent Among Sites

In designing the suite of variables to be observed throughout TEON, we consulted the Arctic LCC technical work groups and a suite of scientists already operating and maintaining sites in the arctic. From this feedback we were able to generate a 'most favored' suite of variables, instruments and protocols. Variables fall into 4 coarse categories: meteorology, surface waters, soil/permafrost and vegetation. These categories provide the most basic information relevant to the broadest array of users while minimizing costs of installation and maintenance. The particular parameters in each category are relatively simple, robust and can be measured using either automated environmental sensors or infrequent manual measurements. This 'core' suite of parameters will be observed with the same frequency and accuracy at each of the sites and inform users about the basic habitat template available at each site. If active research efforts require the measurement of variables beyond the core suite at a particular site, these can be added to the existing infrastructure of power and communications. At some of the existing sites that we hope to incorporate into TEON, parameters or protocols differ slightly different from what we propose. Over time, as hardware requires replacement, we will transition existing stations toward a uniform suite of instrumentation and protocols

2.4.1 Meteorological Observations:

In order to serve a diverse community of users (modelers, operational logistics, hydrologists, etc.), while minimizing costs, meteorological observations at TEON sites focus on measuring basic fluxes of

energy and water. More complex parameters such as evapotranspiration require instrumentation such as flux towers or lysimeters that are either too expensive, too power intensive, or too difficult to maintain at all of our remote, unmanned sites. These parameters can be added to some of the sites as required by local investigators, but will not be a part of the common suite of variables measured at all sites. For now, we will collect data that allow us to estimate the more complex parameters.

- The **radiation energy balance** between incoming short-wave and long-wave infrared radiation relative to surface-reflected short-wave and outgoing long-wave infrared radiation is measured using a net radiometer. This measurement is valuable for understanding energy fluxes in and out of the soil and quantifying the effects of seasonally varying albedo. The selected instrument describes the net flux but if affordable should be upgraded to measure the 4 fluxes independently.
- **Air temperature and relative humidity** measurements are made 2 meters above the ground surface. This characterizes the more mixed, near-surface air and is less sensitive to local variations driven by vegetation or micro-topography.
- **Barometric pressure** is measured to characterize the movement of storms through the region and provide necessary data for the calibration of water level and water quality sensors.
- **Wind speed and direction** are measured at 3 meters height to help estimate evapotranspiration losses during the warm season and snow redistribution during the winter.
- **Liquid precipitation** is measured using a tipping-bucket rain gage. This sensor records the magnitude, duration and intensity of liquid precipitation events with the incremental precision of 0.1mm. These data are especially valuable as precipitation is one of most poorly constrained parameters in climate models.
- **Snow depth** is measured using an acoustic snow level sensor that looks down at the ground surface and measures the distance from the sensor to the top of the snowpack. Though this instrument does not give information about the snow water equivalent (SWE), is provides a good measure of the accumulation and persistence of snow cover which has a large influence on the thermal state of the subsurface. If feasible, some sites will be visited during the early spring (April 1) to make physical measurements of snow characteristics along transects (depth, density, structure, etc.). Other types of instruments such as snow pillows are not affordable or maintainable. Snow accumulation will be measured with a Nipher snow gage. We have discussed the possibility of coordinating with the NRCS to install their future SnoTel sites near our installations.

2.4.2 Surface Water Observations:

Measurements of surface water conditions focus on both the quantity and quality of water in both river and lake/wetland environments. These measurements are responsive and tied to the meteorological parameters and impact industrial operations such as ice road construction or water withdrawals as well as management priorities such as waterfowl and fisheries. Because of the

unpredictable, destructive nature of ice-out events in streams and lakes, some of the following observations will be only available during the ice-free season.

- **Water level** (stage) is measured using a pressure transducer. Depending on the stability and location of the installation, transducers may either be cabled to the data logger or autonomous. Depending on the installation, transducers may also be vented or unvented (requiring barometric correction). Water level will be recorded in streams and in lakes. In streams, infrequent measurements of **stream discharge** (volumetric water flux) will be paired with measurements of stage (water level) to construct a mathematical relationship between the two variables. This stage-discharge relationship allows the high frequency stage data to be converted to continuous estimates of discharge. Discharge measurements will be made in the spring and fall, near the annual extremes using standard USGS techniques and an Acoustic Doppler Current Profiler (ADCP) or Acoustic Doppler Velocimeter (ADV).
- **Water quality** parameters are numerous but a core suite can function as robust indicators of stream health and are responsive to environmental changes. Multi-parameter sondes are low profile, robust and, for some parameters, do not require calibration during the summer deployment. The suggested parameters for the TEON sites are **water temperature, conductivity, turbidity, pH and dissolved oxygen**. The last two are the most sensitive to sensor-drift and may require more frequent calibration. Depending on the particular location, this suite of parameters might be collected in streams and lakes or just streams. **Biogeochemical sampling** of surface waters occurs infrequently during technician visits twice a year. Though the list of analyses is still under development, we suggest measurements of dissolved inorganic carbon, dissolved organic carbon, particulate organic carbon and a suite of nutrients. Less frequent measurements of cation and anion concentrations and stable isotopes would be useful as well. Analyses would all occur at the same laboratory under strict QA/QC protocols.
- **Sediment flux** in arctic rivers provides an important measure of upstream disturbances and aquatic habitat quality. Autonomous measurements of turbidity made by the multi-parameter sonde can be correlated to infrequent in-field water sampling for **total suspended solids** (TSS). Though there are demonstrated issues with correlating turbidity to TSS, this procedure is easy, inexpensive and provides a valuable measure of water quality and bed conditions.

2.4.3 Soil/Permafrost Observations:

The design of our installations is based on the existing transect of ground and borehole temperature measurements maintained by the Permafrost Laboratory at the Geophysical Institute at UAF. Their data demonstrate that ground temperatures are rising and that the nature of that change is a function not just of latitude, but local soil, vegetation and topographic setting. Automated measurements in the shallow subsurface are relatively easy and robust compared to meteorological or surface water measurements because they require less calibration and protection against exposure, weather and abuse.

- **Shallow temperature profiles (0-1.5m)** are measured at each site using a thermistor string with sensors at 16 different depths, extending to a depth of 1.5 meters. Typical maximum active layer thicknesses in this region are ~50-70 cm so this installation allows the detection of the progressive deepening of the active layer. The thermistor string can be manufactured using inexpensive parts and proven techniques developed by the Permafrost group at the GI at UAF. The large number of measurement depths requires a multiplexer.
- **Deeper temperature profiles (1.5 – 3m)** do not require as many thermistors but extend from 1.5 m to a total of 3m depths, well below the active layer. These data are valuable to understanding the propagation of thermal signals from the surface to the deeper frozen ground. During installation, careful collection and characterization of the subsurface materials will be done. The bore holes for both temperature profiles are drilled with a rechargeable rotary hammer drill and auger bit.
- **Soil heat flux** measurements are made by placing a sensor plate at the base of a soil pit, typically around 0.5 m in depth. In the same pit, three **soil moisture probes** and three **soil temperature sensors** are co-installed at three different depths, in three different soil materials to characterize how water retention varies through time in response to precipitation events and air temperature fluctuations. We will follow the protocols outlined by the AmeriFlux program: measure absolute soil moisture at many depths (preferably in the root zone at 5, 10, 20, 30, 50 and 100cm), compare soil moisture measurements to soil moisture predictions generated from remote sensing datasets. We recommend units of m^3/m^3.
- **Water table height** can be measured using shallow (<1m) PVC wells and capacitance water level probes. Traditional methods involving pressure transducers are problematic because they are sensitive to freezing and the water table can appear to drop even though it is constant and only the frost table is dropping. Investigators are currently struggling to find the best technique to make this important measurement. Water table height in the active layer controls the persistence of anoxic conditions and thus the rate and extent of biogeochemical processes that affect nutrient availability and greenhouse gas (GHG) production.
- **Soil characteristics** will be measured during the initial installation of the hardware and should include parameters such as ice content, gas fluxes, bulk density, soil organic matter (SOM) and carbon and nitrogen concentrations.
- **Active layer thicknesses** will be measured using the well-established Circumpolar Active Layer Monitoring (CALM) protocols and include transects and gridded measurements.

2.4.4 Vegetation Observations:

At each TEON site, infrequent (2-5 years) visits by experts in botany will characterize the diversity and abundance of different species and their structural form using transects, point measurements or counting frames. Each transect should, for example, characterize the diversity of plant communities near the observation site, along a riparian-to-upland transect and along transects radiating away from the edge of a lake or wet sedge environment to a higher and drier environment. Besides transects, the team of experts will make careful observation of the vegetation above the soil and permafrost

instrumentation. The vegetation team returns to the site less frequently because the rate of change in their domain is slower than the instrumental measurements. Numerous protocols exist for vegetation monitoring including those established by the Arctic National Wildlife Refuge (Jorgenson et al. 2010) the BLM's AIM program (MacKinnon et al. 2011) and the International Tundra Experiment (ITEX) group (Molau and Mølgaard, 1996). Explicit protocols will be determined before sites are established.

2.4.5 Remote Sensing:

We also suggest that recurring observations expand beyond the *in situ* field sites to include the acquisition and analysis of remote sensing data including high resolution topography (LiDAR or interferometric synthetic aperture radar (IFSAR)) and multi- or hyper-spectral imagery. These datasets are becoming more broadly available, less expensive and serve numerous important purposes including landcover classification, hydrologic flow routing and other landscape scale analyses. These analyses include, but are not limited to, *snow characteristics* (initiation of coverage, duration of coverage, timing and patterns of snowmelt), *ice characteristics* (freeze-up and ice out on lakes and rivers) and *vegetation indices* (NDVI variation through growing season, NDVI variation between years, variations in plant communities, post-fire succession, etc.). Infrequent ground surveys and measurements will be made to ground-truth the classification schemes. At the more local scale, interval cameras collecting hourly images will track snow, ice, lake, river and vegetation changes through the year. File sizes for these data are too large to send out via satellite communications but will be downloaded during visits.

2.5 TEON Data are Discoverable, Organized and Available

Though the data management strategy of the larger Arctic LCC is addressed in other documents, this section suggests how TEON data should be handled. TEON will generate vast amounts of diverse data that will require careful and thoughtful management. This is a concern and opportunity for a variety of environmental disciplines (Porter et al., 2011 and Michener and Jones, 2012). Data from automated sensors operating in the field will be uploaded to a central server via Iridium satellite communications. These data will be immediately formatted for ingestion into the central database and made available to the public online as 'v0' or raw data. Though the Arctic LCC makes no assurance as to the accuracy of the raw data, it is better to make it immediately available to the wide spectrum of users than to wait for it to be vetted. Arctic LCC staff will periodically review blocks of data for anomalous values indicative of damaged sensors. This information will be tracked and used to inform field technicians of potential issues that will need to be addressed during early summer or late fall visits. Once data undergo QA/QC analysis to remove spurious values or apply shifts to sensors that are drifting out of calibration, these refined data will be categorized as 'v1' data. If there are portions of the time series that are beyond repair, data managers have the option to use statistical or correlative techniques to fill the gaps with modeled data. These continuous data that include modeled values are considered 'v2.' All steps of data versioning are carefully and thoroughly documented in metadata that are associated with each variable at each station. Infrequent but recurring measurements (e.g. water discharge) will also be posted to the same database as the streaming data for consistency. These data can be managed and distributed through a variety of mechanisms: (1) Arctic LCC maintains an in-house, independent data storage and distribution system, (2) field-site-specific data portals are supported and maintained by each project lead, but are pointed to via a TEON page on the Arctic LCC website or (3) all

data stored on a common external database (CUAHSI-HIS, IARC, WERC, USGS, etc.) assuring the most uniform management and long-term data security. Arctic LCC staff will need to ensure that legacy data are brought into a common database with new data, so that the pre and post-TEON data are as seamless as possible. All changes in instrumentation and protocols will be detailed in the metadata for each variable at each site.

Interval camera data will be published as time series movies and raw blocks of imagery for download. Vegetation data will be transferred from field sheets to digital forms and uploaded to the LCC distribution site in a consistent manner after each survey. Raw remote sensing data acquired for the Arctic LCC domain may not be posted for free distribution due to licensing limitations but derivative products generated from that data could be distributed from the Arctic LCC while the data are stored on a centralized system such as GINA. Datasets that use the TEON framework to create interpolated maps of meteorological, hydrologic or other characteristics will also be posted and distributed via a centralized geospatial clearinghouse such as GINA.

3. Proposed Network

3.1 The Nested Watershed Approach

This section describes the rationale and character of the proposed TEON focal watersheds. The network is designed to capture the spatial and temporal variability in environmental conditions within the Arctic LCC domain and thus spans across the three prominent ecoregions in northern Alaska: the Brooks Range, the Brooks Foothills and the Beaufort Coastal Plain (Figure 1). Focal watersheds are also distributed from west to east across the Arctic LCC domain, capturing gradients in moisture availability and the effect of sea-ice duration. Each focal watershed contains two to four nested TEON sites that characterize both local conditions within a particular ecoregion as well as an integrated measure of basin characteristics observed in the mainstem river (Figures 1 and 3). Each site provides a unique contribution to the TEON network and was carefully selected from a larger suite of candidate sites. Though the network may expand over time, we suggest that the following suite of 7 core sites be incorporated into TEON based on the value of their existing legacy data and anticipated future data.

