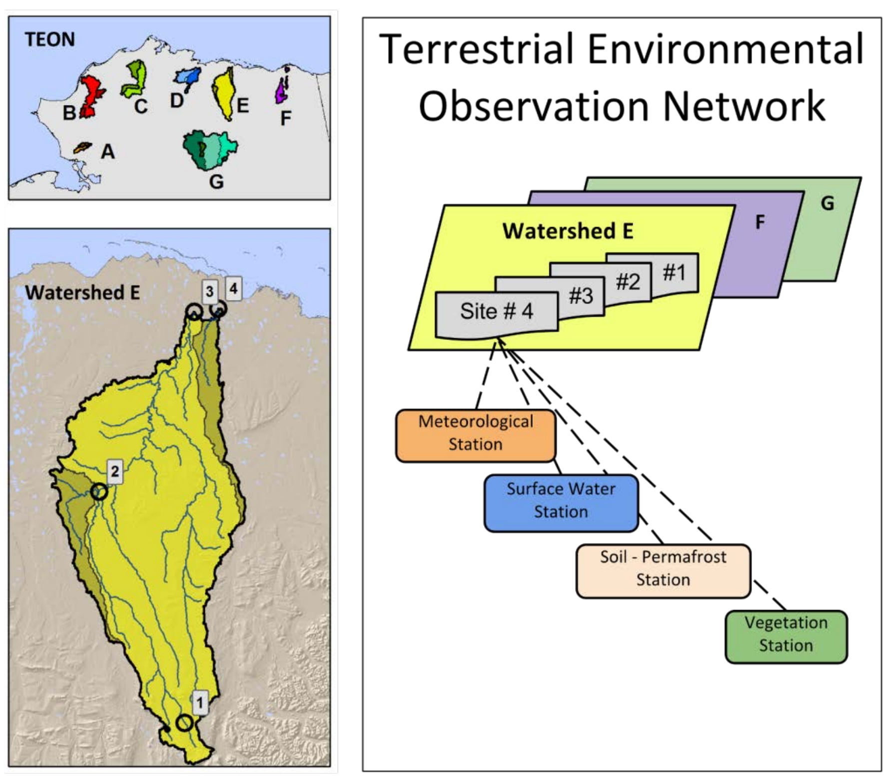
The Terrestrial Environmental Observation Network for Northern Alaska.

What is the Terrestrial Environmental Observation Network (TEON)?

The Terrestrial Environmental Observation Network (TEON) is intended to meet the need for a sustainable environmental observing network for northern Alaska. TEON is organized around representative focal watersheds (Figure 1). TEON will collect, distribute, and synthesize long-term observational data needed to detect and forecast effects of a changing climate, hydrology, and permafrost regime on wildlife, habitat, and infrastructure in northern Alaska.

TEON uses a "nested" approach to data collection. The smallest unit within TEON is a **Station**. Stations include discrete sampling locations or units (e.g., plot or transect) where repeated measures of a given variable are collected to create a time-series. Data collected at a station may be relevant to local conditions (e.g., soil temperature at a given site) or applicable to a larger area (e.g., streamgage located at the lower end of a watershed). A **Site** is a collection of stations that are typically located within close proximity to each other. In the figure below, each site is assigned a number. Sites are grouped into **Watersheds**. Watersheds will encompass many ecotypes and span multiple ecoregions. Watersheds in aggregate form the **TEON** network.



Why is TEON needed?

We expect arctic terrestrial and freshwater systems to change greatly in response to a rapidly warming climate. Exactly how the landscape will change, and at what rate, is difficult to predict. Most terrestrial ecosystem observational data for northern Alaska have been obtained to support short-term research objectives and/or have been limited to a few local study sites. This reduces our confidence that our observations are representative of long-term trends or to the region as a whole. In addition, the data sets that exist are often difficult to access. TEON remedies these problems by providing spatially distributed and consistent, long-term data sets paired with a data management structure that promotes accessibility as well as archival.

