Tiered Manual for Peatland Monitoring in Alaska's Kenai Lowlands

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Preface

The Kachemak Bay National Estuarine Research Reserve (KBNERR) is a partnership of the National Oceanic and Atmospheric Administration (NOAA) and the Alaska Center for Conservation Science (ACCS) at the University of Alaska Anchorage. KBNERR integrates research, monitoring, education, and training activities to improve scientific understanding and management of natural resources in and around Kachemak Bay. ACCS fosters research, education, and collaboration on biological conservation and natural resource management in Alaska and the Arctic.

KBNERR has a rich history of watershed ecology research over the last 25 years. Most of this research has focused on how landscape elements such as alders, peatlands, and groundwater support juvenile salmon in the Kenai Lowlands. Peatlands have emerged as a major research and outreach focus for KBNERR. Recent and ongoing projects have looked at how much carbon peatlands store and whether beavers can help to keep peatlands wet and reduce greenhouse gas emissions.

Table of Contents

Figure 1. Sundew (Drosera rotundifolia) - a small, carnivorous plant species - growing on Sphagnum moss in a Kenai Peninsula peatland. Other species in this photo include cloudberry (Rubus chamaemorus), bog blueberry (Vaccinium uliginosum), bog cranberry (Vaccinium oxycoccus), crowberry (Empetrum nigrum), bog rosemary (Andromeda polifolia), reindeer lichen (Cladonia rangiferina), and cottongrass (Eriophorum sp.) in the distance.

Introduction

Approximately 20% of the southern Kenai lowlands is covered by peatlands (Figure 2; Gracz and Glaser 2017). These wetland ecosystems are critically important for the region. Peatlands store massive amounts of carbon in thick layers of organic soil. They provide cool groundwater to streams and rivers year-round (Callahan et al. 2015), supporting salmonids and human water infrastructure. They supply dissolved organic carbon to headwater streams, contributing to productivity hotspots that further support juvenile salmonids (Robbins et al. 2017). They provide critical habitats for other wildlife, such as moose, sandhill cranes, and Aleutian terns (e.g., HSWCD 2014c). They create natural firebreaks in the landscape (Berg et al. 2009) and act as natural "sponges" that mitigate flooding (HSWCD 2014b). They support numerous plant species, such as blueberries and cranberries, that are culturally significant to Indigenous Alaskans and other communities across the Kenai Peninsula (e.g., Mulder et al. 2023; Parkinson et al. 2024; Garibaldi 1999). And much more (e.g., HSWCD 2014b).

Peatlands fall under the broader category of wetlands, areas where soils are waterlogged for enough of the growing season that they become oxygen-deprived. Wetlands are identified by their soil, hydrology, and vegetation (Appendix 2), and peatlands have unique characteristics for all three parameters. Many wetlands have organic soils created by anaerobic (oxygen-deficient) conditions that slow the breakdown of organic matter. In a peatland, cold, saturated conditions slow decomposition so much that the rate of vegetative growth exceeds the rate of decomposition, creating a fibrous peat layer that can be meters thick. Peat accumulation over thousands of years (Jones and Yu 2010) sequesters an enormous amount of carbon, although the low level of decomposition that does occur in a peatland typically produces methane, a potent greenhouse gas. In terms of hydrology, peatlands are on a spectrum from "minerotrophic" fens (fed by mineral-rich groundwater) to "ombrotrophic" bogs (fed only by precipitation). The majority of peatlands in the Kenai Lowlands are fens, which are more nutrient-rich and less acidic than bogs. Peatland vegetation is also unique, consisting of mosses, dwarf trees and shrubs, sedges, and other species that are adapted to the cold, wet, and often acidic and nutrient-poor conditions (Figure 1). Many peatlands, particularly bogs, are dominated by a specific genus of moss called *Sphagnum* which creates the spongy structure of the peatland and contributes to its acidification. Fens support a wider variety of vegetation than bogs, especially faster-growing groups like forbs, graminoids, and non-*Sphagnum* mosses. Many fens are dominated by sedges.

Kenai Peninsula peatlands currently face many threats. Due to the glacial history of the region, peatlands on the lower peninsula often overlie gravel deposits and are threatened by gravel mining. Peat itself is also extracted, mostly for horticultural use. Additionally, as the climate warms and precipitation patterns change, the region's peatlands appear to be drying (Berg et al. 2009). This trend is exacerbated by isostatic rebound: the Kenai Peninsula is still rising in response to the loss of heavy glaciers since the last ice age. Shallow groundwater use from private wells, which results in local depressions of the water table, can also contribute to peatland drying.

Drying lowers the capacity of peatlands to provide water to salmon streams and may be turning peatlands into carbon sources. As peatlands dry out, they decompose more quickly and become more susceptible to fire, resulting in more carbon dioxide release. Drier peatlands also produce less methane and support more and larger carbon-storing trees, so the overall effect on greenhouse gas emissions is complicated. Still, peat deposits typically store more carbon than the trees growing in them, and research suggests that forested peatlands have lower long-term carbon accumulation than non-forested peatlands (Beaulne et al. 2021). In response to these issues, Kenai Peninsula communities have stepped up through initiatives like Homer Drawdown to collect more data on local peatlands, raise awareness of peatland benefits, and work toward reducing the threats they face ("Homer Drawdown" n.d.).

KBNERR has created this peatland monitoring manual as a resource for members of the lower Kenai Peninsula community to continue working toward peatland conservation. Peatland monitoring data can be used in a variety of ways. For example:

- Monitoring data can establish baseline conditions for later comparison, measuring the effects of acute threats like habitat conversion due to peat and gravel extraction, diffuse threats like climate-related drying, and restoration actions like beaver dam analogs.
- Monitoring can characterize peatlands by hydrogeomorphology, providing information about the ecosystem services they provide (e.g., US EPA 2015, Gracz and Glaser 2017).
- Monitoring can help measure how much carbon Kenai Peninsula peatlands are storing, and how that carbon balance is changing.
- Monitoring can assess the populations of economically and culturally significant species, and whether their habitat requirements are being met.

This manual focuses on wetland/water parameters and carbon storage. These two categories of monitoring data directly address many of the most important services that peatlands provide (e.g., groundwater storage, flood mitigation, and carbon sequestration) and can indirectly address additional services (e.g., habitat quality for moose or salmon; cultural significance).

This manual is organized into four tiers, representing varying levels of "rigor" or "robustness" for peatland monitoring. This tiered approach is meant to provide monitoring protocols suited for partners with differing objectives, interests, and available resources. Each tier contains an assessment of human disturbance and a vegetation survey of some kind, with additional components in Tiers 2 through 4 that address the core wetland indicators (soil, hydrology, and vegetation) and peatland carbon storage. Particularly with higher tiers, KBNERR anticipates collaborating with partners on equipment and project planning. The tiers outlined here represent an example framework: while monitoring components in each tier are intended to produce a cohesive set of information, users may want to mix and match components based on their capabilities and goals. Many important aspects of peatlands are beyond the scope of this manual, including additional biological data (e.g., birds, insects, and juvenile salmonids) and nutrient cycling data (e.g., soil nitrogen and dissolved organic carbon). KBNERR encourages additional monitoring that addresses user interests and decision-making contexts.

Before monitoring a peatland, be sure to obtain any necessary permissions from landowners or managers for accessing the site and conducting monitoring protocols. The Background Data and Resources section of the manual contains maps and assessments that may be relevant to your peatland(s) of interest. Review these resources before determining the rest of your monitoring plan. In addition, review the General Notes on Locations and Photos, as these recommendations are relevant throughout the manual.

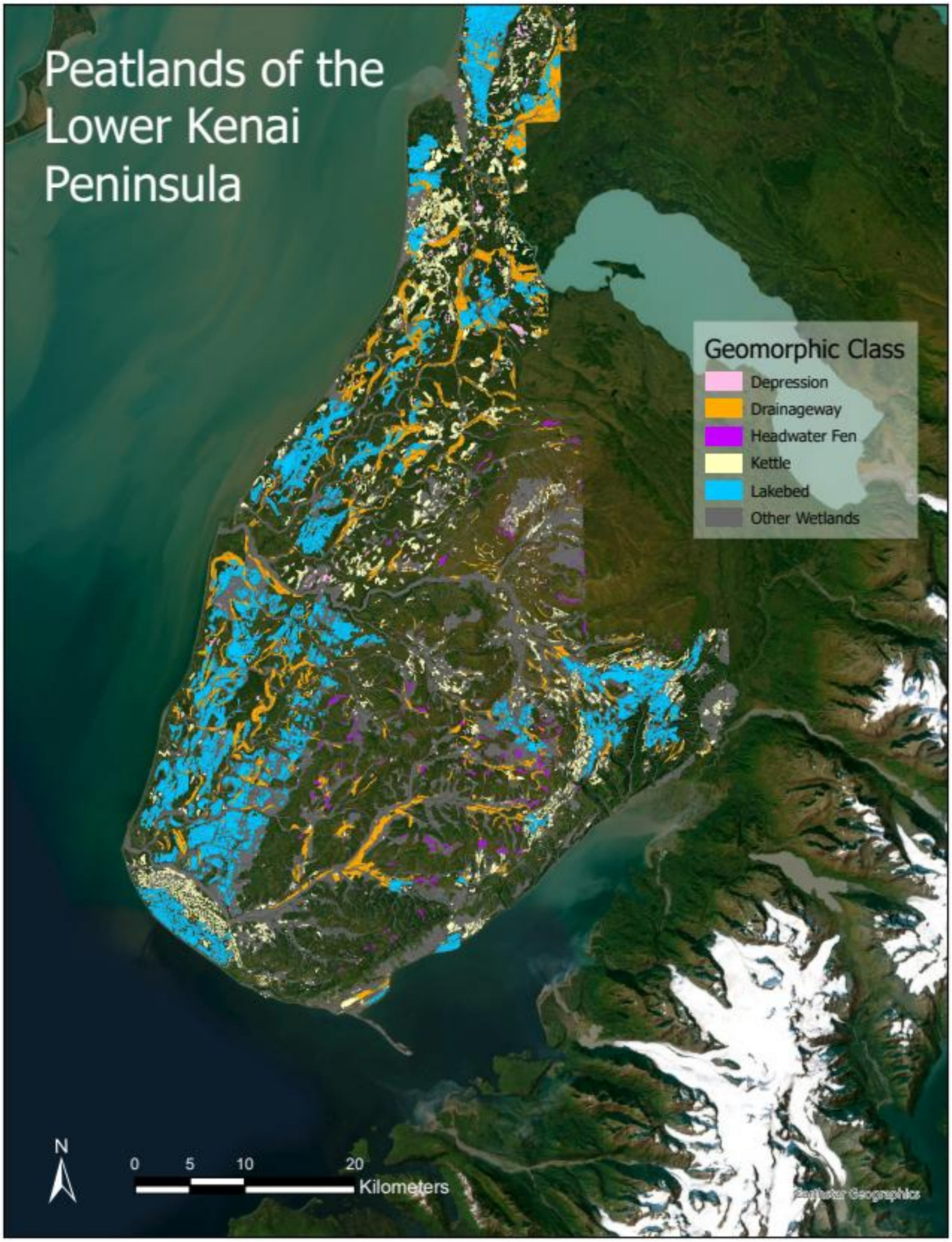

Figure 2. Peatlands of the lower Kenai Peninsula, mapped by geomorphic class. Non-peat wetlands are shown in dark gray. These spatial data were adapted from the Cook Inlet Wetland Classification (Gracz and Glaser 2017) and do not include any wetlands in the Kenai National Wildlife Refuge (KNWR). Peatlands cover 20% of the area south of the Kasilof River, north of Kachemak Bay, and west of KNWR.

Background Data and Resources

Kenai Peninsula scientists, analysts, and natural resource managers have developed many resources that map, classify, and otherwise characterize peatlands and other local wetlands. Here are few to look at:

1) *Cook Inlet Wetland Classification* (Kenai Watershed Forum n.d.): This map, hosted by the Kenai Watershed Forum, classifies all wetlands in the Kenai Lowlands (outside of Kenai National Wildlife Refuge) by their geomorphology and hydrology (Gracz and Glaser 2017; see Figure 2 for a peatland-specific version). Each wetland polygon is associated with an alphanumeric code: for example, LB2 would be a lakebed ("LB") with a water table near the surface for most of the year, often dominated by sedges (code "2"). The five geomorphological wetland types typically associated with peatlands are lakebeds, kettles, drainageways, headwater fens, and depressions. The Kenai Watershed Forum also provides information about the classification system, including definitions. Keep in mind that:
    - This map is NOT an official wetland delineation. While the map reflects extensive field data collection (soil properties, hydrology and water chemistry, vegetation), not all wetlands were visited; many were mapped using aerial image pairs and a stereoscope. Consider the boundaries and classifications as probable rather than exact.
    - Some wetland units have photos associated with them. Click the polygon on the map and scroll down to the "PHOTOURL" field.
    - Each wetland unit has a "Habitat Function" field that describes whether it is coho salmon or sandhill crane support habitat.
2) *National Wetlands Inventory* (USFWS n.d.): The US Fish and Wildlife Service's National Wetlands Inventory (NWI) maps wetlands across the US. The NWI follows the Cowardin classification system, the national standard, which categorizes wetlands by landscape position, vegetation cover and hydrologic regime. The NWI is outdated for this region and is generally less accurate than the Cook Inlet Wetland Classification; an update for all Southcentral Alaska will be released in 2025.
3) *Lowland Peatlands with Homer Drawdown depth data* (Argueta 2021): This map was created by Jacob Argueta, former watershed ecologist at KBNERR, using the peatland polygons from the Cook Inlet Wetland Classification. The point layer shows each peat depth collected by Homer Drawdown in 2021. Click on a point to see the depth and the associated metadata (date, vegetation, etc.). Note that depressions, which are relatively sparse on the southern Kenai Peninsula, are classified as "other wetlands" rather than peatlands on this map.

4) *HSWCD Wetland Function Assessment*: In 2014, Homer Soil and Water Conservation District completed a thorough assessment of the functions and values associated with wetlands on the Kenai Peninsula (e.g. moose winter habitat, salmon habitat support, groundwater recharge). There are specific maps for each of these functions, as well as a few reports: the technical report (HSWCD 2014a) details the methodology, while the Kenai Peninsula Wetlands - A Guide For Everyone (HSWCD 2014b) includes a wealth of information about Kenai Peninsula wetlands. Managing Kenai Peninsula Wetlands (HSWCD 2014c) has a helpful overview of peatlands and how they are defined on pages 36-38.
5) *viewKPB* (Kenai Peninsula Borough n.d.): Kenai Peninsula Borough's map viewer has a number of layers that are potentially relevant to peatland monitoring:
   - An aerial photo mosaic for the northern Kenai Peninsula from 1950-52.
   - Historic aerial photos from various years: zoom in to see the locations and years, then click on an individual point to access the photo.
   - 9" imagery collected between 2020 and 2024; the 9" imagery index shows the years when different pieces were collected.
   - Terrain: you can look at 2008/09 LiDAR data, as well as 5-foot contours.
   - Currently, viewKPB also shows the Cook Inlet Wetland Classification.

General Notes on Locations and Photos

Locations and photos can be extremely valuable for tracking changes over time. Throughout this manual, photographs and GPS coordinates are recommended as easy and effective methods to complement other sources of data. Here are a few tips for making the most out of photos and GPS coordinates:

Photos

1) Site photos are almost always helpful. If you're wondering whether or not to take a photo, do it!
2) Align general camera angles for consistency, use landscape orientation, and make sure that photos are in focus.
3) Use a handheld whiteboard to note location (e.g., plot number), date, project, and direction (e.g., N) if applicable.
4) Minimize backpacks, people, and other obstructions in photos. The whiteboard is an exception to this guideline; for photos capturing a landscape (rather than just the ground), a person holding the whiteboard is also acceptable.
5) Keep photos organized and backed up, with a consistent filing and naming convention that includes the date (e.g., project name, date, site number). Note that cell phone photos are typically tagged with date and time.

GPS

1) GPS coordinates can be collected from a dedicated GPS unit or from a smartphone. However, some GPS units are more accurate than others, and phones are typically not very accurate. Consider how much accuracy is needed; it may be helpful to look at both coordinates and photos when coming back to a location. For better precision, use a GPS/GNSS receiver with real-time kinematic (RTK) capabilities and a handheld antenna. These units offer cm-level accuracy given a close enough base station, but do require training and practice to collect and process data.
2) Wait for your location to stabilize. On a dedicated GPS unit, you can view the accuracy of your location and wait for that accuracy to reach a certain threshold (e.g., 3 m).
3) To maximize accuracy, use decimal degrees rather than degrees-minutes-seconds. 1 second is equivalent to 0.00028 degrees, so using degrees-minutes-seconds sacrifices the last two decimal places typically obtained from a GPS unit. For mobile apps, you may need to change the units in settings.
4) There are many mobile locator apps (e.g., Gaia, Avenza, Field Maps, Google Earth) that can track locations without cellular service, but you will need to download a map before leaving service.
5) Note the datum used by your app or GPS unit (e.g., NAD83 or WGS84), or specify which datum should be used.

Tier 1 Monitoring

For the base level of peatland monitoring, KBNERR recommends a check for human disturbance (to understand baseline health condition) and a visual estimate of vegetation coverage. Hydrophytic (water loving) vegetation is a well-proven proxy for a saturated-to-inundated water regime. A transition from typical upland plants to hydrophytic species indicates where a peatland transitions from upland to wetland, and the presence of particular wetland plant communities indicates how wet a particular part of the peatland is. For example, if the community is dominated by obligate wetland species (i.e., plants that virtually never occur outside wetlands), then inundation is typical during the growing season. Alternatively, if the community is dominated by facultative wetland species (i.e., plants that often occur in wetlands, but can also live in uplands), then soil saturation may be more variable. Because drying is the greatest threat facing peatlands in the Kenai Lowlands, establishing a baseline wetness level is critical for monitoring how peatlands are changing over time, and how ecosystem services like groundwater for streams might change as a result.