3.1.1 Kokolik River Area

Motivation for Site Selection

This watershed was suggested by the Arctic LCC Steering Committee for two reasons. First, the western North Slope has almost no existing observation stations. Second, recently permitted off-shore oil exploration in the Chukchi Sea will require terrestrial baseline data to support impact assessments. Discussion of the potential construction of a new pipeline further emphasized the need for pre-development observations in the region. The watershed drains directly to Point Lay village and the furthest downstream site is easily accessible from that site, decreasing logistics costs (Figure 4, site 3). The two upstream sites will require bush-plane or helicopter access and can be accessed from Point Lay, Kotzebue or Red Dog Mine. The two upstream sites are located where Brabets (1996) suggested installations of gaging stations to support an ideal regional streamflow network (Arctic 5 and 6). The 3

selected sites characterize each of the main ecoregions, though the Brooks Range area is disproportionately small.

Existing Infrastructure and Data

Table 3. Characterization of existing resources at each sampling location in the Kokolik River Area. **Table under construction.**

Topographic and Environmental Characteristics

The Kokolik River drains from the northwestern corner of the Brooks Range south and west to Kasegaluk Lagoon and the Chukchi Sea (Figure 4). It crosses the three ecoregions but has very little high elevation area (Table 4). Folded and faulted carbonate and siliclastic rocks create a unique ridge and valley topography. Historic resource exploration has occurred in this region but there are no developed oil or gas fields. Land in the watershed is primarily managed by the BLM (eastern half of the basin), though the downstream station near the village is on native land and the upstream site is on state patented land.

Sampling location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Kokolik River tributary 1	307.16	1148.54	567.26	6.27	39.93	-9.0	541.6	516.35
Kokolik River tributary 2	98.08	622.23	254.66	3.33	22.11	-9.4	384.0	748.93
Kokolik River mainstem 1	306.34	1262.6	583.26	7.44	47.75	-8.6	540.0	984.76
Kokolik River mainstem 2	91.00	1262.6	460.36	5.74	47.75	-8.9	482.1	3128.41
Kokolik River mainstem 3	6.33	1262.6	282.01	3.49	47.75	-9.3	398.6	6390.80

Table 4. Environmental characteristics at each sampling location in the Kokolik River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

At present, we are not aware of any active participants collecting observations in this watershed. Potential agency partners that have expressed interest include BOEM, EPA and NOAA. Potential local partners could include the Native Village of Point Lay and the North Slope Borough. Site 3 is on Native Corporation land, and Site 1 is on state land, so appropriate permissions and permits would have to be obtained.

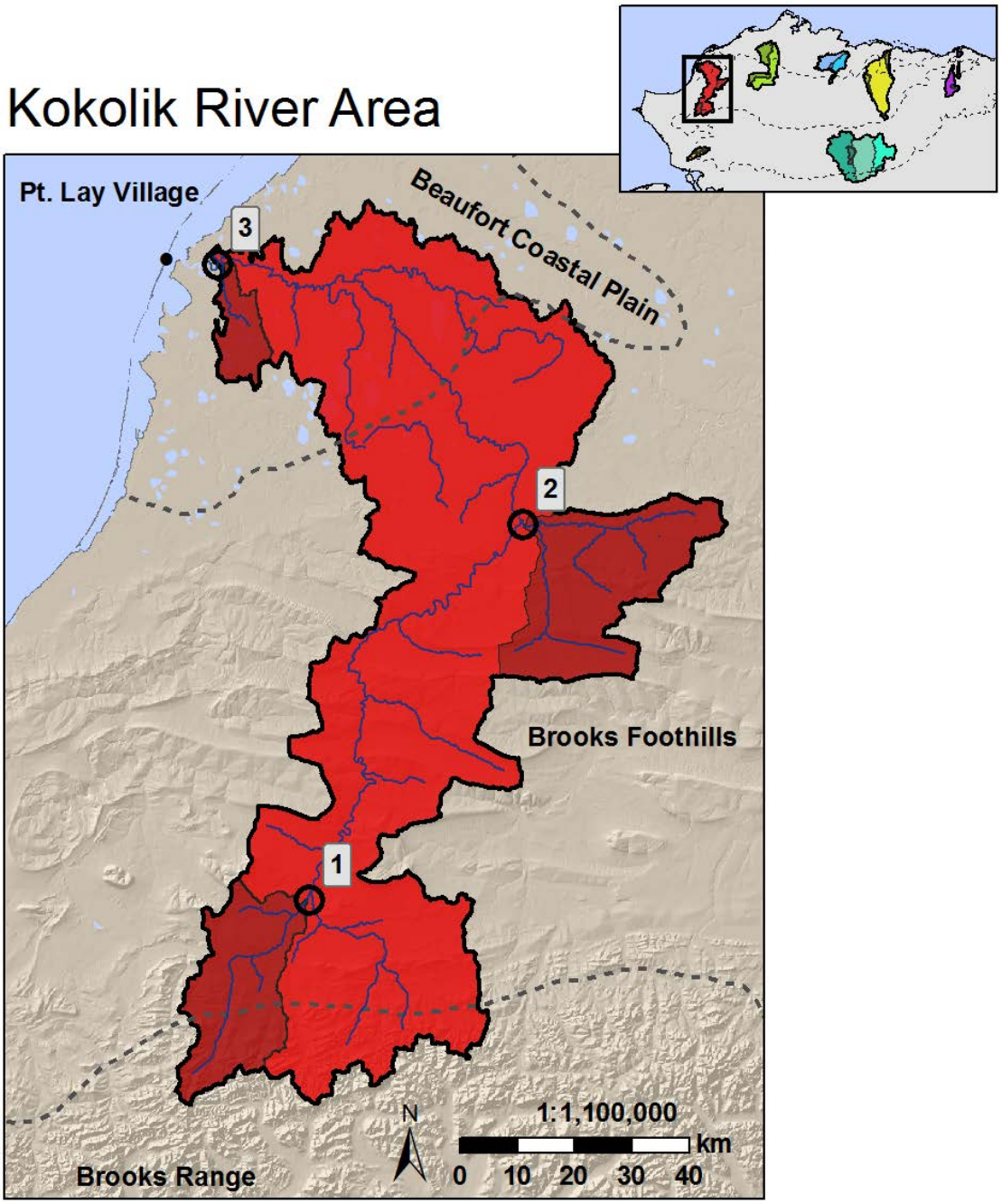


Figure 4: Map outlining the extent of the Kokolik River Area including the locations of observation stations (circles with numbers) and an inset regional map showing the distribution of all focal watersheds. Note that the downstream site [3] is close to Point Lay village and that the upstream site [1] is a mix of the Brooks Range and Foothill ecoregions.

Kokolik River Area					
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Per-Item Costs**
Logger/Power/Communications			Kokolik R and Tingmerkpuk R	Kokolik R and Avingak C	Kokolik R and Unnamed Trib	
	Data logger	1440	1	1	1	4320
	Multiplexer	600	1	1	1	1800
	Enclosure	290	1	1	1	870
	Battery enclosure	200	1	1	1	600
	Solar Panel	500	1	1	1	1500
	Charge Regulator/Controller	100	1	1	1	300
	Battery bank, storage	500	1	1	1	1500
	Tripod and mast	250	1	1	1	750
	Iridium radio and antenna, subscription	1500	1	1	1	4500
Meteorology						0
	Solar Radiation (net incoming and outgoing)	2000	1	1	1	6000
	Air temperature and RH -2m	650	1	1	1	1950
	Barometric Pressure	800	1	1	1	2400
	Wind Speed and Direction -3m	1000	1	1	1	3000
	Tipping bucket rain gage	410	1	1	1	1230
	Acoustic snow level sensor	1150	1	1	1	3450
Streams: Mainstem						0
	Water level (stage)	2000	1	1	1	6000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Streams: Tributary						0
	Water level (stage)	2000	1	1	1	6000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Wetland-Lake						0
	Water level (stage)	600	1	1	1	1800
	Temp	0				0
	Conductivity	700	1	1	1	2100
Soil-Permafrost						0
	thermistor probe, 16 measurements (1.5m?)	500	1	1	1	1500
	deep borehole (3m?, necessary?)	500	1	1	1	1500
	soil moisture (3 different depths)	1200	1	1	1	3600
	temp sensors with soil moisture probes	500	1	1	1	1500
	heat flux	700	1	1	1	2100
	water table height - capacitance water level probe	1000	1	1	1	3000
Etc.						0
	Interval Camera	500	2	2	2	3000
		37590				**114270**
Installation Costs						
Shipping	Fed Ex, UPS, USPS to FAI	2000				2000
Transport to s	Plane, Helo, Truck, Boat, etc.	20000				20000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000				5000
	Field installation, 4 days per site?	5000				5000
	Field visits 2 day per site (spring and fall)	5000				5000
		37000				**37000**
Recurring Costs; Field Activities/Collections/Measurements						
Personnel and Transportation						
	Plane, Helo, Truck, Boat, etc.	15000				15000
	Preparation for field maintenance (1 person)	1000				1000
	Time spent in field (spring and fall visits, 2 people)	3000				3000
Logger/Power/Communications						
	Confirm that all systems are operational and in good health	0	1	1	1	0
	Download any internal memory	0	1	1	1	0
	Replace batteries?	200	1	1	1	600
	Download interval camera	0	1	1	1	0
	Iridium data per year	600	1	1	1	1800
Meteorology						
	lysimeter measurements?	0	1	1	1	0
	Empty precip sampling container?	100	1	1	1	300
	Confirm that all systems are calibrated and level	0	1	1	1	0
Streams						
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	600
	Suspended Sediment Flux (TSS)	200	1	1	1	600
	Calibration of water quality sensors	100	1	1	1	300
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	3000
	Install/remove water level and water quality sensors	0	1	1	1	0
Wetland-Lake						
	Expansion/Contraction surveys?	0	1	1	1	0
	Water Chemistry	1000	1	1	1	3000
Soil-Permafrost						
	soil moisture, sample for calibration?	0	1	1	1	0
	Carbon Content	100	1	1	1	300
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	600
	Ice content	100	1	1	1	300
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	0
	Install/remove water level sensors	0	1	1	1	0
						30400

Table 5. Itemized budget for the purchase, installation and maintenance of stations in the Kokolik River Area. Site numbers correspond to the indexing on the map. Note that all sites require the full suite of hardware and that the travel costs are the highest in the Arctic LCC. This reflects the potential need for helicopter support at sites [1] and [2].

3.1.2 Barrow/Meade River Area

Motivation for Site Selection

Combining the Meade and Barrow regions into a single focal area provides a good, though discontinuous, transect across the central foothills and coastal plain. Barrow has served as a nexus for a wide array of focused research projects over the last two decades. Access is relatively easy via scheduled flights and because most research takes place only a short distance outside of town. Barrow offers one of the longest meteorological records in the circum-arctic and supports both coastal and terrestrial investigations. Near Barrow (Figure 5, site 3), recent terrestrial work has focused on characterizing low-relief tundra/patterned ground and lakes.

Though Barrow lacks a large nearby watershed, the Meade River is just 50 km to the south of town and drains south-to-north toward Barrow. Many scientists have already measured gradients or compared observations between Barrow and Atqasuk Village. We will extend this transect further south, into the Foothills ecoregion, to the Meade River headwaters. This uppermost site (Figure 5, site 1) is located at the same location as Brabets (1996) Arctic 15 suggested site. The central site (Figure 5, site 2) is close to Atqasuk village where there is an active USGS gaging station on the Meade River. In Atqasuk, a diverse suite of meteorological instrumentation is maintained by a variety of research and agency scientists. At present, there is no instrumentation or record for the Nigisaktuvik River, a major Coastal Plain tributary to the Meade River. Because this tributary is just downstream of Atqasuk Village, access will be inexpensive, requiring only a boat with an outboard motor.

Existing Infrastructure and Data

Barrow has a long climate record and has been recently augmented by extensive atmospheric monitoring through the DOE Atmospheric Radiation Measurement (ARM) program and the NOAA Earth System Research Laboratory (ESRL) investment in the Barrow Observatory. A smaller ARM observation site was established at Atqasuk Village. Barrow also has been a focus of the North Slope Science Initiative (NSSI), an intergovernmental and industrial effort to increase collaboration between stakeholders in the region. The Barrow Environmental Observatory (BEO) is a site of focused long term, high resolution measurements. The DOE's Next Generation Ecosystem Experiment (NGEE) is actively focused on quantifying the physical, chemical, and biological behavior of terrestrial ecosystems around Barrow and at the BEO site. The USGS maintained a gage on a very small stream near Barrow (Nunavak Creek, USGS 15798700) but this was discontinued in 9/2004. We intend to reestablish this station. Extensive soil/permafrost observations are already operational in Barrow.

Barrow contains an unusually long-term data set of directly measured evapotranspiration (1999-present) thanks to multiple individual research grants. Hydrological research in Barrow has also included precipitation measurements, snow cover characteristics, and the impact of polygonal surface features on hydrology. Prior to 2006, hydrologic monitoring in Barrow focused on water balance components in different smaller local watersheds (< 8 km2). The Biocomplexity Experiment study (2006-2010) included simultaneous measurements of all components of the water balance (fluxes in and out) including directly measured evapotranspiration and fine-resolution DEM's (0.25 m horizontal resolution). This type of data set is rarely available for Arctic environments.