What criteria were used to select the TEON watersheds? Where are the TEON watersheds located?
Selection of TEON watersheds was based on three main criteria:

- Minimize the cost of installation, operation, access and maintenance while maximizing the representativeness of the network and continuance of existing data archives.
- Sites are broadly distributed, and characterize the spatial and temporal variability in environmental conditions.
- The network of sites is responsive to the collective needs of a diverse suite of federal, state, academic and industrial stakeholders working in the Arctic LCC domain.

On the basis of the above criteria, and guidance from the Arctic LCC Steering Committee, the following watersheds were selected for TEON: Agashashok River, Kokolik River, Barrow/Meade River, Fish/Judy Creek, Kuparuk River, Hulahula/Jago Rivers, and Upper Koyukuk River (Figure 1).

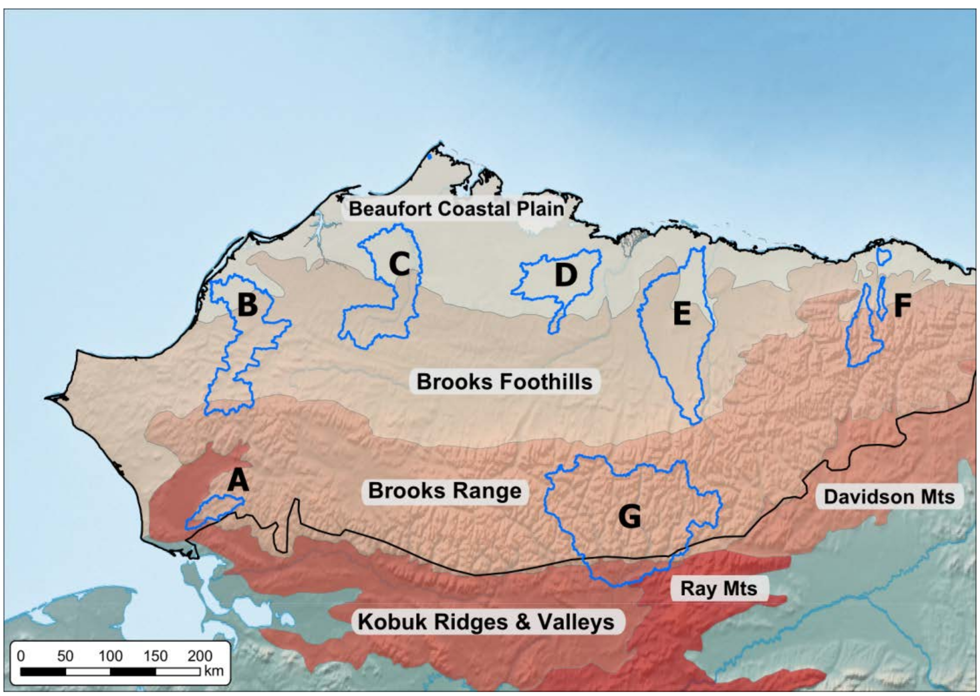
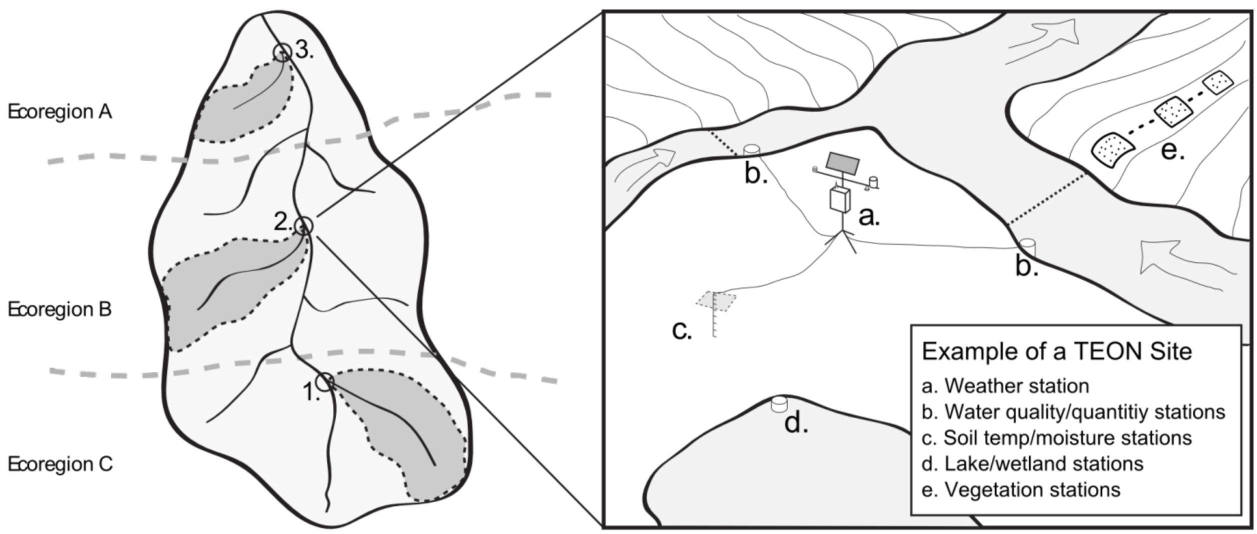