Tier 1 monitoring requires little instrumentation and can be completed relatively quickly. Monitors should have general working knowledge of plant identification or appropriate plant ID guide(s) to refer to (see Appendix 2). Knowledge of the U.S. Fish and Wildlife Service's wetland indicator status (facultative, obligate, etc.) is not necessary for completing the survey, but is helpful for contextualizing plant species data. Indicator status codes for Alaska's plants can be found on the Alaska Wetland Plant List (USACE; see Appendix 2).

Disturbance

Many forms of human disturbance in a peatland damage the insulating 'blanket' of surface vegetation. This can expose subsurface peat, causing an increase in decomposition and, in some cases, erosion. Monitoring for human disturbance can be quick and need not be quantitative. Take date-labelled notes and pictures of any relevant disturbance so that you can compare with future conditions. Take GPS coordinates if relevant. Note ATV trails or other human trails; hydrological disturbance such as draining, ditching or impoundments; littering; peat extraction; vegetation removal or land clearing; and other activities that disturb the ecological integrity of the peatland. Minor disturbance from monitoring activities should be noted if visible but should not preclude monitoring. A clear view of the whole peatland is important to understand holistic conditions. If you can see only part of the peatland, walk around it to observe the rest.

Vegetation

The goal of a quick, visual vegetation survey is to estimate percent cover of the primary vegetation types by looking out across a peatland. Guidelines below offer more detail on conducting surveys in a repeatable, methodical manner. This survey will also establish an approximate perimeter of the peatland and identify key locations to return to over time to detect change. KBNERR recommends surveying with a field partner to compare percent cover estimates.

Where: The first step of a quick visual survey is to determine the approximate boundaries of the peatland. An electronic map (e.g., ESRI Field Maps, Avenza) is helpful for outlining the peatland area. Mark at least four GPS coordinates spread evenly along the boundaries, and mark a GPS point at the approximate center of the peatland. If boundaries are unclear, you may need to set these points somewhat arbitrarily. Install a reference post (rebar or wooden stake) as a physical reference to come back to. Once peatland boundaries are determined, conduct a community-level survey from one of the boundary points (or the center point) that provides broad visual coverage of the entire peatland. If this isn't possible, use multiple vantage points; in that case, keep track of which zone of the peatland you are considering from each vantage point, and make sure that these zones do not overlap (Figure 3). Mark GPS coordinates and set posts for any previously unmarked observation points.

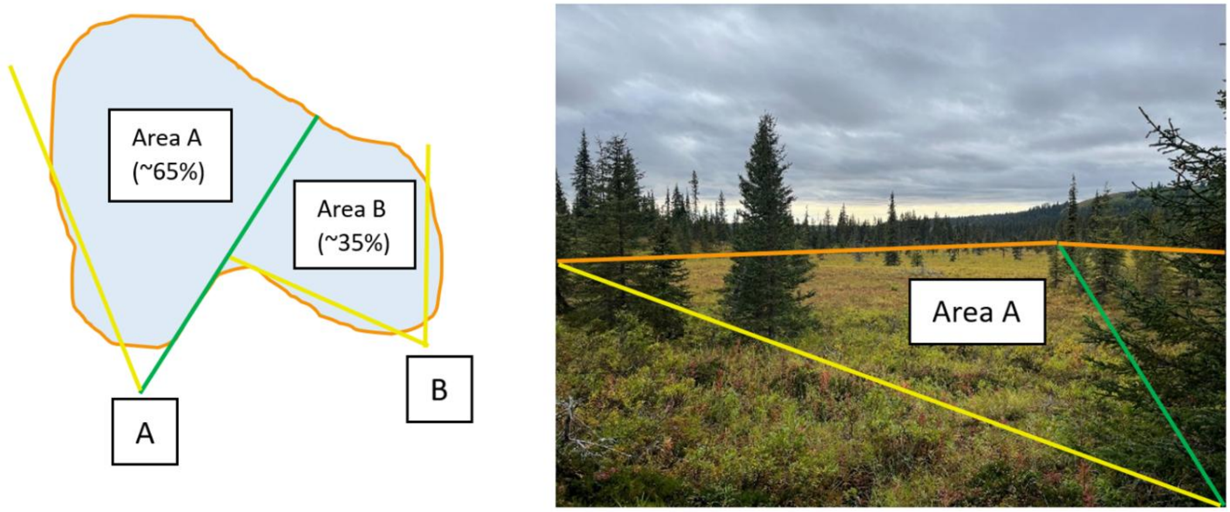

Figure 3. Example of using multiple peatland vantage points (A and B), shown with an overhead diagram (left) and partial ground view (right). Orange lines show peatland boundaries, while yellow and green lines are lines of sight. Everything to the right of the green line isn't visible from point A. If a better observation angle is not available, one would need to add a second observation point (point B), keeping track of landmarks on the green line so that vegetation to the left of the line doesn't get counted twice. Each percent cover would need to be multiplied by the proportion of the peatland taken up by the respective survey area (e.g., 0.65 for Area A) so that the total cover adds to 100%. In this photo, the peatland is large enough that visual observation from boundary points can only determine broad vegetation communities (e.g., tree, shrub, graminoid). One would need to look more closely at each community to determine species coverage.

When: Ideally, vegetation should be surveyed at full flowering, when easily identifiable. Typically, July is most appropriate in Alaska. However, owing to change in foliage, certain species (e.g., blueberry and willows) are highly distinguishable from a distance briefly in September. A rough visual estimate is possible any time from late June through September. Repeat this survey at least once every 5 years.

How: For a quick visual survey, focus on the most common plant species or abiotic (non-living) groundcovers (e.g., open water, gravel, bare soil). The goal is to divide the peatland into categories of percent cover that add up to 100%; consider only the tallest vegetation at any given point ("top cover”). **Note plant species and abiotic groundcovers that cover at least 5% of the peatland**. If you are unable to identify a plant to species, identify the genus (e.g., *Sphagnum*) or the lowest taxonomic group that you can (e.g., sedge).

For many peatlands, it’s easiest to start by dividing coverage by vegetation community rather than species (Figure 4). The following categories are suggested:

1) Tree (e.g., spruce)
2) Shrub (e.g., Barclay willow, dwarf birch, labrador tea, crowberry)
3) Graminoid (e.g., bluejoint reedgrass, sedges)
4) Forb/Pteridophyte (e.g., lousewort, iris, buckbean, horsetail)
5) Moss/Other Non-vascular species (e.g., open *Sphagnum* hummock, lichen)
6) Open Water
7) Bare Soil
8) Rock

Next, identify dominant species within categories. This step will likely require looking more closely at the vegetation: for example, an area that looks like open *Sphagnum* moss may in fact have a significant amount of bog cranberry and sundew. It may be easiest to rank species by percent cover first, then estimate values. For example, if 25% of the peatland is covered by shrubs, maybe the most common species is crowberry, followed by dwarf birch and bog blueberry, while other shrubs (e.g., labrador tea and bog cranberry) are present but sparse. With these rankings in mind, attach rough estimates of percent cover to each species (e.g., 10% crowberry, 5% dwarf birch, 5% bog blueberry, 5% other shrub). Estimate percent covers individually first, without consulting your field partner, and have them do the same. Once both of you have estimates, confer and reconcile discrepancies.

Photographs are recommended at the following locations:

1) GPS-marked boundary points, looking out into the peatland; note the direction (e.g., NE)
2) The GPS-marked center point, looking in each cardinal direction (N, S, E, and W)
3) Any additional observation points, if used
4) A representative location for each vegetation community, with an associated GPS point for each photo. Include an object of known size (e.g., a labelled whiteboard) for size context.

Materials

- Camera
- Whiteboard and marker
- GPS-enabled device
- At least five wood or rebar stakes, and a mallet
- Appropriate plant ID guides (see Appendix 2)
- Data sheet or notebook with pen or pencil, or an electronic device for recording data
- Personal field gear (e.g., rubber boots or waders, weather-appropriate clothing, bear spray)

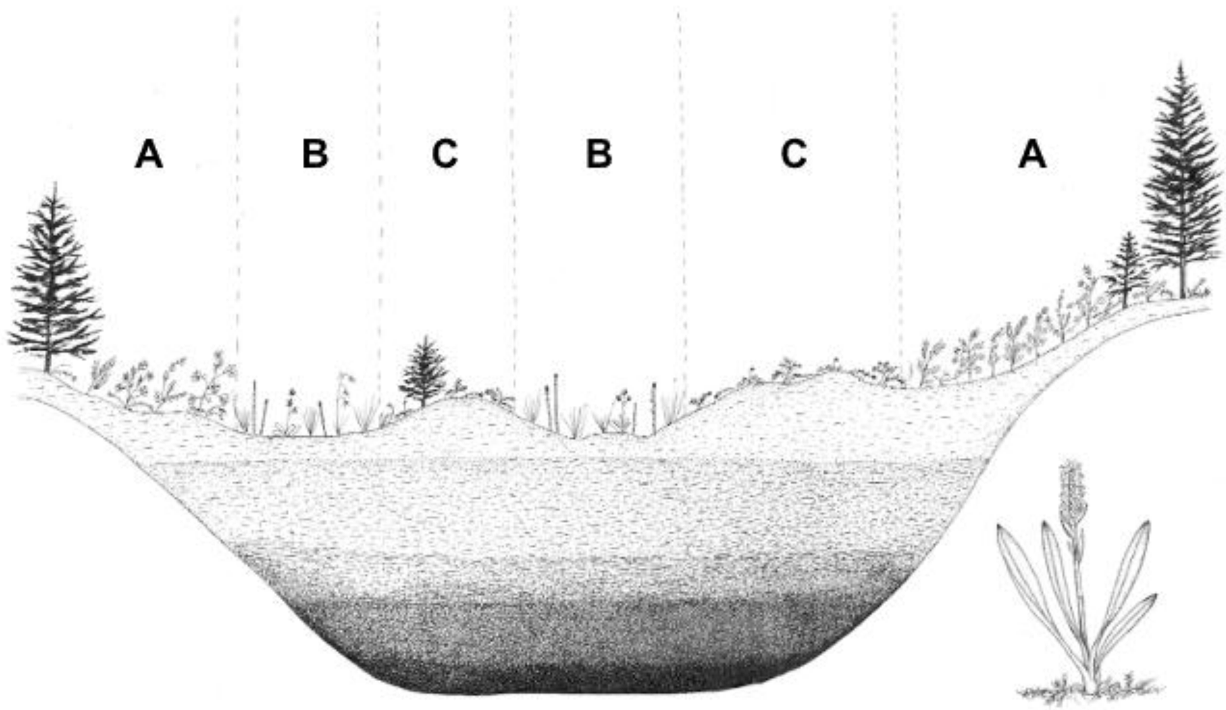

Figure 4. Cross section of a typical peatland showing different vegetation communities. In this example, A is low shrub forest (could be classified as shrub/tree), B is sedge depressions (graminoid or graminoid/forb), and C is moss hummocks (shrub/moss). Illustration by Conrad Field.

Tier 2 Monitoring

The second tier of peatland monitoring incorporates a more in-depth vegetation survey along with a basic soil and hydrology survey. Vegetation data provide a proxy for hydrological regime; soil and hydrology data points can help substantiate inferences based on vegetation. Together, these data characterize a peatland through a wetland delineation lens and establish baseline conditions to assess future peatland drying.

Tier 2 requires a few pieces of basic scientific equipment (e.g., measuring tape); the Tier 2 vegetation survey can be time-intensive depending on the length of vegetation transect(s) and the surveyor's plant identification skills. Surveyors should have a working knowledge of plant identification and appropriate plant ID guide(s) at hand (Appendix 2). A basic understanding of soil science is also recommended. Knowledge of the wetland indicator status system (facultative, obligate, etc.) is not necessary for completing the vegetation survey but is helpful for contextualizing field data. Indicator status codes for Alaska's plants can be found on the Alaska Wetland Plant List (USACE; see Appendix 2).

Disturbance

Follow the Tier 1 protocol for monitoring disturbance. In addition, divide any human disturbance you see into the following categories:

1) Trails (ATV or human)
2) Littering or waste dumping
3) Hydrological disturbance (draining, ditching, impoundments, etc.)
4) Peat extraction or mining
5) Vegetation removal (e.g., logging, land clearing)
6) Construction
7) Invasive species
8) Other (create categories as needed)

For a more exhaustive list of disturbance types, see Table 9 in Bureau of Land Management (BLM)'s *Field Protocol for Lentic Riparian and Wetland Systems* (BLM 2024; see Appendix 2 of this manual). Note that BLM categories include some forms of natural disturbance (e.g., beaver activity, wildfire).

For each relevant category, rate the scope of the disturbance using the categories in Table 1.

Table 1. Disturbance categories are based on the percentage of the plot or landscape that is affected by the disturbance.

Scope	Definition
1 = Rare	Affects a small portion (1-10%) of the plot or landscape.
2 = Restricted	Affects some (11-30%) of the plot or landscape.
3 = Large	Affects much (31-70%) of the plot or landscape.
4 = Pervasive	Affects all or most (71-100%) of the plot or landscape.
P = Present	Used for hydrology disturbances only.

Vegetation

For Tier 2, KBNERR recommends surveying vegetation using the line point intercept technique. This method uses precise points at even intervals along a transect to generate unbiased percent cover estimates of plant species intersected by the transect. Because peatlands and other wetlands are particularly sensitive to trampling, limit the crew working on any transect to two or three people. Trampling can lower the microtopography along the transect, biasing future measurements towards more hydrophytic vegetation than found in the rest of the peatland.

Where: Run a transect upgradient from the wettest portion of the peatland to upland vegetation; continue at least 5 m into upland vegetation as a spatial buffer in case there is future expansion of wetland conditions. This transect may be replicated in multiple directions to increase data quality. Alternatively, if the peatland is too large and/or heterogeneous for a wet-to-dry gradient, survey at least one transect representing each distinct, substantial vegetation community (e.g., sedge meadow, dwarf shrub-*Sphagnum* hummocks, or spruce/shrub edge). Transects should be a minimum of 25 m, or longer as necessary to capture the wet-to-dry gradient or variation in the vegetation community (Figure 6). For each transect, record GPS coordinates for start and end points, and mark these points with wood or rebar stakes as physical references. Take standard transect photos as described below.

When: Ideally, vegetation should be measured at full flowering or seed development. Typically, July is most appropriate in Alaska, but late June through September can also work. Full seed development is often required to identify graminoid species; height measurements will be most meaningful at that time as well. Repeat vegetation transects at least once every 5 years.

Figure 5. A researcher using a transect tape and vertically-mounted laser pointer to survey vegetation using line point intercept methods. These methods reduce bias as compared to a visual survey and enable the calculation of both foliar cover and top cover.

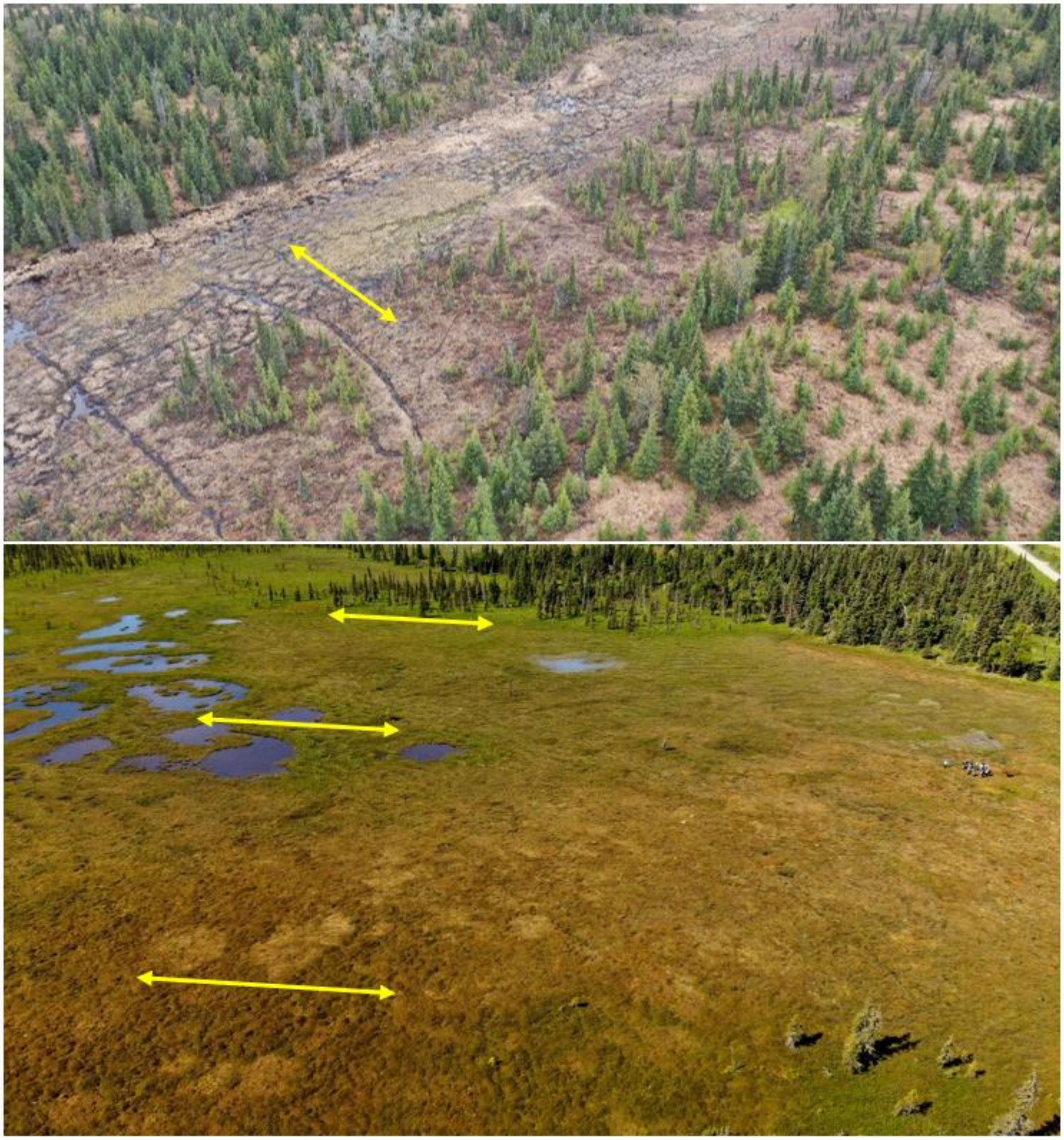

Figure 6. Examples of vegetation transect schemes, with yellow arrows showing transects. The top photo shows a narrow drainageway peatland where a simple wet-to-dry transect from the center of the drainage to the first 5 m of upland vegetation makes sense. The bottom photo shows a larger, more heterogeneous peatland where a wet-to-dry gradient would likely be very long, and less representative of the whole peatland. From top to bottom, the three proposed transects cover the peatland-forest edge, the zone with standing water, and a zone likely dominated by dwarf shrubs. Drone imagery by Jacob Argueta.