At Atqasuk Village, ~100km south of Barrow, a USGS gaging station (USGS 15803000 Meade River at Atkasuk AK) records water stage and discharge just downstream of the village. Daily discharge data are available between 9/2005 and the present. There was one ice-free season of data collected in 1977. The gage is jointly supported by the USGS and the BLM. Also in Atqasuk Village are different meteorological sensors (ARM program starting in ~2004 and a COOP station started in 1960). Temporary measurements of air temperature and precipitation are collected at the USGS station, but they are deleted after 120 days because they are not fully QA/QC'd by that agency. Water temperature measurements were made and archived during the ice-free periods between Fall 2005 and Fall 2008. Air temperature was also recorded and is available from Fall 2006 – Fall 2007. USGS precipitation data exist for the summer of 2007 only. Numerous water quality parameters were measured infrequently between 1976 and 1978. Another, very limited, suite of water quality measurements were made between 2006 and 2008. Discharge measurements are currently made with a frequency of 4-5 times per year typically between the end of May and the end of September. There are no data available from the proposed upstream and Nigisaktuvik River sites.

Table 6. Characterization of existing resources at each sampling location in the Barrow/Meade River Area. **Table under construction.**

Topographic and Environmental Characteristics

This area only includes the Brooks Foothill and Coastal Plain Ecoregions. The watershed does not extend into the Brooks Range. The watershed is almost entirely within BLM lands except for the area around Atqasuk and Barrow which belong to the villages.

Sampling location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Barrow	7.83	19.87	13.32	0.35	3.6	-10.4	208.5	8.23
Meade River tributary 1	43.2	375.7	138.82	2.35	17.23	-10.2	304.7	956.87
Meade River mainstem 1	43.2	468.99	191.73	3.16	30.79	-10.0	331.4	1488.15
Meade River tributary 2	8.96	90.69	36.65	0.46	12.08	-10.2	250.9	1790.26
Meade River mainstem 2	8.96	468.99	117.44	1.99	30.79	-10.1	290.3	4620.04

Table 7. Environmental characteristics at each sampling location in the Barrow/Meade River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

As listed above, numerous stakeholders have worked and continue to work in this region. In particular, the Meade River region is of interest to the BLM (NPR-A) with support from the USGS for the operation of the gage at Atqasuk Village. Anna Liljedahl, Sveta Stuefer, Doug Kane, John Lenters, Matthew Sturm (hydrologists) and Jessica Cherry (hydro-climatologist) from UAF are both engaged in current research at Barrow as is Malcolm Butler (NDSU), Richard Lanctot (USFWS), Vladimir Romanovsky (UAF), Kenji Yoshikawa (UAF), Fritz Nelson, Ken Hinkel, Craig Tweedie (Texas) and a host of other

principal investigators from both agency and academic organizations. The North Slope Borough and Native Village of Barrow are stakeholders already invested in research in the region.

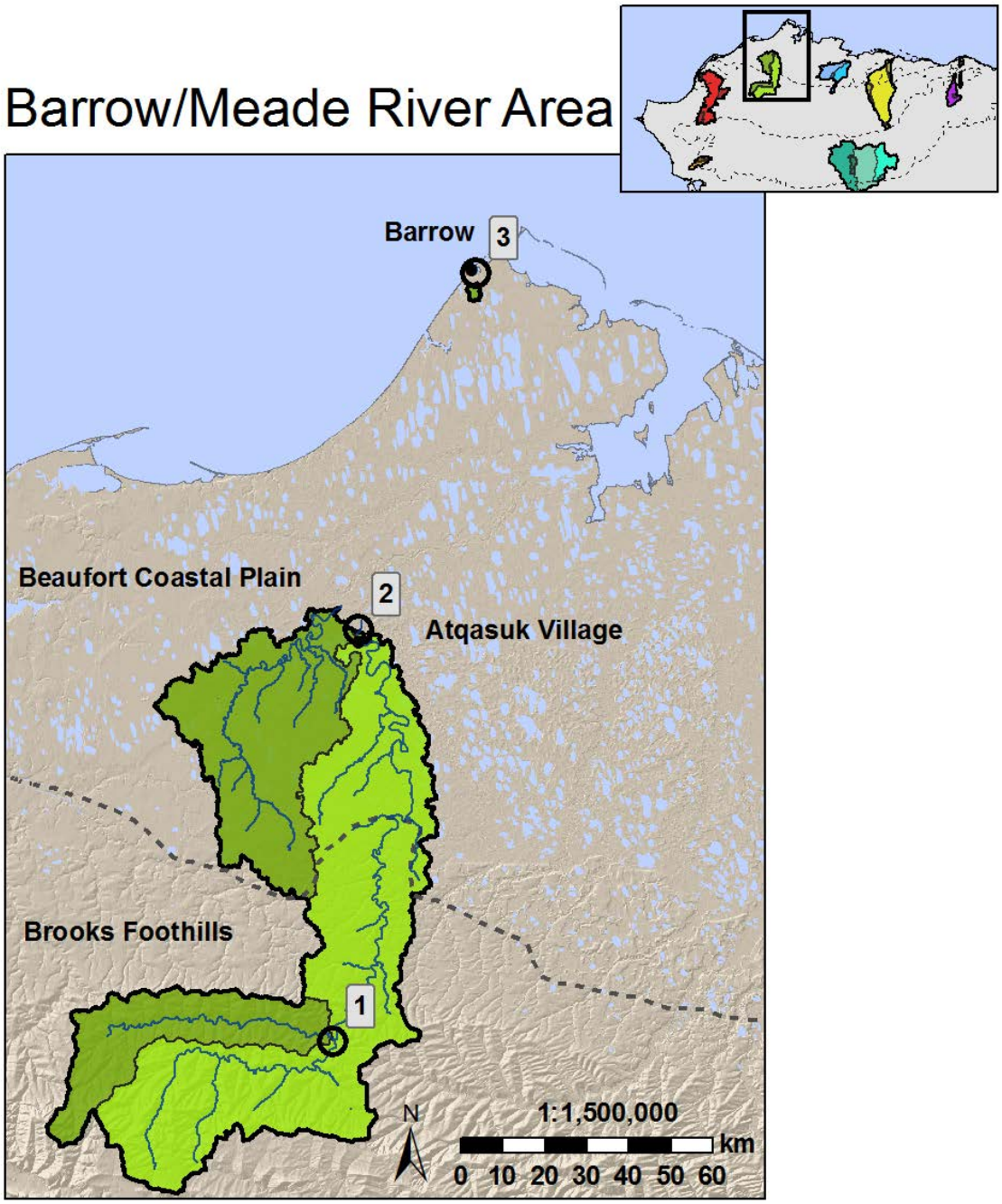


Figure 5: Map outlining the extent of the Barrow/Meade River Area including the locations of observation stations (circles with numbers) and an inset regional map showing the distribution of all focal watersheds. Note that site [1] is entirely in the Brooks Foothills and that site [2] is in the Coastal Plain ecoregion. Nunavak Creek is the small watershed just south of Barrow at site [3].

Barrow/Meade River Area						
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Per-Item Costs**
Logger/Power/Communications			Meade R and Shaningarok C	Meade R and Nigisaktuvik R	Barrow and Nunavak Ck?	
	Data logger	1440	1	1	1	4320
	Multiplexer	600	1	1	1	1800
	Enclosure	290	1	1	1	870
	Battery enclosure	200	1	1	1	600
	Solar Panel	500	1	1	1	1500
	Charge Regulator/Controller	100	1	1	1	300
	Battery bank, storage	500	1	1	1	1500
	Tripod and mast	250	1	1	1	750
	Iridium radio and antenna, subscription	1500	1	1	1	4500
Meteorology						0
	Solar Radiation (net incoming and outgoing)	2000	1			2000
	Air temperature and RH -2m	650	1			650
	Barometric Pressure	800	1			800
	Wind Speed and Direction -3m	1000	1			1000
	Tipping bucket rain gage	410	1			410
	Acoustic snow level sensor	1150	1			1150
Streams: Mainstem						0
	Water level (stage)	2000	1		1	4000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Streams: Tributary						0
	Water level (stage)	2000	1	1		4000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1		16000
Wetland-Lake						0
	Water level (stage)	600	1	2	2	3000
	Temp	0				0
	Conductivity	700	1	2	2	3500
Soil-Permafrost						0
	thermistor probe, 16 measurements (1.5m?)	500	1	1		1000
	deep borehole (3m?, necessary?)	500	1	1		1000
	soil moisture (3 different depths)	1200	1	1		2400
	temp sensors with soil moisture probes	500	1	1		1000
	heat flux	700	1	1		1400
	water table height - capacitance water level probe	1000	1	1		2000
Etc.						0
	Interval Camera	500	2	2		2000
		37590				**87450**
Installation Costs						
Shipping	Fed Ex, UPS, USPS	2000				2000
Transport to si	Plane, Helo, Truck, Boat, etc.	10000				10000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000				5000
	Field installation, 4 days per site?	5000				5000
	Field visits 2 day per site (spring and fall)	5000				5000
		27000				**27000**
Recurring Costs; Field Activities/Collections/Measurements						
Personnel and Transportation						
	Plane, Helo, Truck, Boat, etc.	6000				6000
	Preparation for field maintenance (1 person)	1000				1000
	Time spent in field (spring and fall visits, 2 people)	3000				3000
Logger/Power/Communications						
	Confirm that all systems are operational and in good health	0	1	1	1	0
	Download any internal memory	0	1	1	1	0
	Replace batteries?	200	1	1	1	600
	Download interval camera	0	1	1	1	0
	Iridium data per year	600	1	1	1	1800
Meteorology						
	lysimeter measurements?	0	1	1	1	0
	Empty precip sampling container?	100	1	1	1	300
	Confirm that all systems are calibrated and level	0	1	1	1	0
Streams						
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	600
	Suspended Sediment Flux (TSS)	200	1	1	1	600
	Calibration of water quality sensors	100	1	1	1	300
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	3000
	Install/remove water level and water quality sensors	0	1	1	1	0
Wetland-Lake						
	Expansion/Contraction surveys?	0	1	1	1	0
	Water Chemistry	1000	1	1	1	3000
Soil-Permafrost						
	soil moisture, sample for calibration?	0	1	1	1	0
	Carbon Content	100	1	1	1	300
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	600
	Ice content	100	1	1	1	300
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	0
	Install/remove water level sensors	0	1	1	1	0
						21400

Table 8. Itemized budget for purchase, installation and maintenance of stations in the Barrow/Meade River Area. Note that only the furthest upstream site [1] requires the full suite of hardware while others require a subset of components to bring the stations into compliance with TEON standards.

3.1.3 Fish and Judy Creeks Area

Motivation for Site Selection

The Fish/Judy Creek research area has received interdisciplinary research attention from agency and academic scientists since the late 1990s. Weather and subsurface observations supported by the Global Terrestrial Network for Permafrost (GTN-P) are associated with more recent installations of hydrologic instruments in streams (2002 - present) and lakes (2011-present). Though previous research has supported measurements from a third stream, the Ublutuoch, the Arctic LCC cannot support measurement of three watersheds in the same region. Hydrologic measurements will be made at existing stations (Figure 6) including Fish Creek near Inigok (site [1]), Fish Creek near Judy Creek (site [2]) and Judy Creek above Fish Creek (also at site [2]).

The unique features of the Fish/Judy Creek area include high lake density, high number of beaded streams, and high rate of permafrost degradation. Climate and permafrost data (GTN-P) in this region suggest significant warming of both air and ground temperature since monitoring began in the 1998, though this data have not been published yet in the primary literature. Analysis of aerial photography in 1945, 1982, and 2001 suggested an abrupt increase in melting of ice wedges in portions of the Fish Creek, which altered surface topography and hydrology (Jorgenson et al. 2006). InSAR measurements of regional deformation also suggest that this watershed may be experiencing rapid permafrost degradation (Liu et al 2010). Lake change studies conducted in the upper portion of the Fish Creek watershed showed considerable interannual variability in lake surface area related to precipitation and a trend towards decreasing ice thickness (Jones et al 2008).

Lakes in the Fish Creek watershed have a very wide range of morphometry and depth ranging from shallow with bedfast ice to relatively deep (>5 m). This diversity of lakes and wetlands (drained lake basins), along with high density of both beaded stream and alluvial rivers, likely provide a broad habitat mosaic for both fish communities during varying parts of the year and water-birds in the summer. Efforts are underway to couple the physical structure of this watershed with the habitat it provides and how both are responding to climate change. Further, anticipated land-use change in the form of petroleum development in the northern portion of the watershed will provide the opportunity to understand the interactions of localized human activities with regional climate forcing mechanisms and the ability to separate these impacts on permafrost, hydrology, and biological resources.

Existing Infrastructure and Data

The longest records of observation in this region are associated with the GTN-P programs (1998-present) which include both meteorological data and ground temperature data. Subsequent additions of gaging/weather stations at the outlets of Judy, Fish and Ublutuoch occurred in 2002 and data collection continues to the present. Smaller installations at streams and lakes in the region continued incrementally up to the present. We suggest formalizing the station near Inigok (FWCO_Hannahbear Creek) with a more complete gaging station to be associated with the existing meteorological station nearby. Beyond the measurement of physical parameters noted above, research into fish habitat has been ongoing under direction of Matt Whitman at the BLM.