Figure 1. TEON watersheds include A) Agashashok River, B) Kokolik River, C) Barrow/Meade River, D) Fish/Judy Creek, E) Kuparuk River, F) Hulahula/Jago Rivers, and G) Upper Koyukuk River. Collectively, these watersheds sample the major ecoregions (Nowacki et al. 2001[1]) and the longitudinal range represented within the Alaska portion of the Arctic LCC. Image by Arctic LCC staff.

[1]Nowacki, G., Spencer, P., Fleming, M., Brock, T., and T. Jorgenson. 2001. Ecoregions of Alaska, U.S. Geological Survey Open-File Report 02-297.

Where will TEON observations sites be located?

Ideal observation sites are located near tributary-mainstem confluences and provide frequent, synchronous measurements of physical, chemical, and biological attributes. This "nested watershed" design supports characterization of environmental conditions adjacent to the sampling stations, while instream hydrological measurements will reflect both local conditions and inputs from upstream (Figure 2). TEON observations sites are stratified by ecoregions, so we can aggregate data sets across the network to characterize conditions at the ecoregion scale.



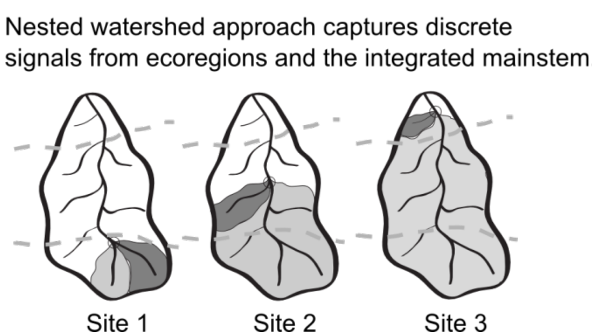


Figure 2. Idealized TEON watershed spanning multiple ecoregions (A, B, C) with nested watersheds (dark gray shading) and observation stations positioned at tributary-mainstem confluence sites (1, 2, 3). A nested watershed approach allows characterization of ecoregion-specific conditions and an integrated signal from the mainstem. In this example, information on water quality/quantity, weather, soil/permafrost, and vegetation is collected at confluence sites (inset). Graphic created by Dr. Benjamin Crosby and modified by Arctic LCC staff.

How well does TEON capture the spatial variability of the landscape?

TEON watersheds span the major ecoregions, north and south sides of the Brooks Range, and include the dominant ecotypes present in the region. See **Appendix A** for details.