Line Point Intercept

For each transect, extend a measuring tape in a straight line. Take data points at 0.5 m intervals. Record the plant and groundcover type(s) present at each point (there may be multiple plants). This method is easiest using a laser pointer oriented vertically down (Figure 5): each plant (or groundcover) intersected by the beam is recorded. For example, if the laser intersects a willow leaf, then a grass blade, then moss, record all three species in that order. Dropping a pin, or an equivalent implement like a pencil, will also work. In particularly muddy zones where dropping a pin isn't feasible, record what plant(s) (if any) intersect the transect at an imaginary vertical line to the ground at the 0.5 m interval on the measuring tape.

When collecting data at point intercepts, record live plants or recently dead stems, if still rooted; note if plants are dead. Record vascular plants to species level if they comprise more than 1% of the foliar cover at point intercepts. Record nonvascular plants or other organisms to at least the functional group level. For Tier 2, KBNERR suggests using the following basic functional groups (Figure 7):

1) *Sphagnum* moss
2) feathermoss
3) other bryophyte (other moss, liverwort, hornwort)
4) soil lichen (often fruticose)
5) rock lichen (often crustose)
6) wood lichen (often foliose)
7) other biotic (algae, fungus, slime mold, cryptobiotic crust)

This is a simplified scheme for grouping nonvascular species into ecologically meaningful yet easily identifiable categories. For a more detailed functional grouping scheme, see Appendix 2 of Alaska's *Minimum Standards for Field Observation of Vegetation and Related Properties* (VTWG 2022; these standards are linked to Appendix 2 of this manual).

Groundcovers should be recorded using the following categories, adapted from Table 8 of the *Minimum Standards for Field Observation of Vegetation and Related Properties* (VTWG 2022; Appendix 2). Record the first non-living groundcover you encounter at each point. If there is a living groundcover (e.g., moss), assume that the underlying material - typically soil - is similar to your surroundings to avoid digging up the vegetation.

1) Dead standing woody vegetation
2) Dead down wood ($\geq$ 2 mm diameter)
3) Plant litter (non-woody or < 2 mm diameter)
4) Exposed bedrock
5) Rock fragments
6) Soil
7) Water
8) Other non-living biotic material (e.g., dung, bones)

If you are unsure of an identification, take photos and consider collecting a sample outside of the transect. Plants should be collected, and ideally photographed, as full specimens, including roots, stems, leaves, and flowers if present. For longer-term preservation, plants can be arrayed and pressed between two hard surfaces to remove moisture while maintaining form. If you suspect the unknown plant is a rare species, take a photo instead of collecting a sample. For further confirmation, note that UAA's Alaska Center for Conservation Science Herbarium offers plant determination and annotation services for collected specimens. See the ACCS Services page for more information (ACCS 2025).

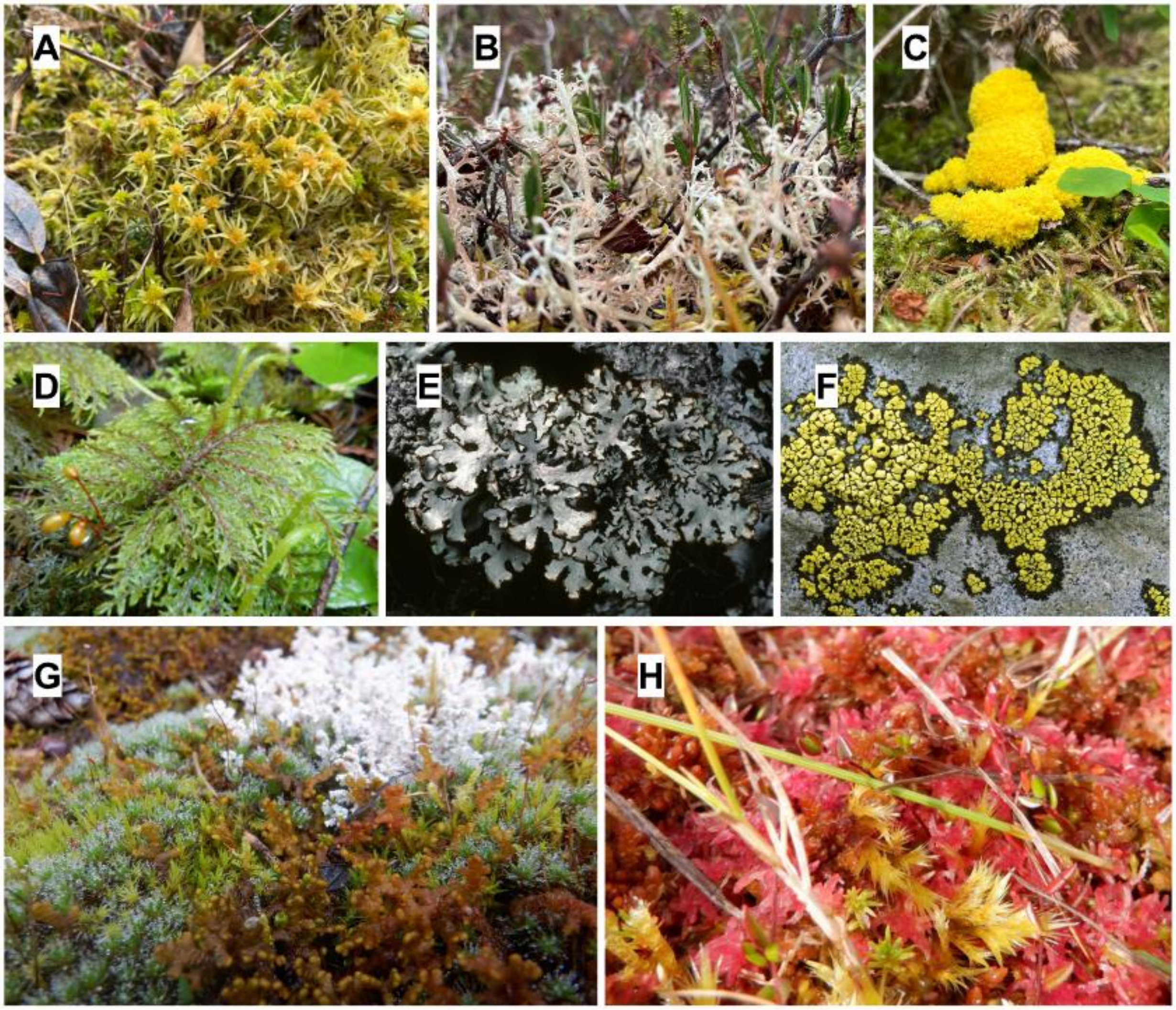

Figure 7. Examples of nonvascular species groups. A is a Sphagnum moss (Sphagnum angustifolium). B is a fruticose soil lichen (Cladonia rangiferina) amid some dwarf shrubs. C is a slime mold (Fuligo septica), which fits in "other biotic." D is a feathermoss (Hylocomium splendens). E is a foliose wood lichen (Hypogymnia physodes; photo by Steven Sharnoff). F is a crustose rock lichen (Rhizocarpon geographicum; photo by Steven Sharnoff). G contains a mix of "other bryophytes," including the liverwort Ptilidium ciliare (brown species in foreground and background) and other mosses. There is also a white fruticose lichen in the background. H is primarily a red Sphagnum species, but the yellow-green moss mixed in (Aulacomnium palustre) would be categorized as "other bryophyte".

After returning from the field, estimate percent cover of plant species and abiotic groundcover types for the site by dividing the number of occurrences by the total number of points sampled along a transect, multiplied by 100. For example, if the laser encountered Species A at 25 of the 75 points sampled, then the percent cover of Species A is estimated to be (25/75)*100 = 33%. If a transect is on a wet-to-dry gradient, create subsets by general vegetation community (e.g., wetter side vs. drier side), then estimate percent cover within each subset. Subsets will be somewhat subjective and based on field observations; aim for broader subsets (≥ 10 m) when possible. For change analysis, these subsetted percent covers will likely be more informative than overall site percent covers.

Heights

Heights of plant species along the transect(s) provide a proxy for site-level biomass. Every 5 m (or more frequently), measure the second highest woody and herbaceous individuals located within a 15 cm radius of the sampling point; record the species of each. The second highest plants are targeted to avoid measuring individuals with outlying heights. Height is measured from the base of the plant at ground level. For thick moss, "ground level" is defined as the point where the moss transitions from live to dead (note the difference in color), or where the density increases substantially (moss-soil transition); generally, these are about the same point. Herbaceous species such as grasses and horsetails should be extended to full length for measurement, while woody species such as willows should be measured at their natural standing height. You may want to note phenological state as well: a flowering grass in late summer will be taller than the same grass earlier in the season. Monitoring techniques should be consistent over time.

Photos

At a minimum, take the standard transect photographs described below. Transect lines can appear in photographs.

1) A photo from each end of the transect facing towards the other end to capture landscape context. For wet-to-dry transects, one photo will be looking toward the peatland center from the upland edge, while the other will be opposite.
2) A photo capturing vegetation along the transect every 10 m. The portion of the transect should take up the entire frame of the photograph.

Additional photos from GPS-marked points on the boundary or in the center of the peatland are encouraged (see Tier 1 vegetation).

Materials

- Laser with mount, pin, or equivalent implement
- Measuring tape and ruler
- Two wood or rebar stakes for each transect, and a mallet
- Data sheets with a pen or pencil, or an electronic device for recording data
- Appropriate plant ID guides (Appendix 2)
- Hand lens
- Camera
- Small whiteboard and marker
- GPS-enabled device
- Resealable storage bags for plant specimens not identifiable in field (3 gallons ideal for larger specimens)
- Permanent marker for labeling bags
- Personal field gear (e.g., rubber boots or waders, etc.)

Soil and Hydrology

Equally important to documenting hydrophytic vegetation is assessing wetland soil and hydrology. Hydric, or wetland, soils are defined in different ways depending on whether they are predominantly organic (derived from plant material) or mineral (sand, silt, and/or clay). Organic material tends to accumulate in wetlands because decomposition is slowed in soils that are saturated or inundated for much of the growing season. For this reason, soils with surface accumulations of organic material more than 20 cm (8 in) thick are considered hydric in Alaska (Figure 8). Peat soils are distinguished by this thick layer of organic material.

When examining mineral soils, primary indicators that they may be hydric include a hydrogen sulfide (rotten egg) odor and/or the coloration of the soil matrix. Under aerobic (oxygenated) conditions, iron and manganese oxides give mineral soils their reddish-brown color. When soils are saturated or inundated for long enough, oxygen is depleted; iron and manganese become soluble and are transported to less reduced soil, resulting in a bluish- or greenish-gray color referred to as “gleyed.” Either a uniformly or partially gleyed horizon is evidence of a hydric soil (Figure 8). Partially gleyed horizons may have patches of reddish-brown “rust,” often in pore spaces or around plant roots. These rust patches consist of iron and manganese oxides, and are often called “redox features.” For a more detailed list of local hydric indicators, see the *Field Indicators of Hydric Soils in Alaska* (Appendix 2; Moore 2018).

Wetland hydrology is indicated by evidence of significant periods of inundation or saturation. Presence of surface water indicates current inundation, whereas current saturation is indicated by a high water table (within 30 cm (12 in) of the soil surface). Indicators of past inundation are less straightforward and include evidence such as water marks on tree trunks or shrub stems, sediment deposits in topographic lows, drifted material, drainage patterns, water stains on vegetation, surface iron deposits, or surface soil cracks (Figure 9).

The national standard for identifying soils is to describe soil horizons using the NRCS *Field Book for Describing and Sampling Soils* (Appendix 2; Schoeneberger et al. 2012). However, describing soil horizons is a complicated process, even for soil scientists, so for Tier 2 surveys, KBNERR recommends simply noting the thickness of the organic layer (if present), as well as noting any hydric indicators evident in the mineral soil. For hydrology, KBNERR recommends taking point measurements of water levels, as well as noting any indicators of past inundation or saturation.

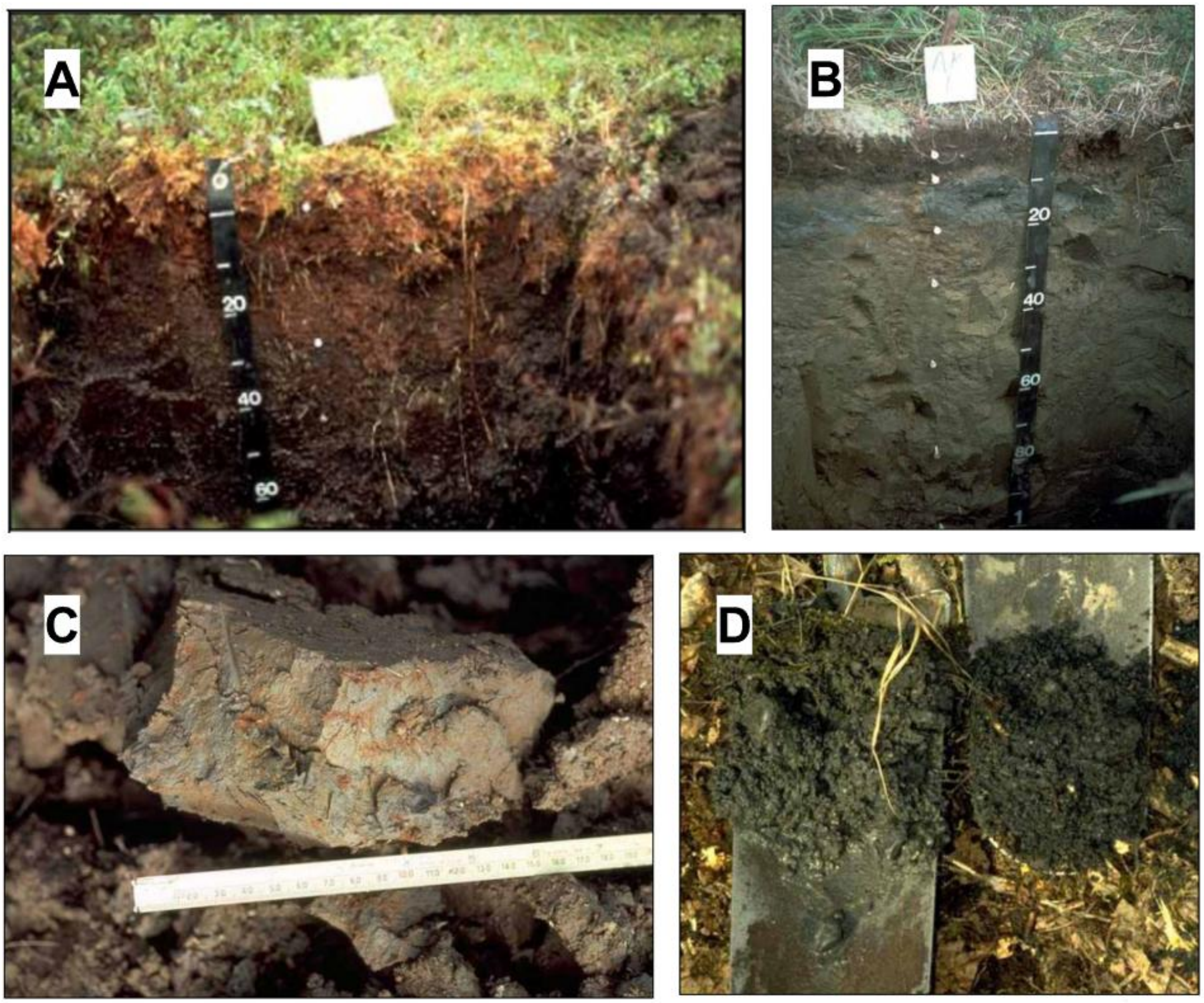

Figure 8. Hydric soil indicators. A shows a saturated organic soil horizon 60 cm (24 in) thick; B shows a narrow gleyed horizon between two aerobic horizons; C shows gleyed soil with redox features around root channels; D shows a comparison between gleyed soil on the left and aerobic mineral soil on the right. Images are from the Alaska supplement for wetland delineation (USACE 2007).