Table 9. Characterization of existing resources at each sampling location in the Fish/Judy Creek Area. **Table under construction.**

Topographic and Environmental Characteristics

Fish and Judy Creeks are almost entirely within the Beaufort Coastal Plain Ecoregion, though a small portion of Judy Creek extends into the Brooks Foothills.

	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
Sampling location	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Fish Creek mainstem 1	36.55	119.74	62.15	1.42	9.9	-10.3	202.0	126.73
Judy Creek mainstem 1	5.51	335.66	57.64	0.9	24.27	-10.3	199.9	1774.18
Fish Creek mainstem 2	5.51	119.74	49.4	1.04	13.42	-10.2	205.6	2135.85

Table 10. Environmental characteristics at each sampling location in the Fish/Judy Creek Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

Work at the Fish/Judy Creek area has been supported through the efforts largely of the BLM, though recent investments from the USGS have helped expand the scope of studies. Matt Whitman (BLM), Horacio Toniolo (UAF) and Chris Arp (UAF) are the most central points of contact for hydrologic work and Ben Jones (USGS) is the best contact for active lake work. The watershed overlaps proposed expansion of oil production facilities, so there may be potential for partnering with industry to operate this portion of TEON.

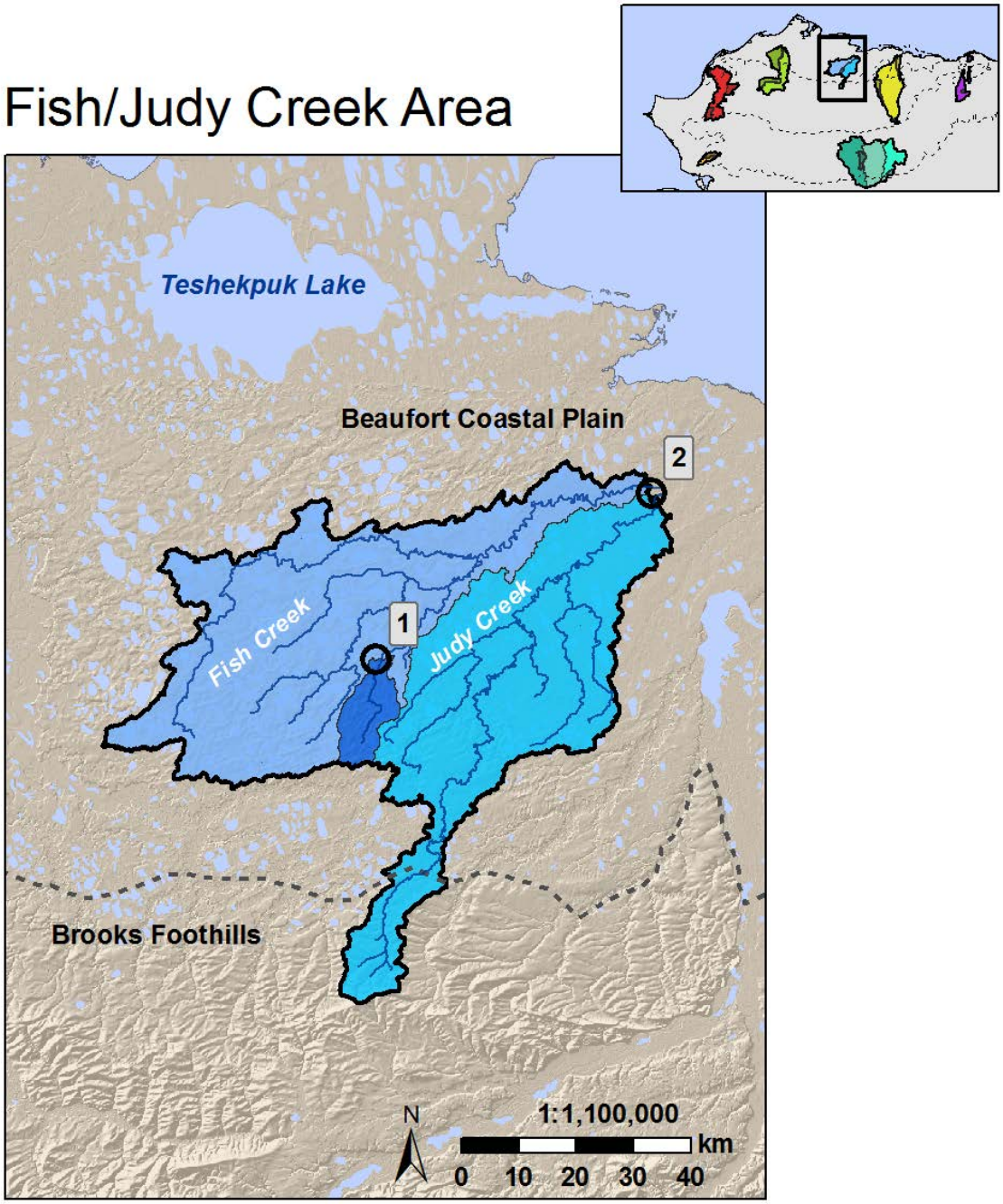


Figure 5: Map outlining the extent of the Fish/Judy Creeks Area including the locations of observation stations (circles with numbers) and an inset regional map showing the distribution of all focal watersheds. Note that this watershed is almost entirely in the Coastal Plain ecoregion. Weather, stream gaging, lake monitoring and ground temperature monitoring are active at sites [1] and [2].

Fish/Judy Creeks Area					
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Per-Item Costs**
Logger/Power/Communications			Fish Ck nr Inigok, Hannahbear	Fish/Judy Creek Confluence nr Nuiqsut	
	Data logger	1440	1	1	2880
	Multiplexer	600	1	1	1200
	Enclosure	290	1	1	580
	Battery enclosure	200	1	1	400
	Solar Panel	500	1	1	1000
	Charge Regulator/Controller	100	1	1	200
	Battery bank, storage	500	1	1	1000
	Tripod and mast	250	1	1	500
	Iridium radio and antenna, subscription	1500	1	1	3000
Meteorology					0
	Solar Radiation (net incoming and outgoing)	2000			0
	Air temperature and RH -2m	650			0
	Barometric Pressure	800			0
	Wind Speed and Direction -3m	1000			0
	Tipping bucket rain gage	410			0
	Acoustic snow level sensor	1150			0
Streams: Mainstem					0
	Water level and Temp (stage)	2000	1		2000
	Conductivity, Turbidity, DO, pH	8000	1	1	16000
Streams: Tributary					0
	Water level and Temp (stage)	2000			0
	Conductivity, Turbidity, DO, pH	8000		1	8000
Wetland-Lake					0
	Water level and Temp (stage)	600	2	2	2400
	Conductivity	700	2	2	2800
Soil-Permafrost					0
	thermistor probe, 16 measurements (1.5m?)	500			0
	deep borehole (3m?, necessary?)	500	1	1	1000
	soil moisture (3 different depths)	1200	1	1	2400
	temp sensors with soil moisture probes	500	1	1	1000
	heat flux	700	1	1	1400
	water table height - capacitance water level probe	1000	1	1	2000
Etc.					0
	Interval Camera	500	2	2	2000
		37590			**51760**
Installation Costs					
Shipping	Fed Ex, UPS, USPS	2000			2000
Transport to s	Plane, Helo, Truck, Boat, etc.	15000			15000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000			5000
	Field installation, 4 days per site?	5000			5000
	Field visits 2 day per site (spring and fall)	5000			5000
		32000			**32000**
Recurring Costs; Field Activities/Collections/Measurements					
Personnel and Transportation					
	Plane, Helo, Truck, Boat, etc.	12000			12000
	Preparation for field maintenance (1 person)	1000			1000
	Time spent in field (spring and fall visits, 2 people)	3000			3000
Logger/Power/Communications					
	Confirm that all systems are operational and in good health	0	1	1	0
	Download any internal memory	0	1	1	0
	Replace batteries?	200	1	1	400
	Download interval camera	0	1	1	0
	Iridium data per year	600	1	1	1200
Meteorology					
	lysimeter measurements?	0	1	1	0
	Empty precip sampling container?	100	1	1	200
	Confirm that all systems are calibrated and level	0	1	1	0
Streams					
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	400
	Suspended Sediment Flux (TSS)	200	1	1	400
	Calibration of water quality sensors	100	1	1	200
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	2000
	Install/remove water level and water quality sensors	0	1	1	0
Wetland-Lake					
	Expansion/Contraction surveys?	0	1	1	0
	Water Chemistry	1000	1	1	2000
Soil-Permafrost					
	soil moisture, sample for calibration?	0	1	1	0
	Carbon Content	100	1	1	200
	Gas Flux (CO2, CH3, NOx)	200	1	1	400
	Ice content	100	1	1	200
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	0
	Vegetation transects, samples?	0	1	1	0
	Install/remove water level sensors	0	1	1	0
					23600

Table 11. Itemized budget for purchase, installation and maintenance of stations in the Fish/Judy Creeks Area. Though there are existing infrastructure at all sites, a subset of components will need to be replaced to bring the stations into compliance with TEON standards.

3.1.4 Kuparuk River Area

Motivation for Site Selection

The hydrologic research that began at the Kuparuk River (8140 km2) basin in the mid-1980's based out of UAF-WERC provides one of the longest sets of hydrologic observations in Arctic North America, extending beyond summer runoff monitoring. This extensive record is facilitated by the watershed's close proximity to the Dalton Highway ("haul road") and the Deadhorse camp near the mouth of the watershed. The measurements have resulted in a multitude of internationally recognized peer-reviewed publications (e.g. Kane et al. 2000). The measurements of spring and summer runoff, snow accumulation, snow ablation, soil thermal and moisture regime, as well as weather, represent an invaluable dataset that is unmatched elsewhere in Alaska. Alongside the hydrological monitoring and modeling efforts in the last three decades are aquatic, lake and plant-level ecological studies based out of Toolik Field Station.

The upper Kuparuk (site [1] on Figure 7) and Imnaviat watersheds have a long legacy of detailed observation and provides a good measure of the weather and discharge behavior of the southern part of the Brooks Foothills. Further downstream, near the discontinued west Kuparuk meteorological station, we propose installing another gaging station that measures flux from a mid-slope tributary and the mainstem Kuparuk (site [2] on Figure 7). This site characterizes the middle of the Brooks Foothills Ecoregion and takes advantage of existing meteorologic data and existing infrastructure for data communications. Near the outlet, the mainstem Kuparuk River is gaged by the USGS (15896000). There are no small tributaries to the Kuparuk at this location that would be representative of the Beaufort Coastal Plain. Instead, we select the Putuligayuk River as a good alternative representative of this ecoregion because there is existing data (15896700 and WERC) and the station is easily accessible. Weather data for this northern region can come either from the Betty Pingo meteorological station or the West Dock station. Extensive ground temperature and moisture sensors are installed at West Dock.

At present, we have not included a Brooks Range tributary for this watershed because the Kuparuk watershed's headwaters are in the Foothills ecoregion. This transect could be expanded to include the USGS gaging station at Atigun River below Galbraith Lake. The only concern with this station is that the lake could mute the hydrologic and biogeochemical signal from the upper basin, but lake-effects are a concern for many rivers that drain glaciated regions in the central Brooks Range.

Existing Infrastructure and Data

The longest running dataset in this region is the Imnaviat meteorological station that became operational in 1986 and continues to the present. The upper Kuparuk meteorological site (site [1] on Figure 7) is closer to the gaging site but began in 1993 (Kane 2000). Measurements of discharge in the Upper Kuparuk became regular in 5/96 and continues (with Arctic LCC support) to the present

The mid-basin site at [2] on Figure 7, has no record of instrumented discharge observations. The Kuparuk west meteorological station is close by and operated between 7/95 and 6/08. The TEON network would bring this data station back online. Some historic data are available from the USGS (see links above) and the WERC website. The Arctic LCC will help support the continued maintenance and

distribution of the gaging station and weather station data. The NRCS maintains a suite of SnoTel sites along the Dalton Highway that would be valuable to characterizing conditions in the Kuparuk River area.

Table 12. Characterization of existing resources at each sampling location in the Kuparuk River Area. ***Table under construction.***

Topographic and Environmental Characteristics

The Kuparuk area watershed spans from the upper Brooks Foothills to the Coastal Plain Ecoregions.

Sampling Location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Putuligayuk River	9.00	357.06	67.88	0.38	10.25	-10.0	190.3	565.49
Kuparuk River tributary 1	99.01	461.34	166.59	0.80	10.28	-10.0	189.7	600.19
Kuparuk River mainstem 1	733.38	1509.99	977.22	6.14	44.53	-8.7	371.4	147.76
Kuparuk River mainstem 2	99.00	1509.99	525.87	2.49	44.53	-9.0	252.7	1313.12
Kuparuk River mainstem 3	8.00	1509.99	267.56	1.50	44.53	-9.5	209.1	8599.07

Table 13. Environmental characteristics at each sampling location in the Kuparuk River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

The greatest supporters of continuing work in this watershed have been the NSF, WERC and the Arctic LCC. With continued support, it would make sense for the WERC team (Kane, Arp, Schnabel, etc.) to continue the maintenance of the stations they established and gradually increment in new sensors that are consistent with the rest of the Arctic LCC observation network. As the Kuparuk is central to industrial activity based out of Deadhorse, the oil field operators may also want to be involved in maintenance and measurements at the station. Though the NEON-STREON program will focus on Oksiukuyik Creek to the east of the Kuparuk basin, there may be opportunities to take advantage of some of the infrastructure that this new development brings.