What type of data will TEON generate?
The intent of TEON is to measure key system drivers and processes in a standard fashion across sites. Variables to be measured 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. Much of the data will be collected by automated sensors located at mainstem/tributary confluences within each watershed. See **Appendix B** for more information.

How can the information collected by TEON be used?
We use models to help us understand what how the landscape may be altered by climate change, but often we lack sufficient observational data to accurately calibrate models, or evaluate the accuracy of their projections. An important motivation for TEON i*s* to provide data to support those activities, so that models of Arctic ecosystem change can be continually improved. TEON observations can tell us *how* conditions are changing, but also provide a foundation for process-based research that helps us understand *why* conditions are changing.

Long-term, regional-scale data on trends in environmental conditions are also expected to be pertinent to many local management applications. Land managers must often evaluate the environmental impact of human activities, so it is important to have measures of regional "background change." Wildlife managers often want to know why populations of animals are changing, and how variables such as snow cover or forage availability influence populations. Engineers designing river-crossings need long-term records of stream discharge so that infrastructure can be built to last for its intended design life. These are examples of the many potential uses for long-term observational data by different constituencies.

How will TEON data be managed and distributed?
TEON will generate vast amounts of diverse data that will require careful and thoughtful management. Arctic LCC and USGS staff are actively working on designing a data model that will accommodate data generated from automated sensors as well as infrequent but recurring measurements, such as water discharge. The Arctic LCC is committed to making TEON data discoverable and easily accessed, but the details of how these data will be distributed are still in the early stage of development.

What has been accomplished?
Initial planning and design of TEON was completed in early 2013. Activities for 2013 include technical peer review and development of business and data management plans.

What is the schedule for TEON implementation?
Implementation will be incremental and will likely take place over the course of at least four years. TEON is still in the planning stages and the order that the watersheds are brought online is flexible. In some instances, order of implementation may be determined by the availability of funds from LCC partners.

How does TEON relate to other observation networks such as NEON, AON, or the Western AK LCC Stream and Lake Temperature Network?

NEON, the National Ecological Observatory Network, is a continental-scale project with two sites planned for the "Tundra Domain" - Toolik Lake and Barrow. These sites both occur in TEON watersheds. Thus TEON's distributed sites, which better capture regional ecological diversity, will provide a means of spatial extrapolation from the results of NEON for those parameters they measure in common. In general, NEON will collect a much broader suite of physical and biological measurements than TEON, such as gas fluxes between the terrestrial ecosystem and the atmosphere and a comprehensive survey of biodiversity, from microbes to mammals. NEON's intensive monitoring will provide the opportunity for TEON to relate its findings to physical and biological features not directly measured by TEON.

AON, the Arctic Observing Network, is an interagency initiative to coordinate arctic environmental monitoring. At present, AON has not implemented a coordinated terrestrial monitoring system. Arctic LCC staff is working with the Study of Environmental Arctic Change (SEARCH) group, which advises the main funder of AON, to incorporate TEON as an AON activity.

The Western Alaska LCC is working with a number of partners, including Arctic LCC, to leverage existing data collection efforts to establish an Alaska-wide stream and lake temperature monitoring network. TEON, and Arctic LCC, contribute to this effort in a variety of ways. Water temperature is already a core measurement in the TEON design, thus TEON will contribute data. Western Alaska LCC is engaging many partners to design standardized protocols and data standards for water temperature which will inform TEON's operations. Similarly, data models and data systems developed and adopted by the Arctic LCC for TEON will inform those created for the water temperature network, so as to ensure compatibility.

Visit www.arcticlcc.org/teon/ for more information about TEON.