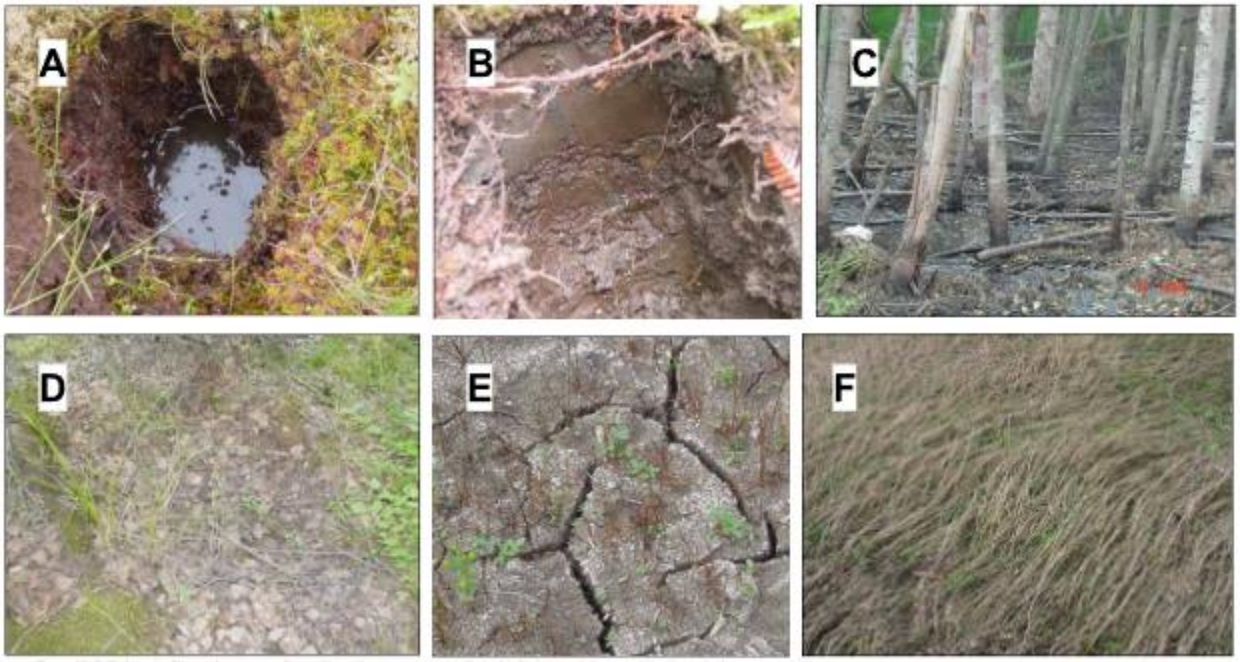

Figure 9. Wetland hydrology indicators. A shows a soil pit with a water table less than 30 cm (12 in) below the ground surface; B shows saturation in a soil pit (note the glistening water); C shows water marks in a birch stand; D shows a drift deposit of leaves from seasonal inundation; E shows cracked soil from drying-related contraction; and F shows vegetation bent over consistently in the direction of water flow. Images are from the Alaska Supplement for Wetland Delineation (USACE 2007).

Where: To assess peatland soil and hydrology, dig two soil pits: one in a representative wetland location within the peatland, and one in a representative upland location just outside the peatland. Take a GPS point for each soil pit, and take a photo of each with a ruler placed in the hole to indicate depth.

When: Soil and hydrology can be characterized any time the ground is not frozen (typically May or June through early October). However, water levels can vary markedly throughout the year: typically, water levels are highest during spring breakup and fall rains, and lowest during the summer. Keep track of survey dates and interpret results in terms of seasonality.

How: If there is standing water prior to digging, measure the distance from soil surface to water surface. Use a shovel to dig soil pits that are 46 cm (18 in) deep and approximately 30 cm (12 in) wide. Alternatively, use a soil auger (see Tier 3). First determine whether the soil is organic or mineral. Organic soil often has visible fibers from decomposing plant material and is darkly colored. If you are unsure whether soil is organic, rub a small sample between your thumb and other fingers a few times. Mineral soil will feel gritty, while organic soil will feel greasy. Determine the thickness of the organic material; if the organic layer is less than 20 cm (8 in) thick, note any hydric indicators associated with the mineral layer(s) (see introduction to this section and Figure 8).

To characterize hydrology, use a ruler or measuring tape to measure the distance from soil surface to groundwater pooling in the pit. If there was standing water at the site, record that depth instead, labelling it as a negative depth. Note any indicators of past inundation or saturation, if relevant (see introduction to this section and Figure 9). When finished, make sure to fill in all excavated soil pits and "cap" them with the removed vegetation layer.

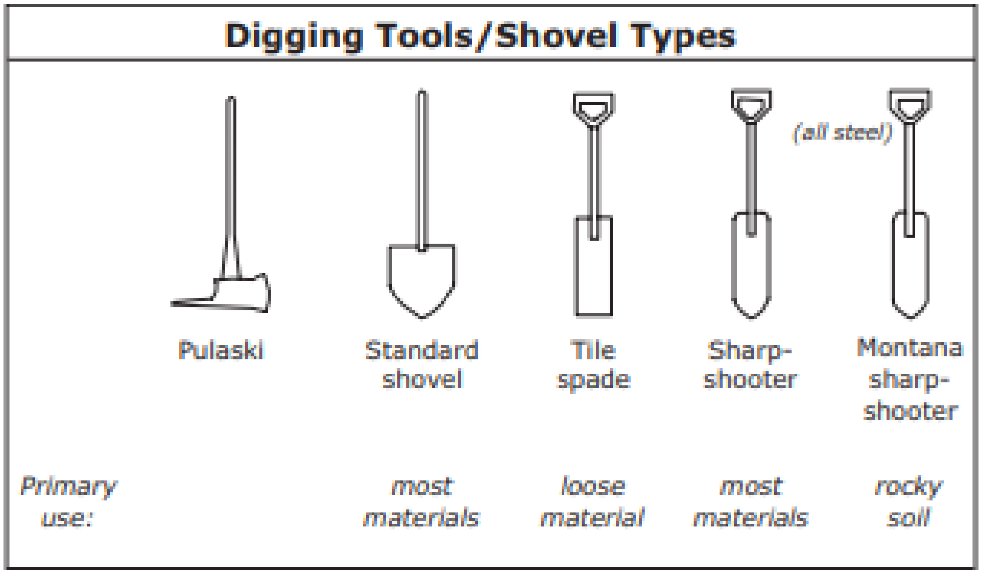

Figure 10. Shovel styles and primary uses, from the NRCS Field Book for Describing and Sampling Soils (Schoenberger et al. 2012, section 8-5). Typically, a sharpshooter style is best for digging soil pits because of its narrow profile, which results in less surface damage than a standard shovel.

Materials

- Shovel (sharpshooter style ideal; Figure 10)
- Data sheet or notebook with pen or pencil, or an electronic device for recording data
- GPS-enabled device
- Camera
- Whiteboard and marker
- Ruler or measuring tape
- Personal field gear (e.g., rubber boots or waders, etc.)
- Clippers to cut roots

Tier 3 Monitoring

The third tier of peatland monitoring incorporates a more detailed assessment of hydrology, as well as a peat depth survey paired with soil coring. At this tier, KBNERR recommends installing groundwater wells (water-table wells or piezometers) to enable more precise water level tracking over time. A high water level for a significant part of the growing season directly indicates wetland hydrology. These wells can also be used to collect water samples; tracking a few key water chemistry indicators (temperature, conductivity, and pH) can indicate where water is coming from - for example, whether the source is predominantly precipitation or groundwater. Water levels and chemistry can also indicate how peatlands might affect nearby headwater stream ecosystems: for example, whether they modulate discharge and/or water temperature in streams flowing through or adjacent to the peatland. Repeated water level measurements, combined with repeated vegetation transects, indicate trends in peatland drying or, in the case of restoration projects, peatland re-wetting.

Surveying peat depth, and pairing that survey with soil coring, can indicate underlying peatland geology and how much organic matter (and carbon) the peatland is storing. Soil coring helps with interpretation of peat depth data because soil cores can show layers that are not peat. This information is especially important in shallow drainageway peatlands or along peatland edges. Soil cores can also be analyzed for hydric indicators, completing the assessment of wetland hydrology.

Tier 3 requires more time and specialized equipment (piezometers, water chemistry probe, tile probe, soil auger) than Tiers 1 and 2. Many Tier 3 steps (piezometer installation, tile probing, soil coring) only need to be done once but can be time-consuming. Vegetation surveys are the most time-consuming repeated protocol, though repetition is suggested only every 5 years. Water chemistry and water depth measurements are repeated seasonally but are much quicker. Monitors should have a strong knowledge of plant identification, as well as a basic understanding of soil science and hydrology. For Tier 3 surveys, KBNERR anticipates collaborating with monitors or monitoring organizations and potentially sharing equipment with them and/or helping seek funding.

Disturbance

See Tier 2.

Vegetation

Survey vegetation in transects using the line point intercept technique. Follow Tier 2 procedures with the following additions:

1) Identify all vascular plants to species, regardless of foliar cover.
2) Identify all non-vascular plants and lichens to species, if possible. For difficult identifications, non-vascular plants and lichens can be identified to genus or, if necessary, life form. Other organisms (e.g., fungi) can be identified by life form. It may be useful to group non-vascular species by functional group after you return from the field; Appendix 2 of Alaska's *Minimum Standards for Field Observation of Vegetation and Related Properties* outlines a possible functional group scheme for these species (VTWG 2022; see Appendix 2 of this manual).
3) Identify groundcovers according to Table 8 of the *Minimum Standards for Field Observation of Vegetation and Related Properties*, which is a more detailed version of the groundcover scheme from Tier 2 (adds mineral and organic soil, as well as more subcategories of rock - gravel, cobble, stone, and boulder). However, only use the "biotic" category for miscellaneous non-living biotic material; living groundcovers such as mosses and lichens should show up in the point-intercept data (VTWG 2022).
4) To the extent possible, organize the rest of your vegetation survey data according to the *Minimum Standards for Field Observation of Vegetation and Related Properties.*

Water Level

Water-table wells and piezometers are pipes that are secured vertically in the ground. These pipes have slits or holes along the side so that groundwater flowing into the pipe can equilibrate with the surrounding water pressure (and thus groundwater depth). Comparing water level data from water-table wells or piezometers across seasons and years indicates trends in peatland hydrology.

Water-table wells have slits or holes along the entire length of the pipe and, therefore, equilibrate with soil water pressure along the entire well depth. Piezometers have slits or holes along a smaller interval (the "screened interval"), typically near the bottom of the pipe, and equilibrate with soil water pressure only along this interval. Unless there is a strong vertical pressure gradient, a piezometer and a water-table well show the same water level. Water-table wells indicate the uppermost water level regardless of the vertical gradient and are sufficient for most peatland monitoring. However, if you are interested in vertical flows and/or water chemistry at different depths, then you need piezometers.

In this manual, "piezometer" refers only to standpipe piezometers (pipes with screened intervals used to measure water depth). Other types of piezometers measure pressure in different ways.

 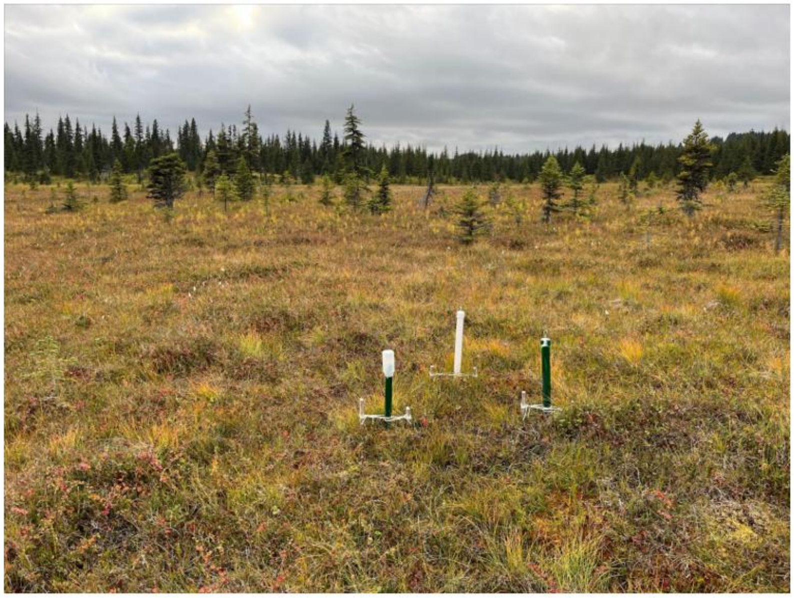

Figure 11. The bottom screened interval of a piezometer before installation (left), and three piezometers installed in a peatland near the Anchor River (right). These three piezometers were installed at different depths to capture water chemistry data from different groundwater depths.

Where: Install at least two water-table wells or piezometers to compare conditions in different parts of the peatland. Installation locations will depend on your monitoring priorities. Here some ideas:

- Install one water-table well in the center of a peatland and one near the edge (e.g., where spruce start to encroach). This setup enables you to track peatland drying and indicates whether the peatland edge is drying faster than the center.
- Install one water-table well near an inflow stream and one near an outflow stream. This setup provides data on how the peatland is affecting groundwater flow and how it may affect water chemistry (see next section).
- Install multiple water-table wells along an elevation gradient in a drainageway peatland. This setup enables you to track downstream groundwater flow, as well as zones of groundwater influence from a beaver dam.
- Install multiple piezometers with screened intervals at different depths (Figure 11). This setup enables you to collect water samples from different depths within the peatland and track differences in water chemistry at these depths (see the next section).
- Record a GPS point for each installed piezometer and take a photo of each.

When: Water-table wells or piezometers can be installed any time the ground is not frozen (typically June through early October). Measure water levels as frequently as possible but at least once per season (i.e., four times per year). A typical annual hydrograph will show low water levels during winter and summer baseflow, and higher water levels during spring breakup and fall freshets (all relative to the annual average). If you don't see this pattern, consider collecting data more frequently to find out why. Frequent measurements will also help you detect issues with the wells (e.g., frost heaving) earlier.

Construction and Installation

Piezometers and water-table wells can be purchased or constructed. Purchased piezometers will often have a drive point at the bottom, a machine-cut screen, and threads to facilitate connecting to solid lengths of standpipe from the chosen depth to above ground surface. To construct a piezometer or water-table well, use a length of PVC pipe and two PVC caps. You will likely need about 50 cm (22 in) of PVC, though length will depend on the maximum water table depth or the desired depth of water sampling. Secure a cap onto one end of the PVC pipe: this end will go into the ground. Next, drill or cut numerous small holes or slits into the sides of the PVC pipe. Holes or slits should extend as far up and down as you want the screened interval to go. The second cap will go on in the field after the water table well or piezometer is installed.

There are many ways to install water-table wells or piezometers, some requiring professional equipment and experience. However, installing shallow water-table wells or piezometers in peatlands can be quite straightforward:

1) Start by auguring a pilot hole of equal or slightly smaller diameter than the water-table well or piezometer (upper left of Figure 12).
2) Assemble the water-table well or piezometer (upper right of Figure 12).
3) Push the water-table well or piezometer into the pilot hole (lower left of Figure 12).
4) If necessary, drive the water-table well or piezometer to the specified depth, for example with a rubber mallet (lower right of Figure 12). Depending on the substrate, reaching the desired depth can be quite difficult; in some cases, you may need to alter plans based on the difficulty of installation.
5) Cap the water-table well or piezometer to prevent any above-ground interference, leaving at least one hole to prevent pressurization. It can be helpful to secure this cap temporarily with duct tape.

Figure 12. Steps for installing a simple, shallow water-table well in a peatland to measure changes in water level. Photo credit: USF-ERG.

A common issue with piezometers and water-table wells in Alaska is frost heaving. Mitigating against frost heave requires professional judgement based on field conditions, but in general, each well needs to be securely anchored vertically in the soil. Strategies that can be helpful include 1) driving monitoring wells into underlying mineral soil to give them more solid bases (unrealistic in deeper peatlands), and 2) anchoring the wells to wooden stakes with tightly wound twine. These strategies can also help mitigate against wells floating if you anticipate major flooding at your well sites.

Once a piezometer or water-table well is installed, it should be "developed" - that is, cleared of sediment blockages around the pipe and within the pipe screen so that water flows freely into or out of the well. This is typically accomplished using a surge block method, where either a surge block or a bailer that just fits inside the well casing is plunged up and down ("surged") repeatedly. A surge block – typically a heavy disc or cylinder – pushes water out of the well then pulls it back in, while a bailer mainly just pulls water into the well and collects it for disposal. Surge a few times, then empty the water out and allow surrounding groundwater to flow back into the well. Repeat the process until water flows freely and well water is sediment-free. Developing the well can take anywhere from just a few surge/disposal cycles to dozens. It may be useful to develop the well again at a later date, or even on an annual basis, if you suspect the pipe screen is clogged or bailed water contains sediment.

Elevation

To compare data from two or more water-table wells or piezometers, data must be collected in the same plane of reference. Commonly, the plane of reference is elevation above mean sea level, but the plane of reference can be an arbitrary elevation as long as it is a consistent arbitrary elevation at all water-table wells or piezometers being compared. The reason for measuring elevation is to detect relative elevation differences between monitoring wells, which determine directions of flow. The ground surface can be used as the plane of reference when the only concern is the depth of water relative to the ground surface, which is adequate if change detection at specific sites is the only monitoring goal.

Figure 13. Elevation can be surveyed using an auto level (foreground) and a stadia rod (background). Once the auto level itself is level, direct the eyepiece at a "benchmark" with a known, possibly arbitrary, elevation that is marked in the field for future reference (for example, a triangle cut into the bark of a tree). Determine the height of the level relative to the benchmark by viewing the stadia rod (held vertically with the base at the benchmark) through the eyepiece. Determine subsequent well elevation(s) by turning the eyepiece horizontally and viewing the height of the stadia rod above the well(s). Well elevations can then be calculated relative to the benchmark elevation. If needed, the height or location of the auto level can be adjusted using a "turning point," which involves resurveying a known point (e.g., the last monitoring well surveyed) with the new auto level configuration, then continuing with subsequent measurements. Photo credit: USF-ERG.

Elevation can be surveyed with an auto level and stadia rod (Figure 13). The most important elevation to survey is the top of the well casing because all water levels will be noted as depth below the top of the casing. The precision of an elevation measurement is typically considered to be half the distance between scale bars on the stadia rod. For example, if there are scale bars every 0.10 ft, then your precision is ±0.05 ft (±1.5 cm). For long-term monitoring, note any evidence of frost heaving, and repeat the elevation survey if you have reason to suspect frost heaving has occurred.

Measuring Water Level

There are many ways to measure water level in a piezometer:

1) Use a long ruler or steel measuring tape and chalk. Rub chalk near the end of the ruler or tape, then slowly lower the chalked end into the water-table well or piezometer. Chalk is helpful for seeing the waterline on the ruler or tape when removed from the well. When you suspect the ruler or tape has reached water, read the total length on the ruler or tape, then pull it out of the well. Subtract wetted length from total length to determine depth to water. Avoid lowering the ruler or tape too far underwater (displacement raises the water level); you may need to try multiple times.
2) Use a popper, which can be constructed from materials available at a hardware store (Figure 14). Acquire line, a bell-shaped reducing coupling, an eye bolt, and washers for popper assembly. Once assembled, lower the popper into the water-table well or piezometer and jig it up and down near the water surface. When the popper contacts the water surface, it will make a distinct popping sound. Mark the line where it crosses the top of the casing, retrieve the popper assembly, and measure the total length between where the line crossed the top of the casing and the end of the popper assembly, which is the depth to water.
3) Use an electronic water level meter (e.g., Solinst© Model 102; Figure 14). Lower the graduated line and sensor into the water-table well or piezometer. When the sensor contacts the water, it will make a loud beep. Raise and re-lower the graduated line and sensor to double check, then read the depth to water where the graduated line crosses the top of the casing.