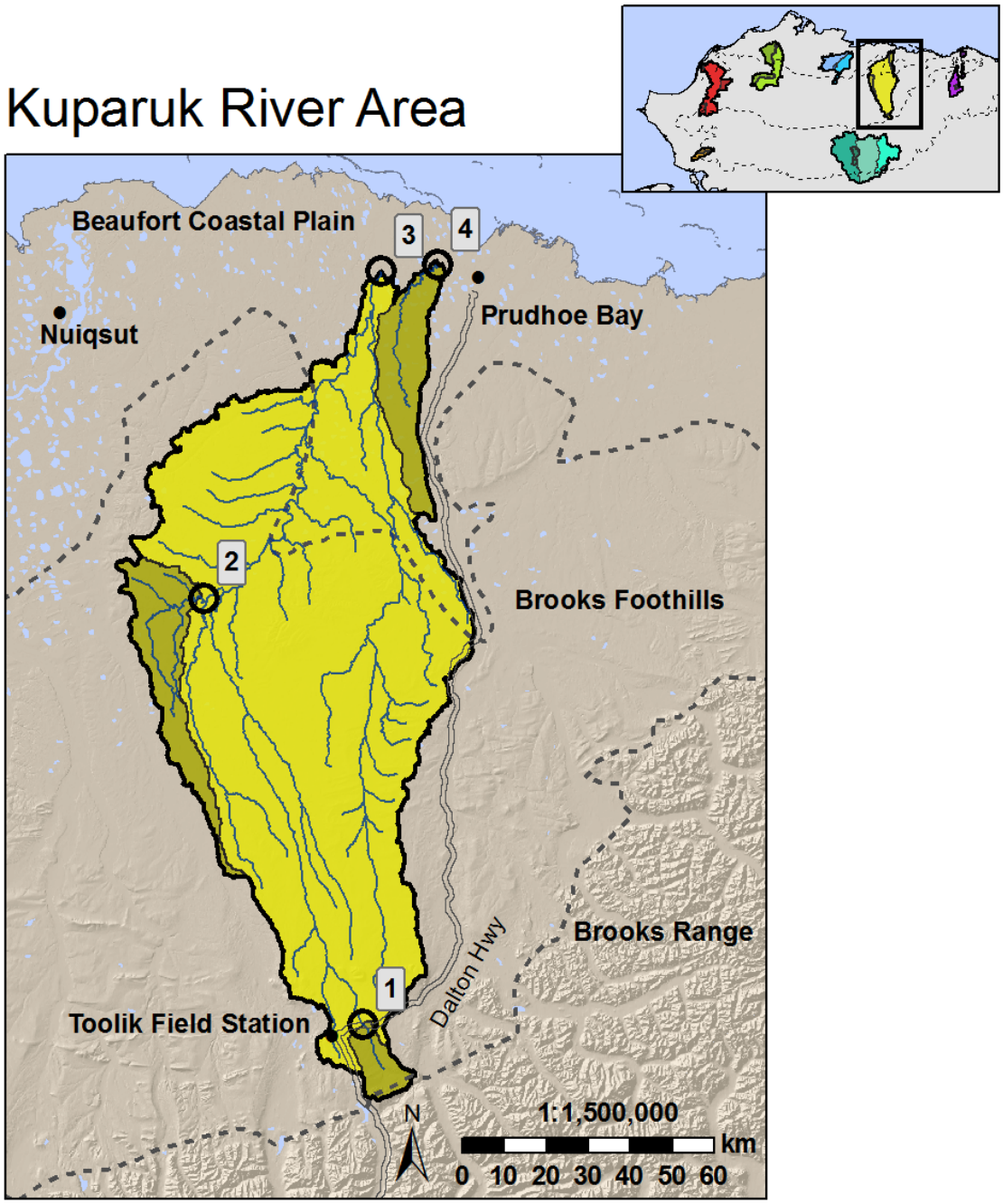


Figure 7: Map outlining the extent of the Kuparuk River Area including the locations of observation stations (numbered circles) and an inset regional map showing the location on the North Slope. Note that the upper sites are along the Dalton Highway, near Toolik Field Station. Site [2] is off the road system and would require helicopter or inflatable access. This site is the only one without existing infrastructure.

Kuparuk River Area						
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Per-Item Costs**
Logger/Power/Communications			Kuparuk R at Dalton Hwy	Western Kuparuk R and Tributary	Kuparuk R and Putuligayuk R at Deadhorse	
	Data logger	1440		1		1440
	Multiplexer	600		1		600
	Enclosure	290		1		290
	Battery enclosure	200		1		200
	Solar Panel	500		1		500
	Charge Regulator/Controller	100		1		100
	Battery bank, storage	500		1		500
	Tripod and mast	250		1		250
	Iridium radio and antenna, subscription	1500	1	1	1	4500
Meteorology						0
	Solar Radiation (net incoming and outgoing)	2000		1		2000
	Air temperature and RH -2m	650		1		650
	Barometric Pressure	800		1		800
	Wind Speed and Direction -3m	1000		1		1000
	Tipping bucket rain gage	410		1		410
	Acoustic snow level sensor	1150		1		1150
Streams: Mainstem						0
	Water level (stage)	2000		1		2000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Streams: Tributary						0
	Water level (stage)	2000		1		2000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000		1	1	16000
Wetland-Lake						0
	Water level (stage)	600	1	1	2	2400
	Temp	0				0
	Conductivity	700	1	1	2	2800
Soil-Permafrost						0
	thermistor probe, 16 measurements (1.5m?)	500	1	1		1000
	deep borehole (3m?, necessary?)	500	1	1		1000
	soil moisture (3 different depths)	1200	1	1		2400
	temp sensors with soil moisture probes	500	1	1		1000
	heat flux	700	1	1		1400
	water table height - capacitance water level probe	1000	1	1		2000
Etc.						0
	Interval Camera	500	2	2	2	3000
		37590				**75390**
Installation Costs						
Shipping	Fed Ex, UPS, USPS	2000				2000
Transport to si	Plane, Helo, Truck, Boat, etc.	10000				10000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000				5000
	Field installation, 4 days per site?	5000				5000
	Field visits 2 day per site (spring and fall)	5000				5000
		27000				**27000**
Recurring Costs; Field Activities/Collections/Measurements						
Personnel and Transportation						
	Plane, Helo, Truck, Boat, etc.	5000				5000
	Preparation for field maintenance (1 person)	1000				1000
	Time spent in field (spring and fall visits, 2 people)	3000				3000
Logger/Power/Communications						
	Confirm that all systems are operational and in good health	0	1	1	1	0
	Download any internal memory	0	1	1	1	0
	Replace batteries?	200	1	1	1	600
	Download interval camera	0	1	1	1	0
	Iridium data per year	600	1	1	1	1800
Meteorology						
	lysimeter measurements?	0	1	1	1	0
	Empty precip sampling container?	100	1	1	1	300
	Confirm that all systems are calibrated and level	0	1	1	1	0
Streams						
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	600
	Suspended Sediment Flux (TSS)	200	1	1	1	600
	Calibration of water quality sensors	100	1	1	1	300
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	3000
	Install/remove water level and water quality sensors	0	1	1	1	0
Wetland-Lake						
	Expansion/Contraction surveys?	0	1	1	1	0
	Water Chemistry	1000	1	1	1	3000
Soil-Permafrost						
	soil moisture, sample for calibration?	0	1	1	1	0
	Carbon Content	100	1	1	1	300
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	600
	Ice content	100	1	1	1	300
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	0
	Install/remove water level sensors	0	1	1	1	0
						20400

Table 14. Itemized budget for purchase, installation and maintenance of stations in the Kuparuk River Area. Though there is existing infrastructure at two sites, a subset of components will need to be added to bring these stations into compliance with TEON standards.

3.1.5 Hulahula/Jago Rivers Area

Motivation for Site Selection

Compared to the other focus watersheds, this site offers the greatest opportunity to study the character of a glacially-influenced Brooks Range ecoregion. A large proportion of the Hulahula River watershed is within the Brooks Range and our proposed monitoring site near the confluence of East Patuk Creek and the mainstem Hulahula offers an opportunity to make hydrologic and meteorological observations in the heart of this region (site [1] on Figure 8). The Hulahula River is an important subsistence use area, providing opportunities to harvest Dolly Varden and good winter access into the Brooks Range. It is also popular for recreational float trips and sport hunting. This site is accessible via wheeled plane using the East Patuk Creek gravel runway identified by the Arctic NWR staff. If this runway proves too difficult, the sampling team could land at the more popular Grassers strip and float down to the observation sites. Our measurements at this site will also characterize the influence of small headwater glaciers on the fluxes from the headwaters of East Patuk Creek and the Hulahula River. Other ongoing measurements in McCall Creek, a tributary to the upper Jago, could be used to augment our inference regarding the unique and changing contributions from glaciers. If current trends continue, these glaciers will likely largely disappear within 50-100 years, causing a substantial change in runoff and sediment export.

Because of the glacier inputs, the ecosystems downstream of the glaciers within these watersheds differ from ecosystems elsewhere on the North Slope. The Hulahula River supports a subsistence use fishery of Dolly Varden. The fish overwinter in pools, migrate during the spring freshet, and return in late July before glacial melt stops. In addition, the deltas of all these glaciated rivers support enormous populations of migratory birds. The deltas are much siltier than deltas elsewhere because of glacial inputs. Birds feeding at the siltier deltas appear to fatten more quickly than sandier deltas nearby. River banks may be eroding more tundra than elsewhere due to the glacial melt and therefore provide more nutrients to the nearshore environment.

Around 70 km downstream, beyond the range front of the Brooks (site [2] on Figure 8), a recently installed USGS gaging station measures both river discharge and a limited set of meteorological parameters. Though this site is not at a tributary confluence, it serves to measure the integrated flux from both the Brooks Range and Brooks Foothills ecoregions. Because both the Hulahula and Jago watersheds become very narrow as they cross the foothills and coastal plain, there are very few tributaries within which to apply the nested watershed approach. To measure an independent tributary that is entirely in the Foothills region, we step ~25 km to the east to Okpirourak Creek, a tributary to the Jago River (site [3] on Figure 8). This location is easily accessed by wheeled plane using the Bitty Strip at the confluence of the Jago River and Okpirouak Creek. This site is also close to two Arctic NWR long-term ecological monitoring plots and a suite of 15 thermokarst terrain monitoring sites that are visited on a 5-year interval. Though it is non-ideal to sample outside the Hulahula watershed, there are too few tributary drainages to employ the nested approach in that single watershed and we believe that the meteorological drivers are similar between the drainages. This assumption will be tested with observations made at both sites over the first few years of the installation.

To characterize the Beaufort Coastal Plain Ecoregion, we had to select another watershed outside of the Hulahula and Jago river basins. Our proposed site is an unnamed tributary that drains the Coastal Plain directly inland from Kaktovik Village. This tributary is along a south to north transect with the Hulahula and Jago rivers. It would be accessible from the village via small boat and not require leaving the lagoon. This will reduce expenses and increase the frequency of visits to this site. The installation will require consultation with Kaktovik Inupiat Corporation which owns the land at the proposed installation site. This concern is present at other alternative Coastal Plain sites.

Existing Infrastructure and Data

In the upper Hulahula basin, a small number of grab samples have been collected that characterize the chemistry, water flux and stream ecology of that region. To date, there have been no persistent measurements made in this part of the basin. The USGS gaging station downstream (15980000) was installed and operational from 9/2010 until present, supported by 14 field measurements of discharge. Besides the known vegetation and thermokarst data at the Bitty Strip confluence (site [3] in Figure 8), there are no known meteorological or hydrological measurements from that site. A weather station was operated at Kaktovik (Barter Island Station) from 1949-1988, but there are no currently-operating stations near site [4].

Table 15. Characterization of existing resources at each sampling location in the Hulahula/Jago River Area. ***Table under construction.***

Topographic and Environmental Characteristics

This focal watershed provides the greatest opportunity to characterize conditions within and fluxes from the northern Brooks Range ecoregion. Though the Foothills region is extensive, the watersheds

Sampling Location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Kaktovik coastal tributary	13.34	116.87	57.06	0.44	5.19	-10.2	112.4	181.86
Okpirourak Creek	144.17	2302.52	659.39	6.87	50.84	-9.0	165.2	242.67
Hulahula River tributary 1	636.71	2425.42	1431.46	23.21	51	-10.0	268.2	110.75
Hulahula mainstem 1	635.77	2502.28	1457.83	23.98	58.97	-10.7	274.5	713.86
Hulahula River mainstem 2	190.75	2728.59	1281.94	20.65	60.82	-10.0	254.4	1779.90

Table 16. Environmental characteristics at each sampling location in the Hulahula/Jago River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

These sites lie within the boundary of the Arctic National Wildlife Refuge (Arctic NWR), administered by the USFWS. Their team has maintained the thermokarst and vegetation sampling sites up to this point and we hope that they can continue to partner with the Arctic LCC in the development of this portion of TEON. Dr. Matt Nolan, a research scientist at UAF has a long legacy of work in the uppermost reaches of these basins studying, among other things, glacial mass balance for these shrinking glaciers. His efforts to characterize the impacts of this change on downstream ecosystems prompted the

selection of sites in this region and the installation of the USGS gaging station on the Hulahula River. Gary Clow from the USGS has been involved in creating and maintaining a meteorological network in this region, though his stations appear to fall outside the Hulahula/Jago Rivers Area. Though we have not initiated a discussion, we look forward to involving the Native Village of Kaktovik in this process as well. Good opportunity for collaboration with wildlife and physical scientists such as Jeff Adams (USFWS), Abby Powell (UAF), Roy Churchwell (UAF), Ken Dunton (Texas) and Jim McClelland (Texas) working in the river and delta regions should not be overlooked.