ECOTYPE	% of AK Arctic LCC	% of TEON	Difference in %
Alpine Carbonate Barrens	0.38	0.17	-0.21
Alpine Carbonate Dwarf Shrub Tundra	0.58	0.59	0.01
Alpine Glaciers	0.08	0.08	0.00
Alpine Mafic Barrens	0.19	0.08	-0.11
Alpine Mafic Dwarf Shrub Tundra	0.16	0.11	-0.05
Alpine Noncarbonate Barrens	5.39	3.91	-1.48
Alpine Noncarbonate Dwarf Shrub Tundra	11.50	11.38	-0.12
Cloud, ice, snow	0.52	0.17	-0.36
Coastal Barrens	0.17	0.00	-0.17
Coastal Grass and Dwarf Shrub Tundra	0.51	0.02	-0.49
Coastal Water	0.75	0.00	-0.75
Coastal Wet Sedge Tundra	0.44	0.00	-0.44
Lowland Lake	3.51	3.59	0.08
Lowland Low Birch-Willow Shrub	1.07	0.97	-0.10
Lowland Moist Sedge-Shrub Tundra	6.61	9.25	2.65
Lowland Spruce Forest	0.41	0.41	0.00
Lowland Wet Sedge Tundra	5.35	5.32	-0.03
Riverine Barrens	0.66	0.45	-0.21
Riverine Dryas Dwarf Shrub Tundra	0.21	0.11	-0.10
Riverine Low Willow Shrub Tundra	0.53	0.36	-0.17
Riverine Moist Sedge-Shrub Tundra	1.91	2.19	0.28
Riverine Spruce Forest	0.16	0.44	0.29
Riverine Tall Alder-Willow Shrub	0.03	0.09	0.06
Riverine Waters	0.52	0.44	-0.08
Riverine Wet Sedge Tundra	0.70	0.67	-0.03
Upland Birch-Aspen Forest	0.07	0.21	0.14
Upland Birch-Aspen-Spruce Forest	0.06	0.19	0.13
Upland Dryas Dwarf Shrub Tundra	2.42	1.30	-1.12
Upland Low Birch-Willow Shrub Tundra	20.28	18.00	-2.28
Upland Moist Sedge-Shrub Tundra	6.72	7.32	0.61
Upland Shrubby Tussock Tundra	19.26	16.52	-2.74
Upland Spruce Forest	1.80	5.29	3.49
Upland Tall Alder Shrub	1.26	2.35	1.09
Upland Tussock Tundra	5.79	8.01	2.22

Table 1. Representation of ecotypes (Jorgenson and Heiner, 2004[2]) within the Alaska portion of the Arctic LCC, compared with the proposed TEON watersheds.

[2] Jorgenson, M. T. and M. Heiner. 2004. Ecosystems of northern Alaska. ABR, Inc. and The Nature Conservancy, Anchorage, AK., 1 map.

Appendix B: Types of data collected by TEON

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

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.
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 that 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. 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.). Snow accumulation will be measured with a Nipher snow gage.

Surface water parameters. Measurements of surface water conditions focus on both the quantity and quality of water in both river and lake/wetland environments. Some data will be only available during the ice-free season.

Water level (stage) is measured using a pressure transducer. Water level will be recorded in streams and in lakes.
Measurements of **stream discharge** will be made in the spring and fall, near the annual extremes. These data will be paired with measurements of **stage** to construct a mathematical relationship between the two variables. This stage-discharge relationship allows the stage data to be converted to continuous estimates of discharge.
The suggested parameters for the TEON sites are **water temperature, conductivity, turbidity, pH and dissolved oxygen**. Depending on the particular location, this suite of parameters might be collected in streams and lakes or just streams.
The list of **biogeochemical analyses** is still under development, but likely measurements include 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.
Sediment flux in arctic rivers provides an important measure of upstream disturbances and aquatic habitat quality. Measurements of turbidity made by instruments 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.

Soil and Permafrost Observations. 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.
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.
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.
Water table height can be measured using shallow (<1m) PVC wells and capacitance water level probes. 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.
Active layer thicknesses will be measured using the well-established Circumpolar Active Layer Monitoring (CALM) protocols and include transects and gridded measurements.
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 and carbon and nitrogen concentrations.

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. Botanists will also 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 and explicit protocols will be determined before sites are established.