All of these methods generate a depth from the top of the casing. To convert to depth from ground surface, subtract the “stick-up” – the length of casing above the ground surface.

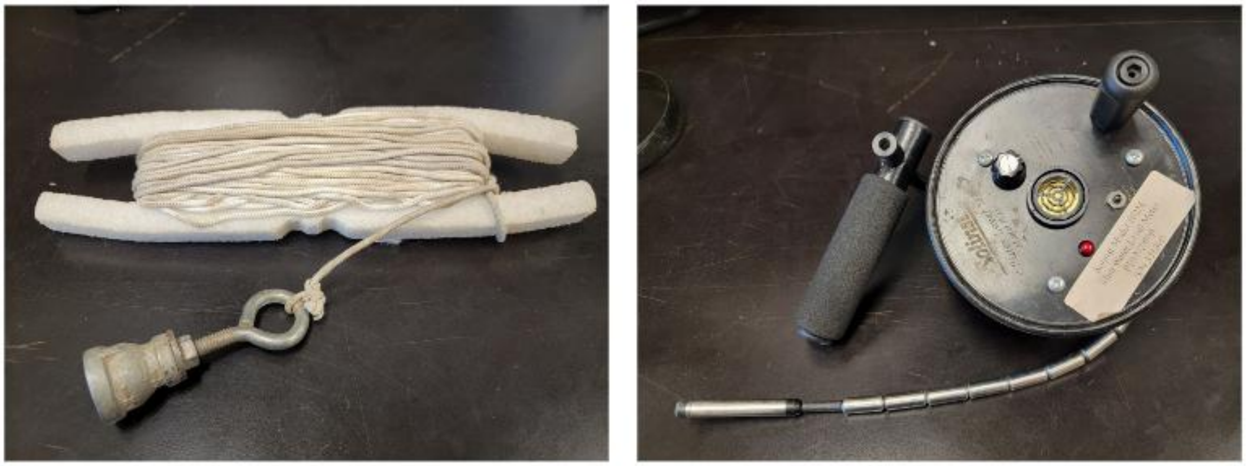

Figure 14. Measurements of water levels in water-table wells or piezometers can be made with a ruler or steel tape, a popper (left), or an electronic water-level meter (right).

Materials

Field data collection

- Long ruler and chalk, steel measuring tape and chalk, popper, or electronic water level meter
- Data sheet or notebook with pen or pencil, or an electronic device for recording data
- GPS-enabled device
- Auto level
- Stadia rod
- Camera
- Whiteboard and marker
- Personal field gear (e.g., rubber boots or waders, etc.)

Construction and installation

- Purchased water table wells/piezometers (drive points, screened intervals, caps, and additional standpipe as needed), or:
    a. PVC pipe with two caps for each well/piezometer
    b. Glue for securing cap to PVC pipe
    c. Drill or other tool for creating holes or slits
- Bucket auger with diameter less than PVC pipe diameter
- Rubber mallet or equivalent pounding implement
- Bailer or surge block system
- Optional: Wooden stakes (three per well) and twine; duct tape

Water Chemistry

The most important water chemistry measurements in a peatland are water temperature, conductivity, and pH. Temperature indicates how much the peatland insulates groundwater it contains. Conductivity indicates how much peatland water is recent precipitation and how much has been stored as groundwater (rain and snow have very few ions, while groundwater picks up ions by interacting with rocks, peat, and other substrates). pH indicates where a peatland lies on the spectrum from bog (very acidic) to fen (closer to neutral). By collecting water chemistry data seasonally from multiple locations, you can often generate inferences about these conditions.

Where: Water chemistry monitoring sites will depend on your specific priorities. At a minimum, monitor water chemistry within each water-table well or piezometer to pair water chemistry data with water levels. Monitoring water chemistry at additional points within the peatland is helpful if:

1) The peatland contains inflow and outflow streams. Measuring water chemistry in both streams enables comparisons between them.
2) A stream flows through the peatland. Tracking water chemistry in at least one location along the stream can be informative.

Take photos and GPS points for any monitoring stations besides the wells.

When: Monitor water chemistry at least once per season (i.e., four times per year). Water chemistry monitoring should be temporally paired with water level measurements. Winter measurements in water-table wells or piezometers may require punching through a thin layer of ice (the water may or may not freeze). Cutting through ice may also be necessary to measure water chemistry in streams.

How: Many tools are available for collecting water chemistry data, particularly temperature. KBNERR suggests using a multiparameter probe such as the YSI© Pro1030, which measures temperature, conductivity, and pH, among other parameters. Its sensors are connected to a cable that can be lowered into a well or stream.

When monitoring groundwater in a water-table well or piezometer, use a bailer to remove stagnant water until data stabilize or three to five well volumes have been purged. Data that have stabilized should not be trending consistently in one direction or showing large fluctuations. To check for data stabilization, you will need to repeatedly shift between bailing and inserting the probe sensor. The bailer can also be used to transfer water out of the well to another container if the sensor doesn’t fit inside the well. The sensor should be rinsed with bailed water before measuring water chemistry parameters.

There are other, more advanced methods for well water sampling that make parts of the process easier. For example, a flow cell eliminates the need for hand bailing and provides continuous parameter readings. However, it requires a pump, batteries, and tubing, which are inconvenient in remote settings. Low-flow sampling at the well screen eliminates the need for bailing entirely by slowly pumping water across the screen from the surrounding soil. However, this method requires specialized equipment and experience.

Materials

- YSI© Pro1030, or equivalent probe(s) or logger(s) (e.g., flow cell with accessories)
- Bailer, and container if measuring bailed water outside piezometer
- Data sheet or notebook with pen or pencil, or an electronic device for recording data
- GPS-enabled device
- Camera
- Whiteboard and marker
- Personal field gear (e.g., rubber boots or waders, etc.)

Peat Depth

One of the most unique and important characteristics of peatlands is the large amount of organic material they accumulate, often over thousands of years. Depth of peat is a good proxy for the amount of organic material contained in a particular peatland section. KBNERR recommends measuring peat depth using a tile probe. The overall goal is to estimate the total volume of organic material in the peatland of interest. For this reason, choose measurement locations with broad, representative coverage. Peat depths only need to be collected once.

Where: Start with a transect along the longest axis of the peatland. Measure depths at roughly equal intervals (e.g., 10 m) or when the vegetation community changes; be sure to collect data from the edges of the peatland, including one depth measurement in presumed upland soil just outside of the peatland. Next, collect depths from at least one (ideally multiple) transects across the shorter axis of the peatland. Co-locate peat depth transects with vegetation transects wherever possible. If the peatland has any irregular "bulges" or other features, collect depths from those as well. For each depth measurement, note GPS coordinates. Figures 15 and 16 show examples of this approach.

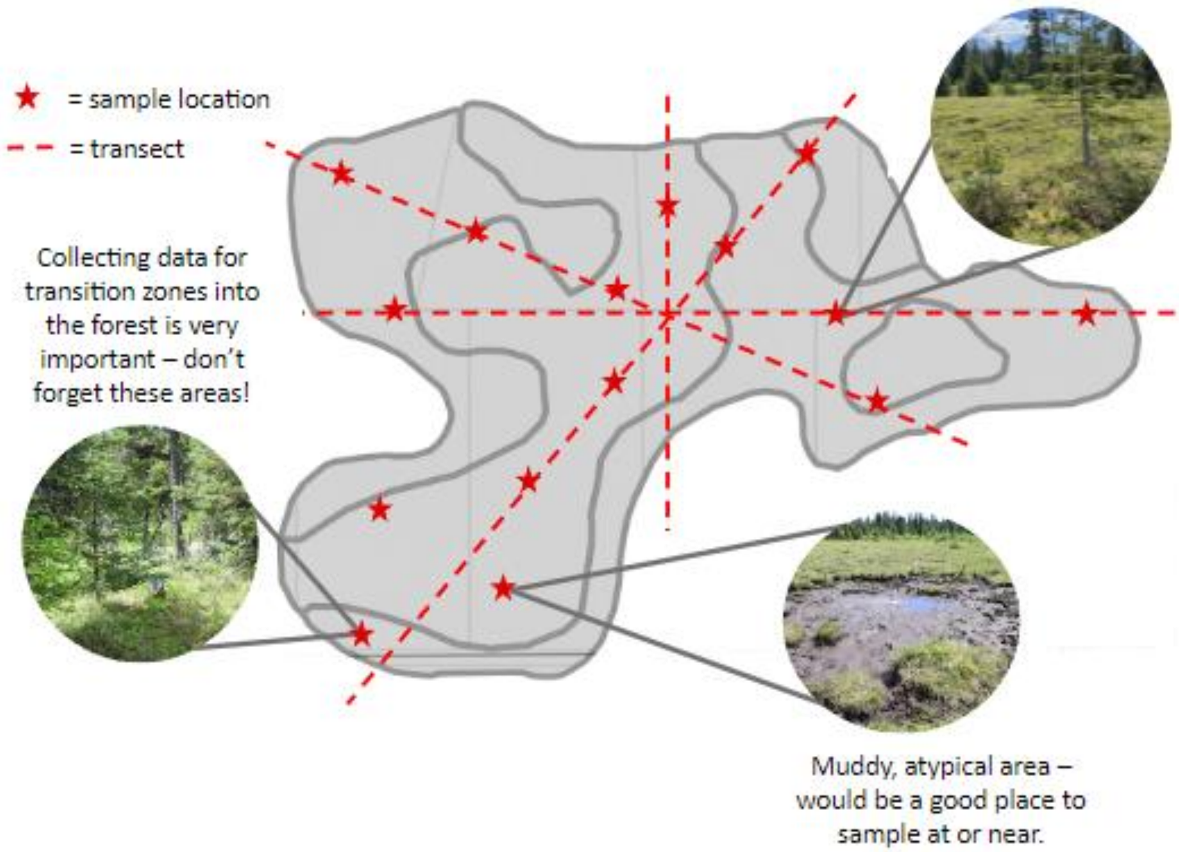

Figure 15. Example of a peat depth sampling scheme at the Wynn Fen. This scheme was developed for the Homer Drawdown Community Monitor Training and Manual.

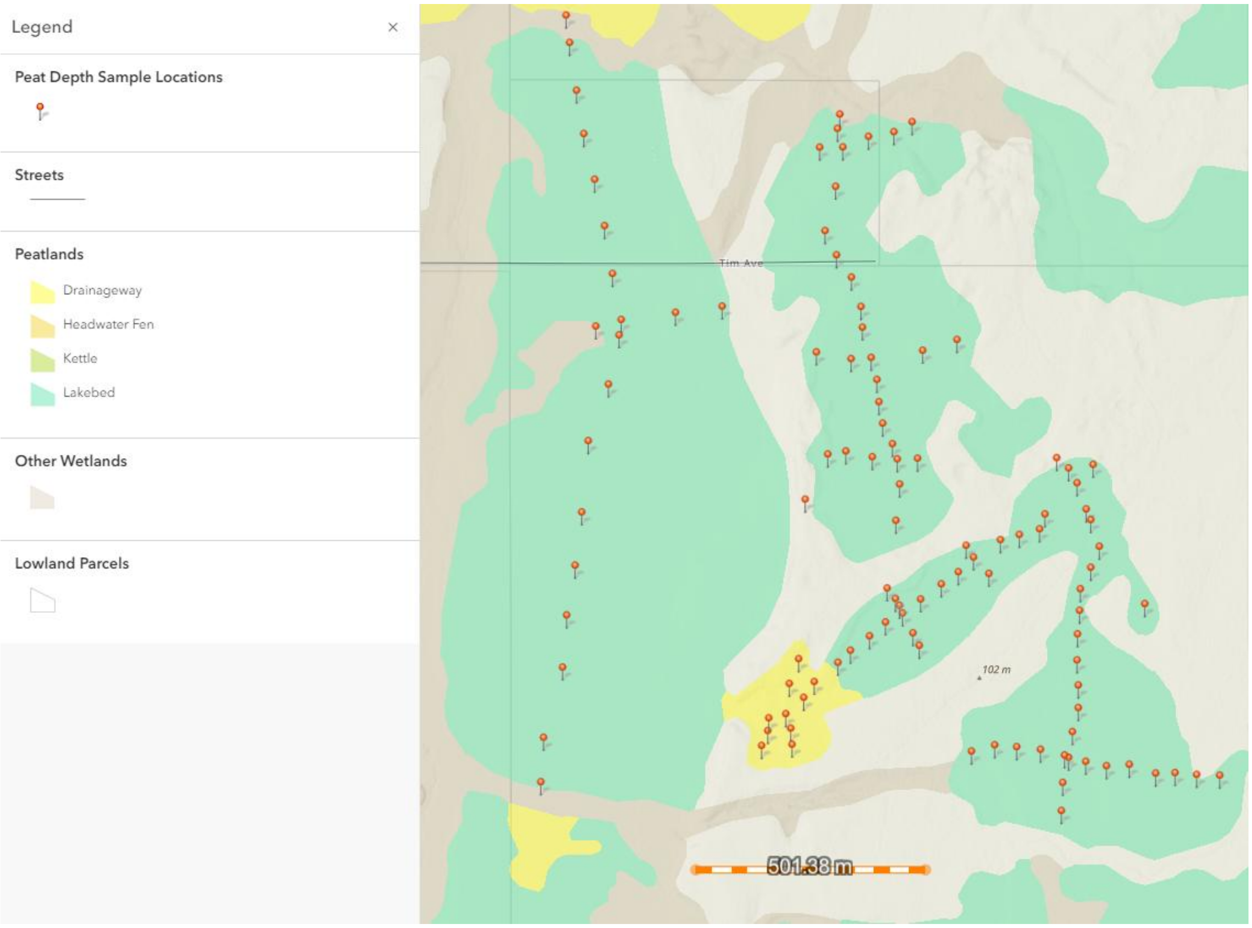

Figure 16. Depth measurement locations for a set of peatlands near Happy Valley. While the transect approach shown here is a good starting point, some isolated depth measurements in areas with sparse data would improve peat volume interpolation.

When: Peat depth data can be collected anytime the ground is not frozen (typically June to early October). However, keep in mind that peat may thaw very slowly, so in some cases measuring accurate depths may not be possible until late July, depending on elevation and aspect.

How: To measure peat depths, use a tile probe with sections that can be screwed together (Figure 17). Insert one section with a pointed metal tip into the peat and push down, making sure to orient the probe vertically. When most of the probe is underground, screw on another section and continue. Gloves are helpful for gripping the probe when driving it down; screwing a handle on top of the probe can also be helpful in some cases. While pushing down, note potential differences in substrate (is it more difficult to push through certain depth ranges?). Push the probe downwards until it refuses to go deeper or hits a confining layer more than 5 cm (2 in) thick. This refusal point will be obvious if the probe hits bedrock (you'll feel it and maybe hear it); refusal will be less obvious if the probe hits a silt layer. High density peat layers can also be difficult, or impossible, to punch through with a probe. This could help explain anomalous depth measurements that don't feel like a contact (e.g., glacial till) was reached.

If you're not sure whether you've reached refusal, mark the probe where it intersects the ground surface, pull the probe up 5-10 cm (2-4 in), and then drive it down again. You may be able to push through a thin layer of gravel or silt. When the probe reaches its maximum depth, measure how much remains above ground, then pull out the probe, measure its length, and subtract the length above ground to determine peat depth.

If you don't have a baseline depth expectation, bring at least 8.2 m (27 ft) of probe sections. Most peat in the Kenai Lowlands is shallower than this, often considerably, but peat depths can exceed 8 m in some places. If you run out of probe sections, return to the site with more.

Because peat layers tend to be much thicker than most soil, and much less resistant to probing, a typical depth to refusal captures mostly peat. However, depth to refusal may also capture some non-peat substrate or miss some high-density peat (see above). The following section (Soil Coring) provides an empirical test of how much soil at the survey points closest to the peatland edge is actually organic. In the deeper parts of a peatland, the vast majority of the probed depth should be peat, but assessing the basal soil is difficult. Observations from probing can inform conjectures about where the peat layer ends, or whether it is discontinuous, but it is important to acknowledge that the true peat depth can be somewhat uncertain.

Figure 17. A researcher measuring peat depth with a tile probe. Peat depth is a useful proxy for the amount of organic material in the surrounding peatland zone.

While some peat depth locations will overlap with vegetation transects, many likely will not. For context, record basic vegetation data at each point where depth is measured. Considering a 5 m radius around the depth point, choose up to three of the following categories that best describe the vegetation community:

1) Tree (e.g., spruce)
2) Tall Shrub > 1.5 m (e.g., Barclay willow)
3) Low Shrub 0.2-1.5 m (e.g., dwarf birch, sweet gale, labrador tea, bog blueberry)
4) Dwarf Shrub < 0.2 m (e.g., bog cranberry, crowberry)
5) Graminoid (e.g., bluejoint reedgrass, sedges)
6) Forb/Pteridophyte (e.g., lousewort, iris, buckbean, horsetail)
7) Moss/Other Non-vascular (e.g., open *Sphagnum* hummock, lichen)
8) Open Water
9) Bare Soil
10) Rock

When choosing dominant vegetation categories, include only those that have at least 20% cover when viewed from above. If more than three categories fit this description, choose the three most prominent. If there is standing water, include an estimate of water depth. Take at least one photograph of the vegetation at each point, looking vertically down. Include an object of known size (e.g., a labelled whiteboard) for scale.