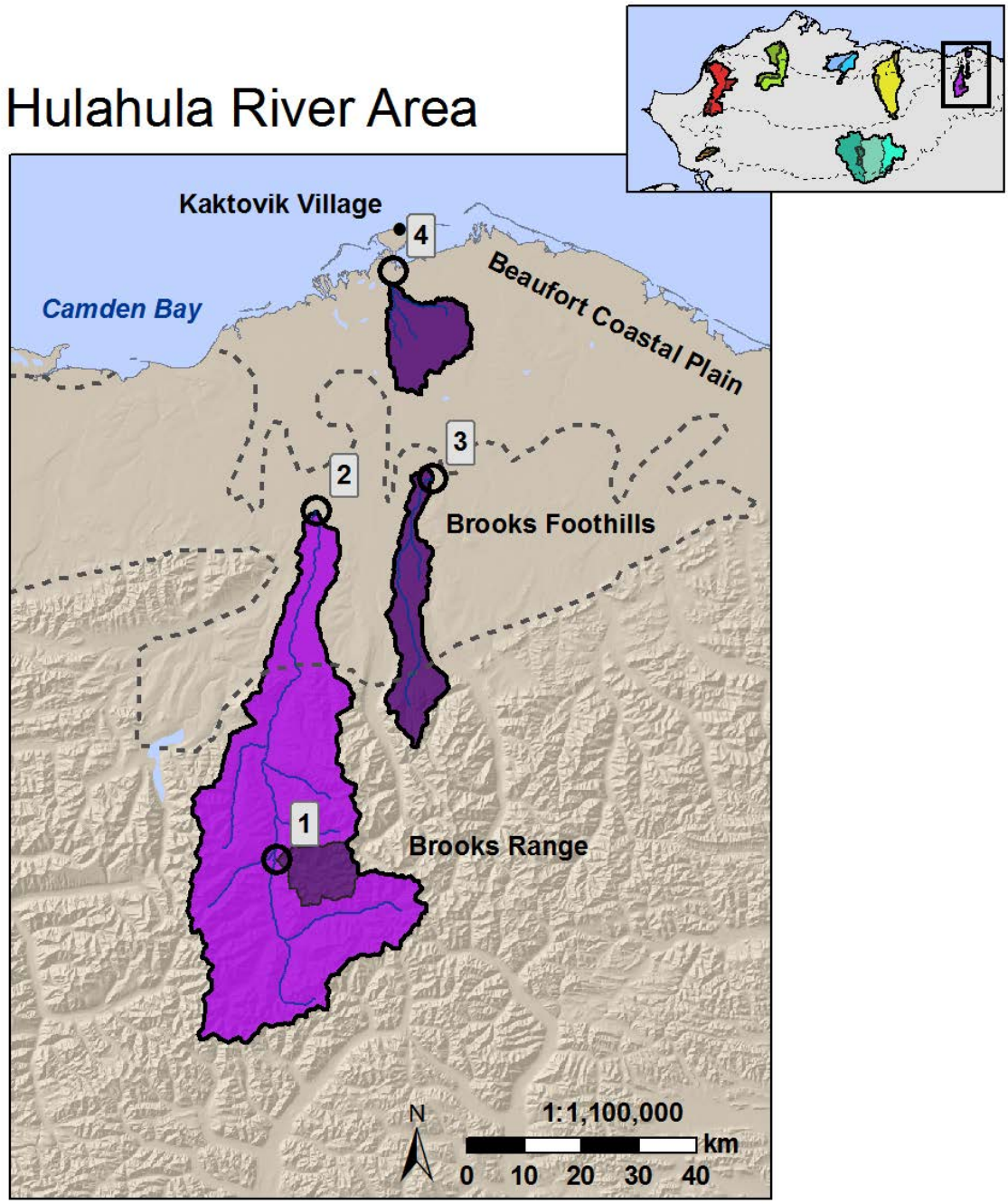


Figure 8: Map outlining the extent of the Hulahula River Area including the locations of observation stations (numbered circles) and an inset regional map showing the location on the North Slope. Note that the upper sites are in the center of the Brooks Range ecoregion (site 1), and an integrated mainstem site [2] includes a portion of the Foothills region. Site [3] uniquely characterizes the foothill region while [4] characterizes the coastal plain. There is no existing infrastructure at [1], [3] or [4].

Hulahula/Jago River Area						
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Per-Item Costs**
Logger/Power/Communications			Hulahula R and E Patuk Ck	Hulahula R nr Kaktovik	Okpirourak C and Jago R	Unnamed Trib nr Kaktovik	
	Data logger	1440	1		1	1	4320
	Multiplexer	600	1	1	1	1	2400
	Enclosure	290	1	1	1	1	1160
	Battery enclosure	200	1	1	1	1	800
	Solar Panel	500	1	1	1	1	2000
	Charge Regulator/Controller	100	1	1	1	1	400
	Battery bank, storage	500	1		1	1	1500
	Tripod and mast	250	1		1	1	750
	Iridium radio and antenna, subscription	1500	1	1	1	1	6000
Meteorology							0
	Solar Radiation (net incoming and outgoing)	2000	1	1	1	1	8000
	Air temperature and RH -2m	650	1	1	1	1	2600
	Barometric Pressure	800	1	1	1	1	3200
	Wind Speed and Direction -3m	1000	1	1	1	1	4000
	Tipping bucket rain gage	410	1	1	1	1	1640
	Acoustic snow level sensor	1150	1	1	1	1	4600
Streams: Mainstem							0
	Water level (stage)	2000	1		1	1	6000
	Temp	0					0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	1	32000
Streams: Tributary							0
	Water level (stage)	2000	1		1		4000
	Temp	0					0
	Conductivity, Turbidity, DO, pH	8000	1		1		16000
Wetland-Lake							0
	Water level (stage)	600	1	1	1	2	3000
	Temp	0					0
	Conductivity	700	1	1	1	2	3500
Soil-Permafrost							0
	thermistor probe, 16 measurements (1.5m?)	500	1	1	1	1	2000
	deep borehole (3m?, necessary?)	500	1	1	1	1	2000
	soil moisture (3 different depths)	1200	1	1	1	1	4800
	temp sensors with soil moisture probes	500	1	1	1	1	2000
	heat flux	700	1	1	1	1	2800
	water table height - capacitance water level probe	1000	1	1	1	1	4000
Etc.							0
	Interval Camera	500	2	2	2	2	4000
		37590					**129470**
Installation Costs							
Shipping	Fed Ex, UPS, USPS	2000					2000
Transport to si	Plane, Helo, Truck, Boat, etc.	20000					20000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000					5000
	Field installation, 4 days per site?	5000					5000
	Field visits 2 day per site (spring and fall)	5000					5000
		37000					**37000**
Recurring Costs; Field Activities/Collections/Measurements							
Personnel and Transportation							
	Plane, Helo, Truck, Boat, etc.	15000					15000
	Preparation for field maintenance (1 person)	1000					1000
	Time spent in field (spring and fall visits, 2 people)	3000					3000
Logger/Power/Communications							
	Confirm that all systems are operational and in good health	0	1	1	1	1	0
	Download any internal memory	0	1	1	1	1	0
	Replace batteries?	200	1	1	1	1	800
	Download interval camera	0	1	1	1	1	0
	Iridium data per year	600	1	1	1	1	2400
Meteorology							
	lysimeter measurements?	0	1	1	1	1	0
	Empty precip sampling container?	100	1	1	1	1	400
	Confirm that all systems are calibrated and level	0	1	1	1	1	0
Streams							
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	1	800
	Suspended Sediment Flux (TSS)	200	1	1	1	1	800
	Calibration of water quality sensors	100	1	1	1	1	400
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	1	4000
	Install/remove water level and water quality sensors	0	1	1	1	1	0
Wetland-Lake							
	Expansion/Contraction surveys?	0	1	1	1	1	0
	Water Chemistry	1000	1	1	1	1	4000
Soil-Permafrost							
	soil moisture, sample for calibration?	0	1	1	1	1	0
	Carbon Content	100	1	1	1	1	400
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	1	800
	Ice content	100	1	1	1	1	400
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	1	0
	Install/remove water level sensors	0	1	1	1	1	0
							34200

Table 17. Itemized budget for purchase, installation and maintenance of stations in the Hulahula River Area. Though there is some existing infrastructure at site [1], most of the sites will require new hardware.

3.1.6 Agashashok River Area

Motivation for Site Selection

The southern and western portions of the Arctic LCC domain are more poorly instrumented than those on the North Slope. Few sites have long-term legacy data or relatively easy access. The Agashashok River in the Noatak National Preserve is one of the few places where research teams have been returning to for over a decade to maintain measurements. Most work at this site has focused on tree-line biogeochemistry (Rhodes et al, 2001; Stottlemyer, 2001; Stottlemyer et al., 2002, 2003; Sullivan and Sveinbjörnsson, 2010) but other workers have also focused on nutrient fluxes through the soil column and soil gas efflux (Binkley et al., 1994, 1995, 1997; Sullivan, 2010). Weather station, soil temperature and stream flow measurements in a small tributary basin (Asik watershed, Figure 9, site 3) have been intermittently maintained over a good portion of the research record. The site is accessible via bush plane from Kotzebue with a good landing strip nearby. Discussions with the Frank Hays, Superintendent of the Western Arctic National Parklands, suggested that of the available options, this basin would be the best place for scientific research that continues to support the acquisition of data at a site with an existing legacy of science activity. If establishing observation stations in the Agashashok River is not feasible, the Salmon River in Kobuk Valley National Park and the Squirrel River on BLM land near Kiana village (where mineral extraction is being considered) would also work, though there is no legacy data at either site.

Existing Infrastructure and Data

The first visits to the Asik site (site [3] on Figure 9) occurred in 1990 and more detailed seasonal meteorological measurements began in 1992. These have been intermittently maintained since then. New installations of weather stations by the NPS Inventory and Monitoring Program will augment this fragmented record in this region. The two upper sites ([1] and [2] on Figure 9) have no existing data or infrastructure but will do a good job of providing replicated measurements of Brooks Range conditions in both pure mountainous and mixed terrains.

Table. Characterization of existing resources at each sampling location in the Agashashok River Area. ***Table under construction.***

Topographic and Environmental Characteristics

This focal watershed is in the southwest corner of the Arctic LCC and largely drains the Brooks Range ecoregion with a small portion of the lower basin in the Kobuk Ridges and Valleys ecoregion. The braided character of the lower river prevents us from suggesting a long term gaging station in that location though there are a few isolated, narrow regions.

Sampling Location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Agashashok River tributary 1	274.5	955.36	516.4	18.39	39.97	-6.6	563.2	12.21
Agashashok River tributary 2	122.52	1245.01	417.39	11.24	59.35	-6.5	553.4	393.56
Agashashok River tributary 3	89.39	669.62	301.42	12.65	33.14	-5.8	497.0	8.59
Agashashok River mainstem 1	275.37	1188.68	561.8	18.97	50.32	-7.0	586.9	60.29
Agashashok River mainstem 2	122.56	1188.68	363.7	10.75	50.32	-6.2	532.4	296.41
Agashashok River mainstem 3	5.22	1245.01	315.63	9.4	59.35	-6.0	520.5	1061.37

Table 19. Environmental characteristics at each sampling location in the Agashashok River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

This site is in the Noatak National Preserve (NPS) and has been primarily investigated by Dr. Bob Stottlemyer of the USGS. In recent years Dr. Paddy Sullivan from Univ. of Alaska Anchorage has continued to work in this region. Dr. Ben Crosby continues to study water discharge, aufice and sediment transport in the adjacent Knapp Creek watershed.

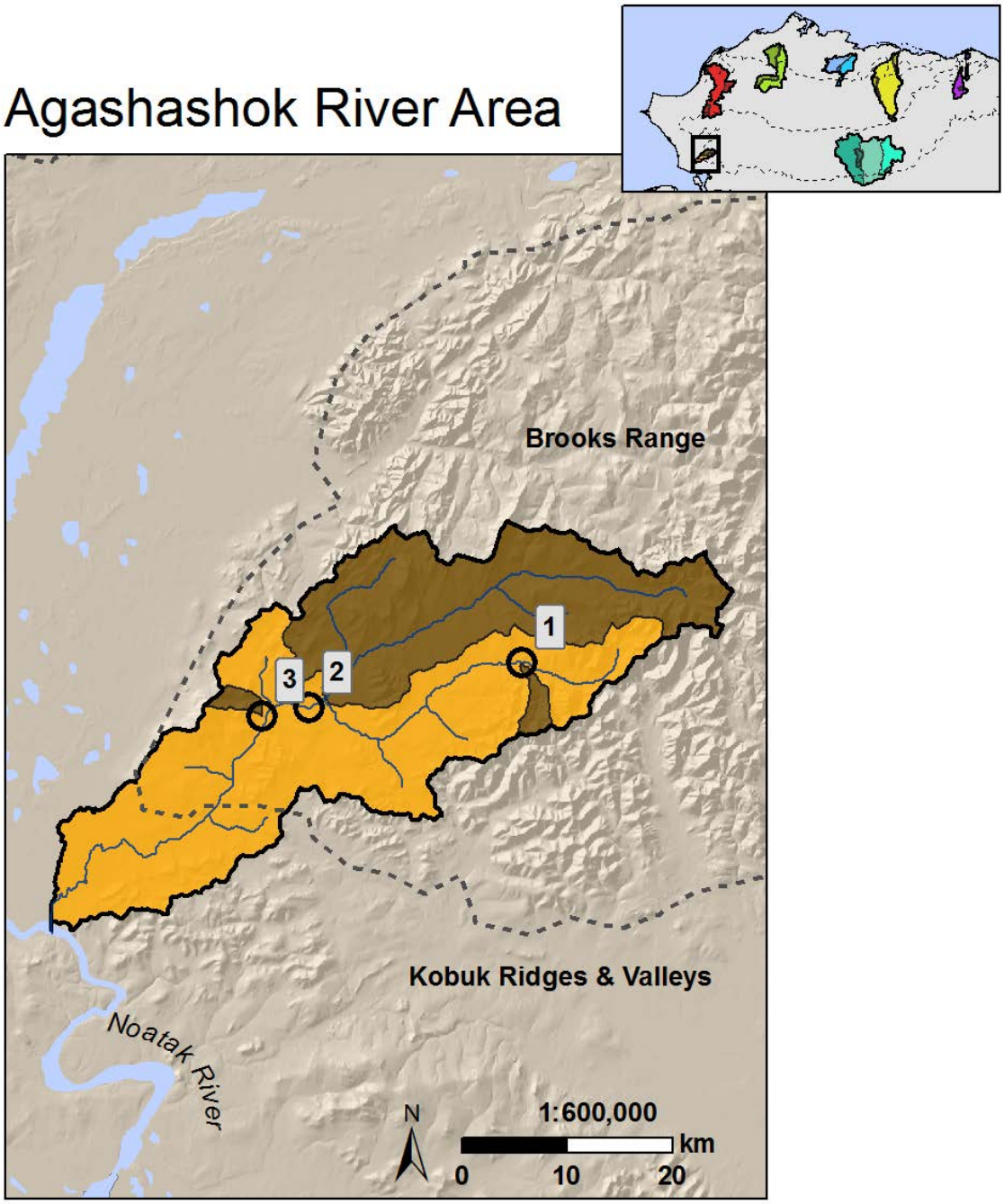


Figure 9: Map outlining the extent of the Agashashok River Area including the locations of observation stations (numbered circles) and an inset regional map showing the location on the North Slope. Photograph shows the lower Agashashok River near the Asik Creek, site [3]. There is no existing infrastructure at this site. Sites [1] and [2] would be accessed via bush planes landing on gravel bars.

Agashashok River Area					
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Per-Item Costs**
Logger/Power/Communications			Agashashok R and Mtn Trib	Agashashok R and Large Trib	Asik Tributary	
	Data logger	1440	1	1	1	4320
	Multiplexer	600	1	1	1	1800
	Enclosure	290	1	1	1	870
	Battery enclosure	200	1	1	1	600
	Solar Panel	500	1	1	1	1500
	Charge Regulator/Controller	100	1	1	1	300
	Battery bank, storage	500	1	1	1	1500
	Tripod and mast	250	1	1	1	750
	Iridium radio and antenna, subscription	1500	1	1	1	4500
Meteorology						0
	Solar Radiation (net incoming and outgoing)	2000	1	1	1	6000
	Air temperature and RH -2m	650	1	1	1	1950
	Barometric Pressure	800	1	1	1	2400
	Wind Speed and Direction -3m	1000	1	1	1	3000
	Tipping bucket rain gage	410	1	1	1	1230
	Acoustic snow level sensor	1150	1	1	1	3450
Streams: Mainstem						0
	Water level (stage)	2000	1	1		4000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1		16000
Streams: Tributary						0
	Water level (stage)	2000	1	1	1	6000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Wetland-Lake						0
	Water level (stage)	600	1	1	1	1800
	Temp	0				0
	Conductivity	700	1	1	1	2100
Soil-Permafrost						0
	thermistor probe, 16 measurements (1.5m?)	500	1	1	1	1500
	deep borehole (3m?, necessary?)	500	1	1	1	1500
	soil moisture (3 different depths)	1200	1	1	1	3600
	temp sensors with soil moisture probes	500	1	1	1	1500
	heat flux	700	1	1	1	2100
	water table height - capacitance water level probe	1000	1	1	1	3000
Etc.						0
	Interval Camera	500	2	2	2	3000
		37590				**104270**
Installation Costs						
Shipping	Fed Ex, UPS, USPS to FAI	2000				2000
Transport to si	Plane, Helo, Truck, Boat, etc.	10000				10000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000				5000
	Field installation, 4 days per site?	5000				5000
	Field visits 2 day per site (spring and fall)	5000				5000
		37000				**27000**
Recurring Costs; Field Activities/Collections/Measurements						
Personnel and Transportation						
	Plane, Helo, Truck, Boat, etc.	10000				10000
	Preparation for field maintenance (1 person)	1000				1000
	Time spent in field (spring and fall visits, 2 people)	3000				3000
Logger/Power/Communications						
	Confirm that all systems are operational and in good health	0	1	1	1	0
	Download any internal memory	0	1	1	1	0
	Replace batteries?	200	1	1	1	600
	Download interval camera	0	1	1	1	0
	Iridium data per year	600	1	1	1	1800
Meteorology						
	lysimeter measurements?	0	1	1	1	0
	Empty precip sampling container?	100	1	1	1	300
	Confirm that all systems are calibrated and level	0	1	1	1	0
Streams						
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	600
	Suspended Sediment Flux (TSS)	200	1	1	1	600
	Calibration of water quality sensors	100	1	1	1	300
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	3000
	Install/remove water level and water quality sensors	0	1	1	1	0
Wetland-Lake						
	Expansion/Contraction surveys?	0	1	1	1	0
	Water Chemistry	1000	1	1	1	3000
Soil-Permafrost						
	soil moisture, sample for calibration?	0	1	1	1	0
	Carbon Content	100	1	1	1	300
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	600
	Ice content	100	1	1	1	300
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	0
	Install/remove water level sensors	0	1	1	1	0
						25400

Table 20. Itemized budget for purchase, installation and maintenance of stations in the Agashashok River Area. Though there is some existing infrastructure at site [3], it will have to be updated to support the TEON protocols.

3.1.7 Koyukuk River Area

Motivation for Site Selection

Though the Brooks Range ecoregion drains largely to the south, most of the proposed TEON effort is on north-draining watersheds. Opportunity exists to take advantage of good access to river sites along both the Dalton Highway and near Bettles village to measure conditions and fluxes from south-draining rivers within the Arctic LCC. Future opportunities in this region may arise if a road to Ambler village is constructed. The location of almost all existing gaging stations are south of the Arctic LCC domain but still represent the processes active in the watersheds upstream.

Existing Infrastructure and Data

A long term gage is operational at a site near old Bettles within the Kanuti National Wildlife Refuge (NWR), near the confluence with the John River. The gage is approximately 5 miles down-river from the Bettles airport and Kanuti NWR office (Figure 10, site 4). It is a real-time site that sends data thru the NOAA satellite system and is currently funded by NWR - Water Resources until ~2014. After that, Kanuti NWR and NPS have committed to cooperatively maintain the gage. We propose to add a gaging station on the John River, just upstream of the gage at Old Bettles. Access to this site [4] is via outboard boat from Bettles village.

3 Hydro-meteorological stations were recently installed and operated by William Schnabel at UAF for the DOT along the proposed road to Ambler. These stations are located very close to the boundary between the Arctic LCC and the Interior LCC. UAF also installed and maintains four meteorological stations at mid-elevations in the Brooks Range for the DOT. The greatest concern with supporting/continuing the UAF/DOT sites is that they almost all require helicopter access for maintenance. The NRCS maintains a SnoTel site at Bettles.

A gaging station and weather station are located near Coldfoot (site [1] in Figure 10), along the Dalton Highway. The gaging station (USGS) is on Slate Creek a small tributary to the Middle Fork Koyukuk River. Though it would be preferable to do so, it is too difficult to gage the mainstem MF Koyukuk at this location because the river is wide and braided. Instead, we suggest gaging the MF Koyukuk above Chapman Island, south along the Dalton Highway where the channel narrows to a single thread (site [2] in Figure 10). No data exist at this location.

We suggest also developing a gaging site near the Crevice Creek landing strip on the John River and a tributary to it, Allen River (site [3] on Figure 10). These rivers would give a good measure of conditions in the interior of the Brooks Range ecoregion and pair well with the John River measurement made near Old Bettles.

Table 21. Characterization of existing resources at each sampling location in the Koyukuk River Area. ***Table under construction.***

Topographic and Environmental Characteristics

This large area drains the southern Brooks Range ecoregion and extends downstream into the Kobuk Ridges and Valleys outside of the Arctic LCC boundary. Compared to other sites in TEON, these rivers are larger basins and reflect higher relief landscapes.

Sampling Location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
John River tributary 1	244.99	1725.32	838.14	17.14	51.69	-7.7	357.1	683.70
John River mainstem 1	244.00	2057.01	963.37	17.79	66.04	-8.2	425.3	4502.34
John River mainstem 2	183.00	2057.01	849.99	16.51	66.04	-7.6	412.1	7044.91
Koyukuk River tributary 1	314.49	1548.14	716.62	11.99	43.45	-6.5	465.0	207.97
Koyukuk River mainstem 1	278.33	2071.55	943.38	18.5	68.11	-7.9	360.5	3946.97
Koyukuk River mainstem 2	183.00	2212.98	847.81	16.75	70.27	-7.5	393.2	18022.68

Table 22. Environmental characteristics at each sampling location in the Koyukuk River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

When added to TEON, sites in this region could be a joint venture providing mutual benefit to the Arctic and Northwest Boreal LCC. Proposed stations are located within, or close to Kanuti NWR, and the Refuge has initiated a 5 year hydrologic investigation into streams in this region. Two of these sites are outside of the Arctic LCC. The gage near Old Bettles will be cooperatively maintained by Kanuti NWR and NPS after 2014. New meteorological and gaging stations have been installed by William Schnabel at UAF in support of DOT efforts to build a road through this region. These sites might be worth supporting as they make direct measure of conditions within the Brooks Range ecoregion of the Arctic LCC.

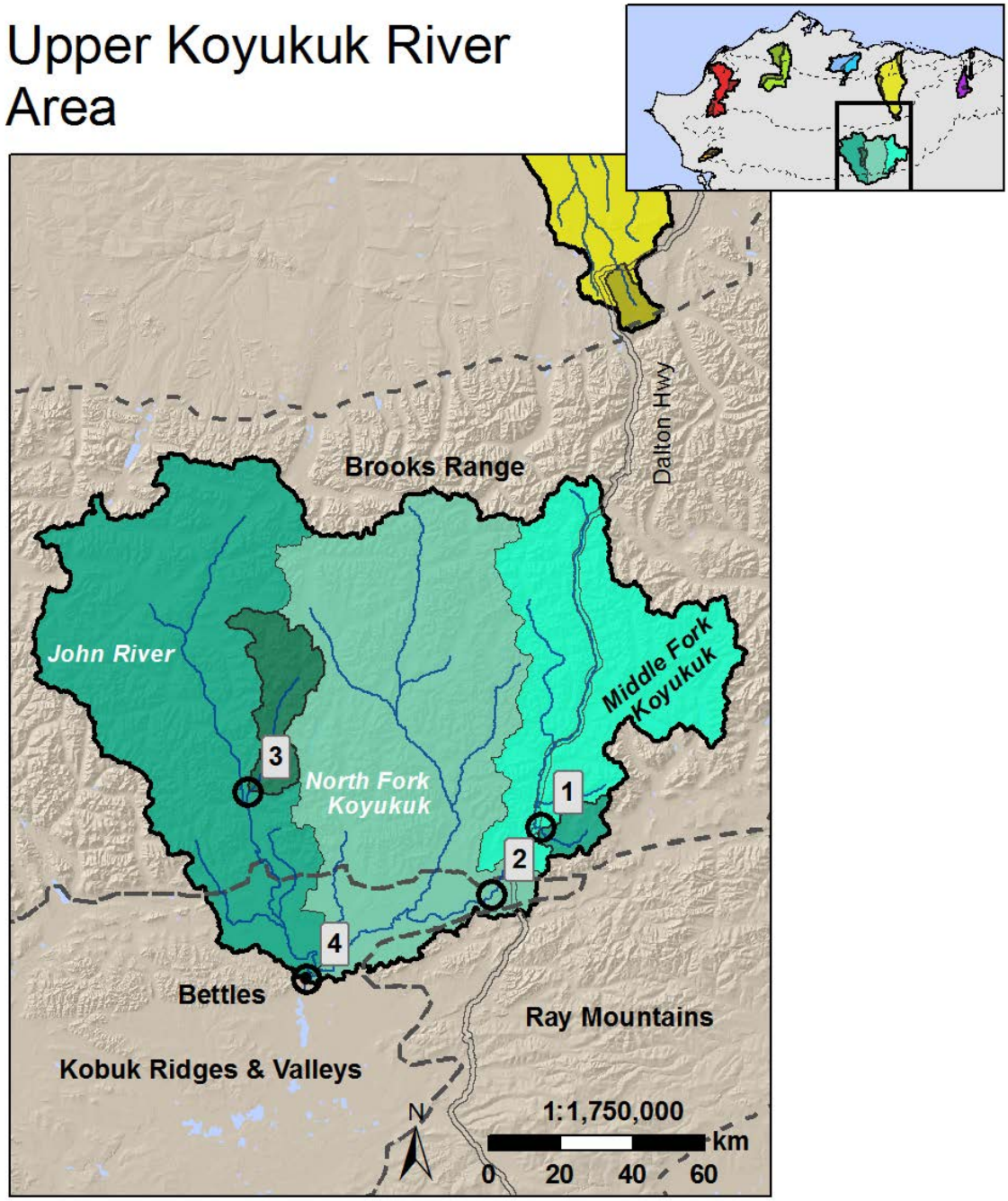


Figure 10: Map outlining the extent of the Koyukuk River Area including the locations of observation stations (numbered circles) and an inset regional map showing the location on the North Slope. Site [1] is on Slate Creek and is maintained by the USGS. At site [2] there is no existing infrastructure but a road leads from the Dalton Highway to the Chapman Island area. Site [3] is accessed by air, landing at the well maintained Crevice Creek airstrip. Site [4] at Old Bettles is accessible from Bettles village via outboard boat. Note that the north/south divide in the Brooks Range is far north of the center of the range.