Materials

- Tile probe (27 ft recommended), with metal tip and handle
- Gloves (rubber grip)
- Data sheet with a pen or pencil, or an electronic device for recording data
- GPS-enabled device
- Camera
- Whiteboard and marker
- Measuring tape
- Personal field gear (e.g., rubber boots or waders, etc.)

Soil Coring

Tier 3 expands soil monitoring by incorporating analysis of soil cores extracted using a soil auger. Soil augers are narrow, cylindrical instruments that are less invasive than digging a soil pit (especially for deeper sampling). At least two soil cores should be analyzed for hydric indicators, completing assessment of wetland hydrology. All cores should be paired with peat depth locations. Pairing soil cores with depth probing matches depth observations with soil profiles and horizons; this reveals whether probed peat depth is capturing non-peat horizons. For this comparison, the most important information from the soil core is the depth of transition from organic to mineral material, if this transition is observed.

Where: Take one soil core at the depth sampling point just outside of the peatland. Take additional soil cores for each depth transect at the following locations:

1) The depth sampling point closest to the peatland edge (within the peatland).
2) If any (or all) of the material in the peatland edge soil core is not peat, take another core at the next sampling point on that depth transect. Continue coring at each depth sampling point until the soil core is all peat.

When: Soil cores can be collected anytime the ground is not frozen (typically June through early October). Soil coring only needs to be done once.

How: Take soil cores from ground level to a depth of at least 0.5 m. If the depth measurement is greater than 0.5 m, continue coring down to 1 m. Depending on difficulty, coring deeper than 1 m may be helpful, particularly if you feel a change in substrate while probing for depth. However, further into a peatland, where peat can be very deep (e.g., 5-10 m), coring the entire depth would be very difficult. In that situation, most substrate is likely to be peat; simply note any clear changes in substrate encountered while probing. In particularly wet areas (e.g., soupy peat or floating mat), obtaining a soil core may not be possible. Note the depth to a more solid substrate; it may be possible to core the solid substrate using a bucket auger (see below).

There are numerous ways to collect soil cores. Here are two common soil corer styles:

1) Russian peat auger (Figure 18): This style collects a half-cylinder of soil and is useful for collecting cores of relatively precise volume. Russian augers are designed for peat but will work for other soils, though not for coarse-grained soils. Push the auger into the ground (you will likely need to repeatedly pull it partway up and slam it down) until the cylindrical part of the auger is fully in the ground. Turn the cutting edge of the half-cylinder 180 degrees until it hits the "fin," an extension from the half-cylinder that stays in place. Then pull out the auger and open it up to reveal the sample. This style does not work for soupy peat and is difficult to use for soil cores deeper than 0.5 m: while you can screw on extensions that can theoretically push the corer much deeper, it can be extremely difficult to hammer in, turn, and pull out deeper cores.
2) Bucket auger (Figure 18): This style works better than the Russian auger for deeper samples. To avoid coring through roots or particularly soupy peat, first remove a surface soil plug with a sharpshooter shovel. Mark the length of that plug, then insert the bucket auger and start turning while pushing down. Once the bucket auger head is close to full, mark where the auger intersects with the ground surface, then pull it out. Gently remove the soil core from the auger head and lay it out next to the initial plug. The maximum depth of the core will match the depth from the ground surface to the end of the auger. Make sure not to overfill the auger head, as doing so will compress the soil. Continue this process down to the target depth. For relatively solid peat, the total length of the laid out cores and plug should match the final depth of the auger below the ground surface. There are different auger head styles that work better for different soil textures and moisture levels. However, like the Russian auger, a bucket auger does not work for soupy peat.

Figure 18: Bucket auger and Russian peat auger. Note that different auger heads (top center) can be attached to the bucket auger (left); the Dutch auger style (top center right) often works best for peat. Each of these heads is made to be twisted down into the soil. In contrast, the Russian auger has a pointed head (right) that is driven directly down before turning the auger 180 degrees around the fin; opening up the fin reveals the half-cylinder sample (bottom center).

Take a photo of each core before closer examination. Include a measuring tape along the core in each photo so that depths and thicknesses can be verified. Ideally, the measuring tape should represent the depth of the core (e.g., for a core from a depth of 50-100 cm, start the tape at 50 cm). At least two representative cores should be characterized in more detail: the core just outside the peatland (representing upland conditions) and the core furthest into the peatland (representing wetland conditions). First, note the type (organic or mineral), depth, and thickness of each soil horizon, and note any hydric indicators associated with the horizons (see Tier 2). Then assess texture, moisture, and color for each horizon in the core using standards outlined in the NRCS *Field Book for Describing and Sampling Soils* (Schoeneberger et al. 2012; see Appendix 2). Organic soil is categorized into three different textures: fibric, hemic, and sapric. Fibric, or "fibrous peat," is the least decomposed; it includes mostly fibrous material and produces relatively clear water when squeezed. Hemic, or "mucky peat," has some fibers and produces dark, turbid water when squeezed. Sapric, or "muck," has few fibers and produces dark, turbid water containing more than a third of the sample when squeezed. Color is assessed for mineral soils only. To assess color, match a sample from each horizon with the closest color on the Munsell Soil Color Chart, which separates soil colors along three axes: hue (spectral color), value (light/dark), and chroma (saturation).

For additional cores along depth measurement transects, record depth of organic soil material. If the organic layer has multiple clear horizons, or is discontinuous, note both the depth and thickness of each horizon. For example, if there is a substantial volcanic ash layer overlying organic material, note depth and thickness of the underlying organic layer. The goal is to determine the depth at which the soil ceases to be organic and, if possible, match this to changes in substrate noted during depth probing. These depths can improve a peat or organic material volume estimate for the peatland. Unless analyzing cores in the lab, return each core to its hole after examination. Note that for many lab analyses, samples should be frozen as soon as possible after returning from the field.

Materials

- Sharpshooter shovel
- Russian peat auger and/or bucket auger with relevant accessories
- Tile probe
- Gloves (rubber grip)
- Data sheet or notebook with pen or pencil, or an electronic device for recording data
- GPS-enabled device
- Camera
- Whiteboard and marker
- Ruler or measuring tape
- NRCS Field Book for Describing and Sampling Soils (Appendix 2)
- Munsell Soil Color Book (not available online)
- Personal field gear (e.g., rubber boots or waders, etc.)

Tier 4 Monitoring

The fourth tier of peatland monitoring offers a comprehensive strategy to track peatland drying (or re-wetting) and to assess peatland carbon sequestration. Tier 4 contains many of the same methods as Tier 3 for assessing wetland condition, including vegetation transects, piezometer installation, water chemistry measurements, and analysis of representative soil cores. Additionally, Tier 4 incorporates continuous measurements of water levels and temperatures.

Assessing peatland carbon sequestration requires measuring both the current carbon stock and the rate of change (flux) of carbon stored in the peatland. Measuring carbon stock involves 1) using peat depths to estimate the total peat volume, 2) using soil bulk density to convert peat volume to mass, and 3) using loss on ignition (LOI) methods to determine what percentage of peat mass is organic carbon. Measuring carbon flux involves using a gas flux analyzer to measure emission or sequestration rates of carbon dioxide (CO_2) and methane (CH_4) in representative peatland locations under different environmental conditions, then extrapolating those measurements to the entire peatland.

Tier 4 is the most time- and resource-intensive monitoring setup included in this manual. Some Tier 4 tasks (piezometer installation, tile probing, soil coring, and measuring loss on ignition) only need to be completed once but are time-consuming. Other Tier 4 tasks should be repeated. Gas flux analysis in particular is complex, expensive, and may require a dedicated staff member. KBNERR anticipates partnering with monitors or nonprofit organizations/agencies on gas flux monitoring and other aspects of Tier 4; please contact KBNERR for more details. Depending on their responsibilities, monitors should have a strong knowledge of plant identification, a working understanding of soil science, and/or a working understanding of hydrology.

Disturbance

See Tier 2.

Vegetation

Survey vegetation along transects using the line point intercept technique. Follow Tier 3 procedures, with the following additions:

1) Repeat vegetation surveys every 2 years using the same transects.
2) For a broader picture of vegetation change, use some form of repeated site-wide photography. At a minimum, use ground-based photos as suggested for Tier 1 visual surveys. For more detailed and precise data, use drone or satellite imagery.

Water Level

While seasonal water level measurements can be informative, they miss the finer details of how water level changes throughout the year. Tier 4 incorporates more frequent measurements using continuous water level loggers installed in water-table wells or piezometers. These loggers can record and store accurate readings for months or years, depending on measurement interval (Figure 19).

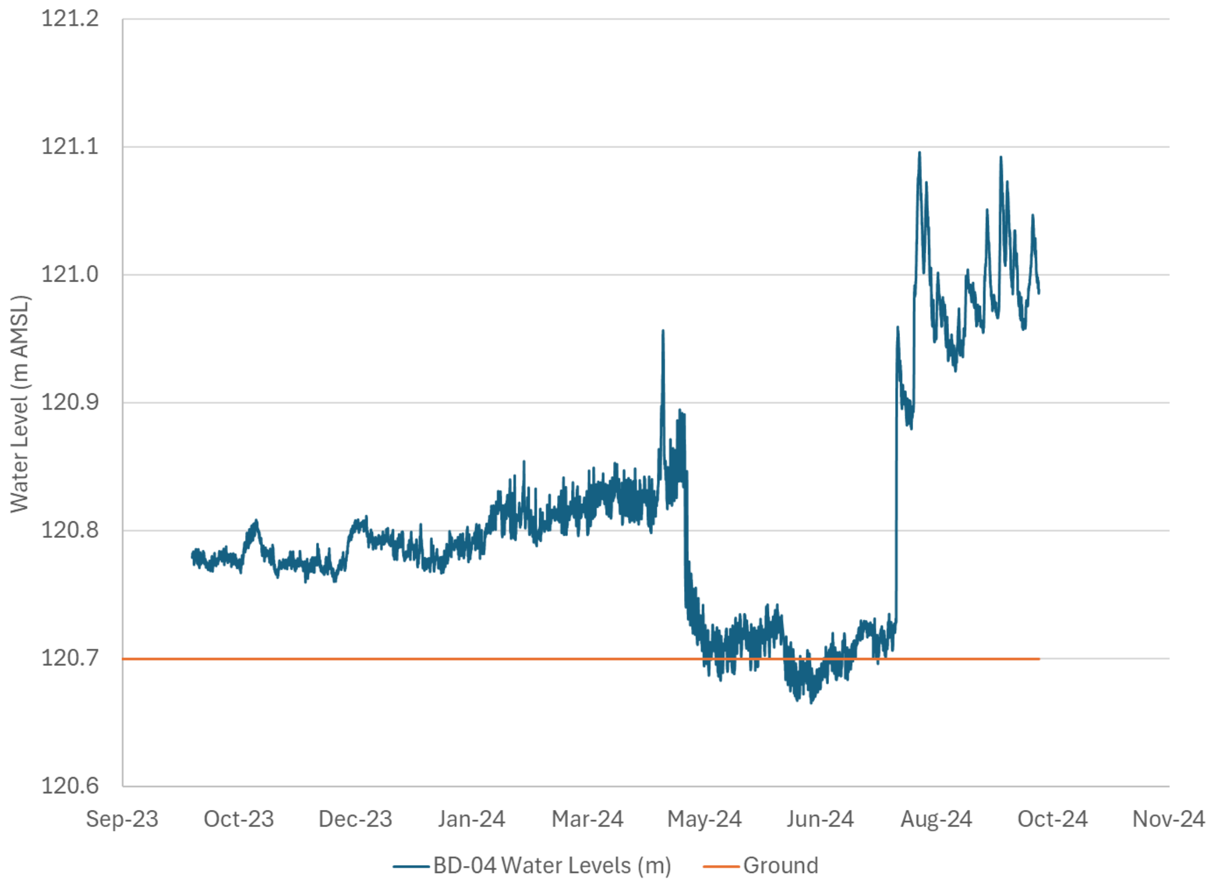

Figure 19. Continuous water-level measurements can show when water levels are above or below the ground surface, among other details. Here, a plot of hourly water levels in m above mean sea level for water year 2024 (i.e., October 1, 2023-September 30, 2024) shows that water levels were generally above the ground surface. Levels rose slowly when an ice dam formed in January 2024, dropped rapidly when the ice dam collapsed during breakup in April 2024, and rose again rapidly when a breached beaver dam was repaired in July 2024.

Where: See Tier 3.

When: See Tier 3 for installation. Manual water level measurements and data downloads may be completed seasonally (as in Tier 3) or less frequently (e.g., twice a year). However, consider that: 1) the more frequently wells are checked, the more likely monitors are to catch problems quickly, and 2) water level loggers have limited data storage, so check dates will need to be scheduled accordingly. Given 15-minute or hourly data collection, logger memory should last through the winter.

How: See Tier 3 for installing, surveying, and taking individual water level measurements at water-table wells or piezometers.

Suspend a water level logger (e.g., HOBO© Water Level Logger, U20L-04) inside each water-table well or piezometer using a wire extending to a hole near the top of the well. Each water level logger should be hung a little above the bottom of the well, no deeper than the bottom of the screened interval. A logger positioned below the screened interval will capture water trapped in the bottom drive point/cap even if the water table drops below that point. These loggers measure total pressure (i.e., the sum of atmospheric and water pressure). One barometric pressure logger (e.g., also HOBO© Water Level Logger, U20L-04) must be installed above ground in each monitored peatland (e.g., in a tree) to measure atmospheric pressure. Water pressure is obtained by subtracting atmospheric pressure from total pressure. Once logger data are downloaded, atmospheric corrections can be made using proprietary software provided by the manufacturer of the water level and barometric pressure loggers.

The water-level logger measures an arbitrary height of the water column above the logger. This height must be converted to actual elevation in the desired plane of reference, requiring manual water level measurements at known dates and times (See Tier 3). Always manually measure water level in the water-table well or piezometer before temporarily removing the water level logger to download stored data; use this manual measurement to convert logged water levels to actual elevation. For example, if a water level reading from the logger is 0.50 m and the manually measured water level elevation is 120.00 m, then 119.50 must be added to all logger readings to convert stored data to actual elevations. Corrections are typically made using proprietary software provided by the manufacturer but can be made manually in a spreadsheet after data have been downloaded.

Materials

- Tier 3 materials
- Water-level logger (e.g., HOBO© Water Level Logger, U20L-04) for each well, with wire to suspend logger in well
- Barometric pressure logger (e.g., HOBO© Water Level Logger, U20L-04) for each peatland, with wire to attach logger to a structure
- Electronic device for downloading data (including any necessary cords/cables), and proprietary logger software for processing data

Water Chemistry

Follow Tier 3 procedures, with the following additions:

1) Collect continuous water temperature data in each water-table well or piezometer. All water level loggers collect water temperatures in order to convert pressure data (what the water level logger measures) to water level.
2) Install at least one water temperature logger in a stream or, if no streams flow through, into, or out of the peatland, in a pool of standing water. Examples of effective loggers include the HOBO© TidbiT v2 Temp (UTBI-001) and HOBO© Pendant MX Temp (MX2201). To secure a temperature logger in a stream, tie it onto a piece of rebar driven into the stream channel.
3) Monitor conductivity and pH seasonally at any new temperature logging stations using Tier 3 methods.

Materials

- Tier 3 materials
- Water temperature logger(s)
- Rebar and string for securing logger(s)

Peat Depth

Survey peat depth following Tier 3 procedures. Depending on available time and peatland size, you may want to record more peat depths than suggested in Tier 3 (e.g., more one-off depths in unsampled regions).

Soil Carbon Content

The first step in analyzing soil carbon content is collecting soil cores. Collect cores along peat depth transects, particularly near peatland edges. These cores have two purposes: they indicate how much of the probed soil is actually peat (as in Tier 3), and they allow the monitor to assess organic carbon content at different depths. Once soil cores are collected, they can be taken to a lab, dried, and burned to determine how much of the non-water mass is organic carbon.

Field Sampling

Where: Follow Tier 3 protocols, with the following additions:

1) Take shallow soil cores (up to 1 m deep) at regular intervals (e.g., every 30 m) along entire peat depth transects, even if the cores are entirely peat.
2) Take at least one deeper core near the center of the peatland (at least 2 m deep; see details below).

When: See Tier 3. Note that deeper peat may remain frozen into July.

How: Follow Tier 3 protocols for obtaining shallow cores.

Deeper cores indicate how carbon content changes with depth. Typically, deeper peat stores more carbon because it is compressed (Figure 21). To take a deep core, use a bucket auger. Continue removing subsections of peat and laying them out, keeping track of the depth range of each subsection, until you either hit the probed depth or the limit of peat extraction (e.g., the auger can no longer be pushed deeper, or the auger handle is pushed down to ground level and you don't have an auger extension). Aim for at least 2 m of depth unless the peatland is shallower than 2 m.

A more technical method for capturing deep peat is to use a Livingstone corer. A Livingstone corer has a steel tube and a piston attached to a cable, which is secured to a pulley above. Livingstone corers are effective for obtaining chronological samples of deep peat, useful for radiocarbon dating, reconstructing climate history, and examining records of volcanic activity (Berg 2023). However, this method compresses the peat, and thus is not useful for bulk density measurements.

Photograph each core before closer examination. Follow Tier 3 protocols for field assessment of soil cores (horizon characterization and hydric indicators for representative upland and wetland cores; organic material depth for the rest). In addition, check whether cores appear to have significant clay content (more than ~5%) in the organic layer; if any do, note the rough clay content and take photos. Clay content is important when running loss on ignition procedures. Any mineral soil below the organic layer(s) can be disregarded for further analysis.

To analyze bulk density and carbon content, remove samples of precise volumes at regular intervals (depths) along each core. Choose intervals that make sense given your sampling equipment and take samples from the midpoints of these intervals (Figure 20). Use the same intervals for each core within a peatland. Aim for ~120 cm^3 of soil per sample (about the size of three D batteries), or more if you suspect that the soil/peat has a particularly low bulk density (< 0.1 g/cm^3 dry weight). However, it is more important to *know* the precise volume of soil than to collect exactly the same amount each time. For example, if the cavity of the auger isn't full at a sampling interval, cutting out a partial section with known dimensions is fine (more details below). If distinct organic soil horizons are identifiable by differences in fiber content and density, you may want to take additional samples from any unsampled horizons.