Upper Koyukuk River Area							
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Per-Item Costs**
Logger/Power/Communications			Slate Ck at Coldfoot	WF Koyukuk R at Chapman Bar	John R and Allen River at Crevice Creek	Koyukuk R and John R at Old Bettles	
	Data logger	1440	1	1	1	1	5760
	Multiplexer	600	1	1	1	1	2400
	Enclosure	290	1	1	1	1	1160
	Battery enclosure	200	1	1	1	1	800
	Solar Panel	500	1	1	1	1	2000
	Charge Regulator/Controller	100	1	1	1	1	400
	Battery bank, storage	500	1	1	1	1	2000
	Tripod and mast	250	1	1	1	1	1000
	Iridium radio and antenna, subscription	1500	1	1	1	1	6000
Meteorology							0
	Solar Radiation (net incoming and outgoing)	2000	1	1	1	1	8000
	Air temperature and RH -2m	650	1	1	1	1	2600
	Barometric Pressure	800	1	1	1	1	3200
	Wind Speed and Direction -3m	1000	1	1	1	1	4000
	Tipping bucket rain gage	410	1	1	1	1	1640
	Acoustic snow level sensor	1150	1	1	1	1	4600
Streams: Mainstem							0
	Water level (stage)	2000		1	1	1	6000
	Temp	0					0
	Conductivity, Turbidity, DO, pH	8000		1	1	1	24000
Streams: Tributary							0
	Water level (stage)	2000			1	1	4000
	Temp	0					0
	Conductivity, Turbidity, DO, pH	8000	1		1	1	24000
Wetland-Lake							0
	Water level (stage)	600	1	1	1	1	2400
	Temp	0					0
	Conductivity	700	1	1	1	1	2800
Soil-Permafrost							0
	thermistor probe, 16 measurements (1.5m?)	500	1	1	1	1	2000
	deep borehole (3m?, necessary?)	500	1	1	1	1	2000
	soil moisture (3 different depths)	1200	1	1	1	1	4800
	temp sensors with soil moisture probes	500	1	1	1	1	2000
	heat flux	700	1	1	1	1	2800
	water table height - capacitance water level probe	1000	1	1	1	1	4000
Etc.							0
	Interval Camera	500	2	2	2	2	4000
		37590					**130360**
Installation Costs							
Shipping	Fed Ex, UPS, USPS	2000					2000
Transport to si	Plane, Helo, Truck, Boat, etc.	10000					10000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000					5000
	Field installation, 4 days per site?	5000					5000
	Field visits 2 day per site (spring and fall)	5000					5000
		27000					**27000**
Recurring Costs; Field Activities/Collections/Measurements							
Personnel and Transportation							
	Plane, Helo, Truck, Boat, etc.	10000					10000
	Preparation for field maintenance (1 person)	1000					1000
	Time spent in field (spring and fall visits, 2 people)	3000					3000
Logger/Power/Communications							
	Confirm that all systems are operational and in good health	0	1	1	1	1	0
	Download any internal memory	0	1	1	1	1	0
	Replace batteries?	200	1	1	1	1	800
	Download interval camera	0	1	1	1	1	0
	Iridium data per year	600	1	1	1	1	2400
Meteorology							
	lysimeter measurements?	0	1	1	1	1	0
	Empty precip sampling container?	100	1	1	1	1	400
	Confirm that all systems are calibrated and level	0	1	1	1	1	0
Streams							
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	1	800
	Suspended Sediment Flux (TSS)	200	1	1	1	1	800
	Calibration of water quality sensors	100	1	1	1	1	400
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	1	4000
	Install/remove water level and water quality sensors	0	1	1	1	1	0
Wetland-Lake							
	Expansion/Contraction surveys?	0	1	1	1	1	0
	Water Chemistry	1000	1	1	1	1	4000
Soil-Permafrost							
	soil moisture, sample for calibration?	0	1	1	1	1	0
	Carbon Content	100	1	1	1	1	400
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	1	800
	Ice content	100	1	1	1	1	400
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	1	0
	Install/remove water level sensors	0	1	1	1	1	0
							29200

Table 22. Itemized budget for the purchase, installation and maintenance of stations in the Koyukuk River Area. Though there is some existing infrastructure at site [1] and [4], some of it will have to be updated to support the TEON protocols.

3.2 Network Adaptability

The design of TEON is primarily focused on supporting and augmenting sites with existing legacy data. New sites with limited or no data have been selected to fill gaps in our distribution and increase the representativeness of the network. Though the network is rooted in providing long-term data for change detection and modeling efforts, it is not intended to remain static. As new variables become important to scientists and managers, sensors can be added to the existing power, datalogger and uplink infrastructure. As new opportunities motivate the expansion of the network (e.g. road building) TEON will already have the station installation experience and data management infrastructure to rapidly and efficiently support new sites. This allows the network to retain its core sites while being responsive to new opportunities. For projects outside of the TEON domain, the ArcticLCC will continue to fund RFP-initiated projects that may take advantage of TEON data, but do not need to be situated at those sites.

3.3 Integration across the Network

The TEON network is designed not to simply support measurements at points within the Arctic LCC domain, but rather to support comparative and synthetic analyses that make use of many, if not all, of the stations. The distribution of observations covers the range of ecoregions and ecological landscapes present in the Arctic LCC. These data can be used to either characterize variability within individual domains or make comparisons between domains. The network provides a good distribution of consistent measurements that will be valuable for calibrating and validating regional biophysical models. It would be advantageous for program sustainability and applicability if the Arctic LCC were able to incorporate other programs (e.g. CALM, ITEX, AON, other LCCs, etc.) into their protocol development. Because the data are intended to be used in a synthetic manner, the Arctic LCC will need to assure that some basic level of data management, QA/QC and interpretation are done to facilitate external studies. Higher level, more focused analyses on single or multiple sites could be achieved through RFPs. Remote sensing data will be very valuable in interpolating conditions in regions outside the TEON network. Many of these kinds of studies are already underway and require more ground-truthed data to support their efforts (Chris Potter, ABoVE, NASA, etc.). This integrated analysis across the TEON network will provide a model that other LCCs in Alaska and beyond can potentially adopt. The network provides a structure for multiple agencies/academics to work together under one collective purpose, while still supporting their local, site-based needs.

4. Implementation Plan

Because TEON is largely built around the necessity to support legacy sites, the greatest implementation challenge will be establishing consistency between the new and existing sites. A diverse array of instrumentation, collection techniques, communication protocols and data formats are found at the different legacy sites and will have to be gradually migrated into a unified, consistent system. At new sites, such as the Kokolik River Area, the installations will be more costly but less complicated because the instrumentation, protocols and data management are new. If existing sites elect to replace older sensors with new ones, we suggest that records from the different sensors overlap for ~1 year. This redundant data will be used to recalibrate the historic data so that it is consistent with the readings from the new sensor.

Of the 22 observation stations distributed in the 7 TEON watersheds in the Arctic LCC, 11 are either fully or partially operational and 11 will require completely new installations. Though this section of the document does not provide a timeline or suggested sequence of events, we outline which steps are necessary in each focal watershed. Instead of activating the network all at once we suggest incrementally adding focal watersheds through time. We attempt to keep the annual Arctic LCC expenditures around $350k during the installation. This is enough funding to install ~2 expensive stations per year or three inexpensive stations (Table 23). Note that in year 2, the costs will include the second installations and the maintenance of the sites installed in the first year. As the installations are completed, the annual cost of maintenance will become more and more significant. Once the network is installed, costs will stabilize around $180k per year. Though stakeholder needs can affect installation prioritization, we suggest first working at well-established, easily-accessible sites to develop skills and familiarity with the process. This also allows for preservation of legacy data that might be in jeopardy of shutting down. The incremental installations allow the Arctic LCC to distribute the cost of installation over multiple years, to learn from prior experience, to develop strong partnerships with agency and academic partners, and to develop a sound method for data ingestion, formatting and distribution.

Once a station is installed, we suggest spring and fall visits. Before the spring visit, technicians will use the streaming data to know ahead of time if any of the sensors are not functional and plan for repairs. During the spring, technicians deploy ice-sensitive sensors and provide routine maintenance and sampling tasks as described above in the tables above. During the fall, besides routine maintenance and sampling tasks, technicians will focus on winterization of the stations, removing ice-sensitive sensors and assuring adequate power and communication through the winter. The costs associated with these two visits depend largely on who does the work, how they access the site, if there is broken hardware and what level of analyses are run on the samples collected. Sites accessible by road, near a village with easy air logistics are considerably less expensive to maintain. Once the installation is complete, transportation costs at more remote sites can be reduced if technicians are able to travel by inflatable boat between stations rather than requiring closed support from a helicopter or bush plane. In Table 24 we provide rough estimates of the cost of these 2 visits for each site. Though the hardware is expected to last ~10 years, items will need to be infrequently replaced if they are damaged or become prematurely worn. These costs are not accounted for, but could be assessed by simply amortizing the cost of a new station over a 10 year period. Because these sites are intended to persist into the foreseeable future, there is no removal plan, but all stations and installed components can be removed as necessary.

	Hardware and Install	Maintenance	Total	Watersheds
Year 1	300600	0	**300600**	Barrow, Fish, Kuparuk
Year 2	282540	65400	**347940**	Kokolik , Agashashok
Year 3	169220	121200	**290420**	Hulahula
Year 4	157360	155400	**312760**	Upper Koyukuk
Year 5	0	184600	**184600**	
Year 6	0	184600	**184600**	
Year 7	0	184600	**184600**	
Year 8	0	184600	**184600**	
Year 9	0	184600	**184600**	
Year 10	0	184600	**184600**	

Table 23. Possible sequence of installations that keep program costs close to $300k per year. In the first year, 3 stations are installed, 2 in the second year and 1 station in years 3 and 4. The number of installations must go down because the cost of station maintenance increases over time. This suggests that the 7 stations can be installed and operational in 4 years.

Focal Watershed	Hardware	Installation	Annual Maintenance
Kokolik R Area	114270	37000	30400
Barrow/Mease R Area	87450	27000	21400
Fish/Judy Ck Area	51760	32000	23600
Kuparuk R Area	75390	27000	20400
Hulahula/Jago R Area	132220	37000	34200
Agashashok R Area	104270	27000	25400
Upper Koyukuk Area	130360	27000	29200
Total	695720	214000	184600

Table 24. Summary table of costs associated with each site. Hardware and installation costs would occur only in the first year but maintenance would recur each year. The maintenance costs are largely in accessing sites, personnel time to maintain the site and perform analyses.

5. Acknowledgements

This document has been prepared with support from the USGS and the Arctic LCC. Guidance and revisions from the Hydrology, Climate and Permafrost technical work groups were invaluable in assuring the broad applicability of TEON (especially Anna Liljedahl and John Trawicki). Numerous investigators with experience in the TEON sites provided detailed information regarding data availability and infrastructure including Doug Kane (UAF), Matt Whitman (BLM), Chris Arp (UAF), Matt Nolan (UAF), Bill Schnabel (UAF) and Bob Stottlemeyer (UNM, USGS). Figures were prepared by Jennifer Jenkins, Arctic LCC Geospatial Specialist. The Arctic LCC Steering Committee provided valuable feedback regarding the prioritization of different sites and variables. Technical consultation with experts in station design (William Cable, Ken Irving, Bob Busey) improved the rigor and consistency of our recommended hardware and communications.

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- Rick McClure (907-271-2424-x113) at NRCS-Snow Survey. Will we get more snowtel sites? Where will they be located? Can we focus them at our sites?

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