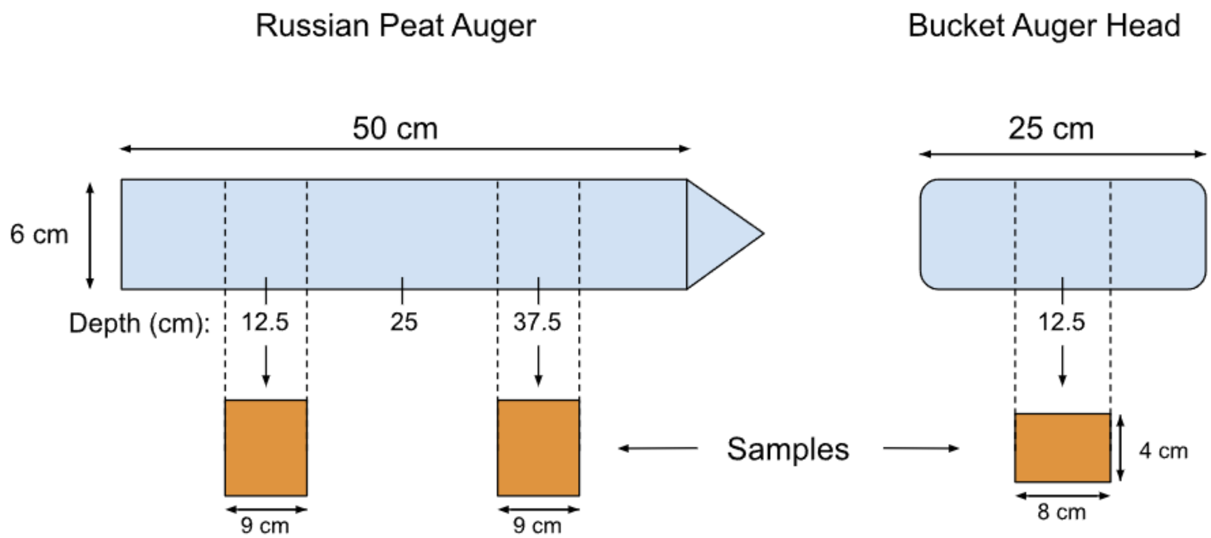

Figure 20. Examples of sampling intervals for different types of equipment. The cavity of the Russian peat auger on the left is 50 cm long, so sampling every 25 cm would make sense. Samples are taken at the midpoint of each 25 cm interval (depths of 12.5 cm and 37.5 cm for the top 50 cm of soil). By contrast, the bucket auger head on the right is 25 cm long, so one sample every 25 cm, in the middle of each head length, would make sense. Samples contain approximately 120 cm^3 of soil, assuming semi-cylindrical samples from the Russian auger and rectangular prism samples from the bucket auger.

For a Russian peat auger, if the cavity is full at the sampling interval, cut out a defined half-cylinder. If using a bucket auger, or if the Russian auger did not collect a full core at the sampling interval, cut out a known volume of soil and measure its dimensions. For example, you could cut a rectangular prism from a bucket auger or a quarter-cylinder from a Russian peat auger. Calculate and record the volume of soil collected in each sample; place each sample in a plastic bag. A scraper can be helpful to avoid losing material; a tarp may be helpful as a surface for laying out cores and samples.

Label each bag of soil with location ID, depth, and date. Return any extra soil to its respective core hole. Samples should be refrigerated (between 1 and 8 ºC) or frozen if they will not be processed within a month. These storage methods minimize microbial activity that could affect soil carbon content.

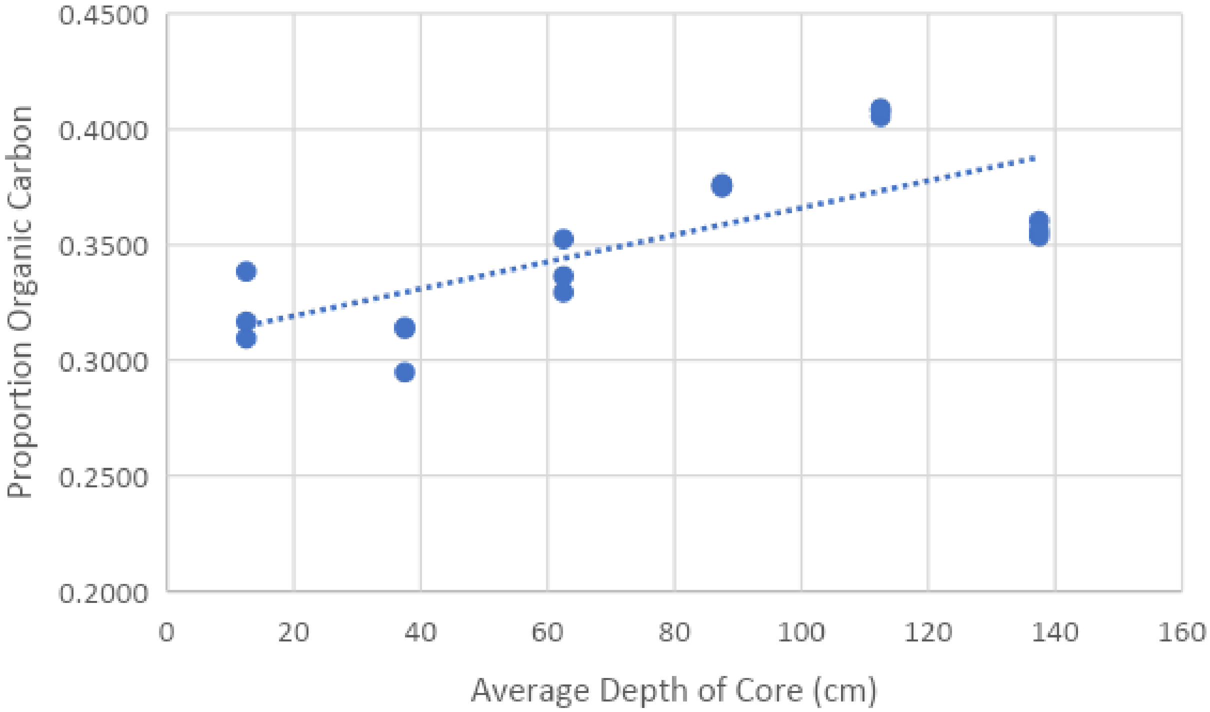

Figure 21. Proportion organic carbon for core subsections from different depths in a low shrub peatland near Kachemak Dr in Homer, AK. Organic carbon mostly increases with depth; measured peat depth near this location was 178 cm, so the deepest sample is relatively close to the bottom of the peat.

Sample Processing

This procedure determines bulk density and organic carbon content of soil samples collected in the field (Joshi 2024; Riley 2021). Soil samples are first weighed wet in crucibles, then dried in a laboratory oven. Bulk density is the dry mass of the sample divided by its initial volume. Dried samples are then ground and burned in a muffle furnace, removing the organic matter (Figure 23). Percent organic matter and organic carbon content are determined by comparing dry mass before and after ignition. Throughout this process, following two basic laboratory protocols will prevent sample contamination and measurement errors (e.g., Peck n.d.):

- Wear gloves while handling samples or crucibles. Moisture and organic material from your hands can be a significant source of error.
- Clean the tools you use after each sample. At a minimum, clean them with an antistatic wipe (e.g., Kimwipe©); consider cleaning them with ethanol or methanol at predetermined intervals. If tools are not cleaned between samples, particles from previous samples can cause measurement errors

Sample Preparation

1) Thoroughly remove rust and trace amounts of organic material from a set of crucibles (e.g., aluminum cups).
2) Weigh an empty crucible for the first sample on a calibrated scale, ideally an analytical balance. Depending on sample volume, you may need to weigh multiple crucibles.
3) Add a soil sample to the weighed crucible(s). Transfer the sample as completely as possible to avoid mass loss.
4) Weigh the crucible(s) containing the sample. Label with sample ID, or record each crucible ID (e.g., an etched number) with its corresponding sample ID. Set the crucible(s) aside for drying.
5) Repeat steps 2-4 for each sample; weigh each sample before unbagging the next one to avoid water loss. Note and maintain the crucible order as a check against labelling/recording errors.

Drying Samples

6) Heat a laboratory oven until the temperature reaches 105 °C.
7) Place the crucibles with samples in the 105 °C oven for 24 hours or until all water is removed. If samples appear to contain moisture after 24 hours, weigh the samples (or a subset of them) and return them to the oven for another 24 hours. Weigh the samples again, and if the masses from the two measurements are the same, remove the samples from the oven. If the masses differ, wait another 24 hours. Keep track of the location of each sample.
8) After drying, remove crucibles with samples from the oven and place lids on them. Weigh the dried samples as soon as possible once they are cool enough to handle, ideally using an analytical balance. These steps (crucible lids, weighing as soon as possible) minimize absorption of atmospheric water before measurement.
9) If you let samples sit in open air for a substantial period before running loss on ignition, you may want to take “re-wetted” masses. After 2 days in open air, dried peat may be approximately 3% water by mass. Water reabsorption can be minimized by either storing samples in a desiccator or storing them in a laboratory oven at a low heat setting. Whether you reweigh samples will depend on desired accuracy, access to a desiccator (or an oven), and time between drying and burning the samples.

Figure 22. Laboratory oven (left) and muffle furnace with soil samples (right). The oven is typically used for drying samples, while the muffle furnace (which can get much hotter) is used for combustion. This procedure uses both instruments.

Loss on Ignition (LOI)

10) Like drying, loss on ignition requires crucibles, but the crucibles need not be as large. Consider constructing small “boats” out of aluminum foil - they are inexpensive and easy to make, and you can fit many foil boats in a muffle furnace (Figures 22 and 23). Label each boat using a high-temperature pen. Note that ink from most permanent markers will come off in the furnace. Ceramic or metal crucibles with etched labels will also work.
11) Prepare one sample at a time. To ensure sample uniformity and full combustion, cut larger organic material with scissors and crush or grind the sample using a mortar and pestle, mixing in any irregularities so that the final product is homogenous. This ground-up sample will be split into three representative subsamples for loss on ignition.
12) Weigh an empty crucible (foil boat or alternative style), ideally on an analytical balance.
13) Add a subsample (2-5 g, depending on bulk density) to the weighed crucible and record the mass. Match the crucible label to the subsample in your records.
14) Repeat steps 12 and 13 for the next two subsamples; add the same mass of dried sample to the crucible each time, to the extent possible. You may not need the whole sample for this step.
15) Repeat steps 11-14 for each sample.
16) Arrange subsamples in the muffle furnace so that each sample has a replicate subsample in the front, middle, and back of the furnace; this arrangement controls for differential combustion in different parts of the muffle furnace (Heiri et al. 2001, Hoogsteen et al. 2015). Before putting subsamples in the furnace, create a map showing locations of each, and tape it to the front of the furnace. This map will serve as a secondary identity check when taking samples out.

17) Once subsamples are loaded in the muffle furnace, set the furnace temperature to 550 °C. Run the furnace for 4 hours. Note that combustion at 550 °C promotes structural water loss in clay. If you suspect that the samples contain more than ~5% clay, consider using the conversion factor outlined in Hoogsteen et al. (2015). Keep track of the location of each sample in the furnace. Repeat the process if multiple batches are necessary.
18) After combustion, turn off the furnace and open the door to cool samples until they reach handling temperature (approximately 30 minutes). Carefully remove the crucibles using gloves, tongs, or forceps, keeping track of which sample is which (consult the map and maintain the subsample arrangement as you remove them). It may be helpful to use a tub for offloading samples.
19) Weigh the samples, ideally using an analytical balance.

Figure 23. Wet peat in aluminum cups (top left), dried peat in aluminum cups (top right), dried and ground peat in foil boats prior to loss on ignition (bottom left), and ash remaining after loss on ignition (bottom right).

Calculations

Calculate soil parameters using Equations 1-6. Equations 3-6 use the LOI subsamples. If following step 9, adjust the preignition mass to remove water content using Equations 7-8. For all soil masses, subtract the mass of the container (e.g., aluminum cup or foil boat) before further calculations, unless this container was tared. The conversion factor from organic matter to organic carbon comes from Agus et al (2011).

Equation 1. $Soil\ Water\ Content\ (\%) = \frac{Wet\ Mass - Dry\ Mass}{Wet\ Mass} * 100$

Equation 2. $Bulk\ Density\ (g/cm^3) = Dry\ Mass/Volume$

Equation 3. $Organic\ Matter\ (\%) = \frac{Preignition\ Mass - Ash\ Mass}{Preignition\ Mass} * 100$

Equation 4. $Organic\ Carbon\ Content\ (\%) = Organic\ Matter/1.724$

Equation 5. $Carbon\ Density\ (g/cm^3) = (Organic\ Carbon\ Content/100) * Bulk\ Density$

Equation 6. $Carbon\ Stock = Carbon\ Density * Volume$

Equation 7. Full Sample: $Rewetted\ Water\ Content = \frac{Rewetted\ Mass - Dry\ Mass}{Rewetted\ Mass}$

Equation 7. LOI Subsample: $Preignition\ Mass = (1 - Rewetted\ Water\ Content) * Measured\ Mass$

To calculate the total carbon stock of a peatland, multiply carbon density by full peatland volume interpolated from probing. This calculation should be completed piecewise. Here are a few options:

1) Multiply average carbon stock for the first layer (e.g., top 25 cm) by the estimated peat volume in that layer, then do the same for each subsequent layer and add them together.
2) Divide the peatland into Thiessen polygons using ArcGIS and calculate separate carbon stocks for each polygon (weighting by layer) before adding them together.
3) Build continuous models for carbon density by layer and depth of each layer (e.g., using inverse distance weighting), then estimate total carbon stock by dividing the peatland into a grid and determining carbon stock for each cell. Subsurface modelling software can help with this process. You could also use these models to map carbon per unit area by multiplying depth-weighted carbon density by depth of organic material.

Materials

Field

- Sharpshooter shovel
- Russian peat auger and/or bucket auger with relevant accessories
- Tile probe
- Knife, scraper, and tarp (optional)
- Clippers for cutting roots
- Gloves
- Plastic bags for samples
- Data sheet or notebook with pen or pencil, or an electronic device for recording data
- GPS-enabled device
- Camera
- Ruler or measuring tape
- NRCS Field Book for Describing and Sampling Soils (Appendix 2)
- Munsell Soil Color Book (not available online)
- Rubber boots
- Weather-appropriate clothing

Laboratory

- Large crucibles (e.g., aluminum cups)
- Laboratory drying oven (Figure 22)
- Analytical balance
- Muffle furnace (Figure 22; requires a three prong, 240 V outlet)
- Small crucibles (e.g., aluminum foil boats)
- If using foil boats, high-temperature marker (e.g., DYKEM© High Temp Industrial Marker)
- Mortar and pestle
- Scissors
- Forceps or tongs
- Latex or nitrile gloves
- Antistatic wipes (e.g., Kimwipes©), ethanol or methanol
- Optional: rubber gloves
- Optional: storage tub
- Notebook or data sheet and a pen or pencil

Carbon Dioxide and Methane Flux

In order to evaluate the role of peatlands as carbon sinks, monitors and researchers must consider not only current carbon stock, but also how that carbon stock is changing. By definition, peatlands store carbon accumulated over time. During periods of accumulation, peatlands are carbon sinks: due to waterlogged conditions and long periods of freezing, the rate of photosynthesis exceeds the rate of decomposition, leading to slow accumulation of organic matter. However, as climate conditions change, Kenai Peninsula peatlands may be turning into carbon sources instead - emitting carbon dioxide (CO_2) and methane (CH_4) from 10,000+ years of peat storage in some cases (Jones and Yu 2010). Studies from other boreal and arctic ecosystems show that land-based carbon sinks like peatlands are making this transition in response to climatic drivers (e.g., Natali et al. 2019).

To track these potential changes, KBNERR recommends measuring CO_2 and CH_4 flux. CO_2 and CH_4 are the two main forms in which carbon is transferred to and from the atmosphere in peatlands (and other ecosystems). Particulate and dissolved organic carbon may also be transferred via groundwater or surface water flows. Those carbon pathways are not covered in this monitoring manual.

CO_2 is taken in by plants and algae during photosynthesis and released by all organisms during cellular respiration. However, in waterlogged conditions like peatlands, lack of oxygen slows respiration. Certain microbes can complete respiration through alternative pathways that are less efficient but do not require oxygen; in freshwater wetlands, these pathways commonly produce CH_4. CO_2 and CH_4 are the two most significant greenhouse gases contributing to climate change, so their production has implications beyond immediate carbon storage.

Some gas flux studies also measure nitrous oxide (N_2O), a third greenhouse gas; N_2O production increases in anoxic conditions. While N_2O is a potent greenhouse gas, it is not addressed here because: 1) it is not involved in carbon cycling and storage, 2) its concentration (and flux) is relatively low compared to CO_2 and CH_4, and 3) the gas flux analyzer that KBNERR uses does not measure it.

Monitoring gas flux is complex and depends on many environmental variables. KBNERR and ACCS created a separate manual for measuring gas flux in Alaska wetlands using the Li-COR LI-7810 analyzer and a custom-built chamber (Figure 24). This manual, linked in Appendix 2, details the best current methods (Flagstad et al. 2024). A very brief overview is included in this protocol. KBNERR anticipates working with local partners for monitoring gas flux.

There are other ways to measure gas flux that are beyond the scope of this manual. One is an eddy covariance tower; see Appendix 1 for a brief overview. There is also an emerging chamber-based method (Fulweiler and West 2024) for measuring CO2 and CH4 flux with much more cost-effective sensors. This method was piloted in New England saltmarshes; the lightweight and portable equipment costs about $1000. Currently, only CO2 has been measured with sufficient sensitivity, but the project team is working on measuring CH4 as well (Fulweiler and West 2024).

Figure 24. Researchers set up a gas flux chamber in a wetland near Happy Valley, Alaska. The LI-7810 analyzer is connected to the chamber via tubing; the researcher on the right carries the analyzer as a backpack. Containing the gas flux analyzer in a plastic tote during field use offers it more protection and frees up researchers during data collection.

Where: Install open PVC cylinders ("collars") in representative locations across the peatland. The gas flux chamber is placed over the collar during measurement to create a sealed environment. Because gas flux, particularly CH_4 flux, can be highly variable and unpredictable, install as many collars as you can reasonably measure given time and personnel. Measuring gas flux from three nearby collars typically takes 45 minutes to an hour, not counting travel and machine startup time. Take care to choose representative sites for the collars.

When: To calculate an annual gas flux budget, measurements should be taken across the non-frozen seasons and, ideally, at least once during winter. Take measurements at least once a month at each collar from spring through fall. Because environmental variables such as light, temperature, water level, and plant phenology influence photosynthesis, respiration, and methanogenesis, which drive gas flux, consider taking more frequent measurements during dynamic environmental conditions.

How: KBNERR uses a custom-built chamber made from PVC pipe and greenhouse plastic connected via tubing to a Li-COR LI-7810 analyzer. The analyzer pumps in air from the chamber and uses absorption spectroscopy to measure concentrations of CO_2, CH_4, and water vapor every second. Fans in the chamber circulate the air, creating relatively smooth changes in gas concentrations over time. Using the rate of change in CO_2 or CH_4 concentration and the ideal gas law, you can calculate the flux: how much gas is being emitted or sequestered per unit time for a given area (the chamber/collar footprint). Each gas flux measurement is followed by a "dark measurement" during which the chamber is covered with black contractor bags. The dark measurement simulates nighttime and, by blocking photosynthesis, isolates the CO_2 flux from cellular respiration. KBNERR also measures a number of environmental variables (light, air and soil temperature, water level, vegetation cover). Environmental variables help in modeling differences in flux across time, which ultimately helps in calculating an annual carbon budget.

Appendix 1: Eddy Covariance

Eddy covariance is another method for measuring gas flux. Setting up an eddy covariance tower (Figure 25) is beyond the scope of this manual; this section introduces eddy covariance and how it differs from gas flux measurements described above.

The goal of an eddy covariance tower is to measure integrated flux across a wider area than a chamber-based method can capture. This area is called the "flux footprint" and varies over time based on wind conditions. Flux can be measured for particular gases, heat, or momentum. While the calculations involved are complex, the basic idea is to measure how much gas of interest (e.g., CO_2) is carried up or down with each eddy of air that passes the tower. At each moment in time, deviation in wind speed from the mean is measured, as is deviation in gas concentration from the mean; these deviations are multiplied. All measured moments in time are then added together, and the final value is multiplied by the air density. The "eddy flux," in other words, is the covariance of the instantaneous deviation in vertical wind speed and the instantaneous deviation in gas concentration (the "mixing ratio") multiplied by mean air density.

Currently, UAA operates an eddy covariance tower at Lily Lake Fen in the northern Kenai Lowlands (Figure 25). Sullivan (2021) provides more information about the Lily Lake eddy covariance station.

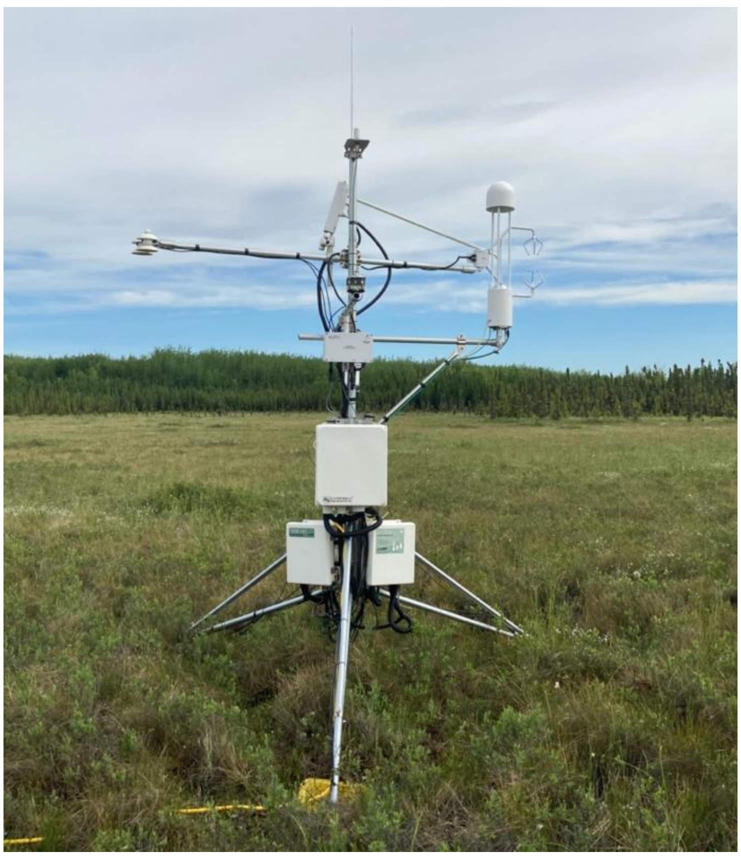

Figure 25. Eddy covariance tower at Lily Lake Fen in the northern Kenai Lowlands. The tower measures carbon dioxide and methane flux, and how these fluxes vary over time.

Appendix 2: Reference Lists and Procedures

The following is a list of references that are likely to be helpful when monitoring peatlands. Most of these references are specific to Alaska. While KBNERR has ensured that the links provided are functional at the time of publication, some links may change over time and may no longer function.

Wetland Delineation

The Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Alaska Region, Version 2.0 (USACE 2007) provides technical guidance and procedures for identifying and delineating wetlands in Alaska. The manual can be accessed under the "Alaska Region" tab of the USACE's Regional Supplements to Corps Delineation Manual.

The National Wetland Plant List (USACE n.d.) gives wetland indicator status codes for every US plant species. You can search by scientific name in the "Species Search" tab, scroll through species by region in the "Species by Region" tab, or download the latest Alaska plant list under "Plant Lists" on the right side of the page. Wetland indicator status codes are defined in Table 2 below.

Table 2. Wetland Indicator Status Codes. "Occurrence in Wetlands" is the estimated percentage of a given species' population that occurs in wetlands.

Status	Code	Occurrence in Wetlands
Obligate	OBL	>99%
Facultative Wetland	FACW	67-99%
Facultative	FAC	34-66%
Facultative Upland	FACU	1-33%
Upland	UPL	<1%

Plant Identification Guides

1) Flora of Alaska and Neighboring Territories (Hultén 1968)
2) Plants of the Pacific Northwest Coast (Pojar and MacKinnon 2016)
3) Mosses, Lichens and Ferns of Northwest North America (Vitt et al. 1988)
4) Alaska Trees and Shrubs (Viereck and Little 2007)
5) Willows of Southcentral Alaska (Collet 2002)
6) A Field Guide to Alaska Grasses (Skinner et al. 2012)

Field Data Collection Manuals

Alaska Minimum Standards of Field Observation of Vegetation and Related Properties (VTWG 2022)

Field Protocol for Lentic Riparian and Wetland Systems (BLM 2024)

NRCS Fieldbook for Describing and Sampling Soils (Schoenberger et al. 2012)

Field Indicators of Hydric Soils in the Alaska (Moore 2018)

Guide for Measuring Greenhouse Gas Emissions in Alaska Wetlands (Flagstad et al. 2024)

Appendix 3: Abbreviations and Acronyms

cm: centimeters

ft: feet

in: inches

m: meters

V: volt

ACCS: Alaska Center for Conservation Science

ATV: All-terrain vehicle

AWA: Alaska Wildlife Alliance

BLM: Bureau of Land Management

GNSS: Global Navigation Satellite System

GPS: Global Positioning System

HSWCD: Homer Soil and Water Conservation District

KBNERR: Kachemak Bay National Estuarine Research Reserve

LOI: Loss on Ignition

NOAA: National Oceanic and Atmospheric Administration

NRCS: Natural Resources Conservation Service

PVC: Polyvinyl chloride

UAA: University of Alaska Anchorage

USACE: United States Army Corps of Engineers

USF-ERG: University of South Florida Ecohydrology Research Group

USFS: United States Forest Service

USFWS: United States Fish and Wildlife Service

Glossary

Abiotic: Not living or derived from living organisms. Abiotic materials include water and the mineral components of soil.

Anaerobic/Anoxic: Lacking oxygen. Typically, anaerobic refers to a condition where cellular respiration is occurring without oxygen, while anoxic simply describes an environment without oxygen.

Beaver Dam Analog (BDA): A human-built dam meant to approximate the structure and function of a beaver dam. BDAs can retain water in dry seasons, recharge groundwater, reconnect floodplains, and create habitat for juvenile salmon and other species. They are increasingly used for stream restoration in other parts of the United States. KBNERR and ACCS are currently experimenting with a BDA to see whether beaver activity can help to mitigate peatland drying.

Bog: An acidic, nutrient-poor, *Sphagnum*-dominated peatland that is raised above the water table and is fed almost exclusively by precipitation.

Bulk Density: The non-water density of soil ($dry\ mass/volume$). Bulk density is important for converting mass-based carbon content to carbon stock.

Carbon Content: The proportion or percentage of soil that is carbon. This manual only considers organic carbon content - the carbon that comes from living things and will combust. Carbon may also be found in other forms in the soil (e.g., calcium carbonate).

Carbon Sequestration: The capture and storage of carbon dioxide by organisms, ecosystems, or artificial processes; often framed as an ecosystem service.

Carbon Stock: The total mass of carbon in a particular location. The procedures in this manual only consider organic carbon stock.

Cellular Respiration: The process of converting energy storage molecules like glucose into readily available energy in the form of adenosine triphosphate (ATP). All organisms perform cellular respiration, producing carbon dioxide as a byproduct. Most organisms use oxygen as an electron acceptor in the reaction, but some microbes living in anoxic environments use alternative electron acceptors.

Cowardin System: The US's official classification system for wetlands, the Cowardin system is used by the U.S. Fish and Wildlife Service for the National Wetlands Inventory. In this system, wetlands are classified by landscape position, vegetation cover and hydrologic regime. The Cowardin system includes five major wetland types: marine, estuarine, lacustrine, palustrine and riverine.

Crustose (lichen): One of three general growth forms of lichen. Crustose lichens form a 'crust' over substrates such as rocks and wood (see USFS n.d.).

Cryptobiotic Crust: A very thin crust of microscopic organisms growing on the soil surface. Cryptobiotic crusts form in arid areas, or after disturbances like fire. They typically include cyanobacteria and can also include various other organisms (e.g., fungi, liverworts) that are too small to be recognizable in the field.

Ecosystem Service or 'Service': A natural process in an ecosystem (e.g., water retention, nutrient cycling, carbon sequestration) that provides value to human societies.

Feathermoss: A non-*Sphagnum* moss with a branching growth pattern. Feathermosses belong to the order *Hypnales*.

Facultative (FAC): In the context of wetland delineation, a facultative plant species can be found in either a wetland or upland habitat (see Appendix 2).

Fen: A nutrient-rich, often sedge-dominated peatland that is in contact with groundwater, from which it receives nutrients like calcium. Most Kenai Lowland peatlands are fens.

Flux: The rate of transfer of a substance (e.g., CO_2) between two locations (e.g., vegetation/soil and the atmosphere). Measured in units of substance quantity per unit area per unit time (e.g., $\frac{\mu mol\ CO_2}{m^2 * s}$). Flux can also refer to the transfer of energy or momentum.

Foliar Percent Cover: Equivalent to aerial percent cover, this vegetation survey metric considers the strict proportional area that plants take up when looking straight down. When there are multiple layers of vegetation, foliar percent cover can exceed 100%.

Foliose (lichen): One of three general growth forms of lichen. Foliose lichens have a "leafy" growth pattern with a top side and a bottom side. Often found on wood (see USFS n.d.).

Forb: An herbaceous flowering plant that's not a graminoid (e.g., orchid, lousewort, iris).

Freshet: A high flow event caused by snowmelt, heavy rain, or both. The Kenai Peninsula tends to see fall freshets.

Fruticose (lichen): One of three general growth forms of lichen. Fruticose lichens grow in a branching, 3-dimensional pattern and can be found on soil, rocks, or wood (see USFS n.d.).

Functional Group: In the context of ecology, a subset of organisms defined by its ecological role rather than phylogenetics (though these may overlap). Functional groups may consider many different aspects of ecology (e.g., trophic level, habitat, life history, or role in nutrient cycling).

Geomorphology: The study of physical features on the earth's surface and how they were formed.

Gleyed: Refers to soils with a bluish- or greenish-gray color that indicates hydric mineral soil. Gleying results from iron and manganese oxides moving into solution and draining from soil due to changing redox chemistry.

Graminoid: A grass, sedge, or rush.

Growing Season: The frost-free period during which plants are growing. On the Kenai Peninsula, this period typically lasts from May or June into September (depending on elevation).

Herbaceous Plant: A non-woody plant.

Horizon: A distinct layer of soil, with distinct material and conditions of formation.

Hydric Soil: A wetland soil - that is, a soil that is saturated for at least part of the growing season.

Hydrogeomorphology: The study of how water movement influences the physical features on the earth's surface. The US Army Corps of Engineers uses a hydrogeomorphic classification system for wetlands - that is, a system that only explicitly considers hydrology and geomorphology - rather than the Cowardin system (Brinson 1993). The Cook Inlet Wetland Classification (Gracz and Glaser 2017) is also based on this approach.

Hydrograph: A plot of water level in a particular location over time, often over the course of a year.

Hydrophytic: "Water-loving"; refers to vegetation that is typically found in a wetland.

Inundated: A condition in which there is standing water on top of soil.

Methanogenesis: The production of methane by certain microbes (methanogens) as a byproduct of anaerobic cellular respiration.

Mineral Soil: A soil that is mostly non-organic. The Natural Resources Conservation Service (NRCS) considers soil material to be mineral if it has less than 12% organic carbon (~20% organic matter) by dry weight (Schoenberger et al. 2012).

Minerotrophic: Receiving water and nutrients primarily from groundwater and flowing surface water; associated with fens.

Non-Vascular Plant: Plant that lacks water-transport tissues (xylem and phloem). Non-vascular plants include mosses, liverworts, and hornworts.

Obligate (OBL): In the context of wetland delineation, obligate plant species are almost always found in wetlands (see Appendix 2).

Ombrotrophic: Receiving water and nutrients from precipitation only; associated with bogs.

Organic Soil: A soil rich in undecomposed or partially decomposed organic matter (e.g., fibers); typically darkly colored. An organic layer deeper than 20 cm (8 in) thick indicates a hydric soil. NRCS considers soil material to be organic if it is less than 2.0 mm in diameter and has more than 12% organic carbon (~20% organic matter) by dry weight (Schoenberger et al. 2012).

Peatland: A type of wetland where permanently saturated conditions and other factors slow decomposition enough that plant material builds up faster than it decays, forming a thick layer of partially decomposed organic matter (peat).

Phenology: The study of biological events and processes in relation to seasonal cycles. For vegetation, "full phenology" refers to the maximum extent of growth before dying or senescing; typically, this is when plants are flowering or setting seed.

Photosynthesis: The process of converting carbon dioxide and water into glucose (sugar) using energy from the sun. Photosynthesis is performed by plants, algae, and cyanobacteria, and is the opposite reaction to cellular respiration.

Piezometer: A narrow well, typically constructed out of PVC pipe, with slits or holes that allow the water level to equilibrate with the surrounding environment by pressure. A piezometer has slits or holes only along a fraction of its length, typically near the bottom of the pipe. Piezometers can be used to track water levels and to sample for water chemistry. In this manual, "piezometer" refers only to standpipe piezometers. There are other types of piezometers that measure pressure in different ways.

Pteridophyte: Commonly referred to as "ferns and allies," pteridophytes are plants that are vascular (have water transport tissues) but reproduce using spores. Pteridophytes include ferns, horsetails, and clubmosses.

Redox Features: Patches of "rust" in a hydric mineral soil that indicate reduction and transport of iron and manganese. "Redox" refers to electron transfer reactions involving simultaneous reduction (addition of electrons) and oxidation (loss of electrons); when waterlogged soils become anaerobic, iron and manganese (among other chemical species) are reduced through microbial cellular respiration, which oxidizes sugars.

Saturated: A condition in which all pore space between soil particles is taken up by water. Soils cannot drain below the point of saturation (i.e., the water table).

Soil Matrix: The solid particles that form the physical structure of a soil.

Sphagnum: This genus of moss is dominant in many peatlands and contributes to the unique conditions present in these ecosystems. *Sphagnum* species can absorb and store large quantities of water. They also make peatlands more acidic by releasing hydrogen ions during cation exchange. Their cell walls contain phenolic compounds that decay slowly, further reducing the decomposition rate (already slow from anoxic conditions and acidity). *Sphagnum* mosses have a unique growth form to other mosses, with a long stem, elongated clusters of branches coming off the stem, and short branches forming a compact head ("capitulum") at the top. The stems and branches also have very thin "stem leaves".

Thiessen Polygon: A Thiessen polygon contains the area closer to a given reference point than to any other reference point. In the context of peat depth and carbon content calculations, one could partition a peatland so that each Thiessen polygon contains the land area closest to one of the depth measurements and/or coring sites.

Top Cover: This vegetation survey metric considers the strict proportional area taken up by the top vegetation layer.

Transect: A line from which field sampling occurs at defined intervals. Typically, a transect is established in the field using a measuring tape run in a straight line for a defined length.

Upland: An area that is not a wetland.

Vascular Plant: A plant that has water-transport tissues (xylem and phloem). Vascular plants include ferns, conifers, and all flowering plants.

Water-Table Well: A water-table well is similar in purpose and function to a piezometer but has holes or slits along the entire length of the pipe, eliminating the ability to selectively sample water by depth or detect vertical pressure gradients.

Wetland: An area where soil is saturated or inundated for enough of the growing season that it becomes oxygen-deprived.

Wetland Delineation: The process of determining whether a parcel of land is a wetland, and where the wetland boundaries lie, typically to determine where legal restrictions on land use apply. Wetland delineation uses standard indicators from three categories - vegetation, soil, and hydrology - to make these determinations.

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