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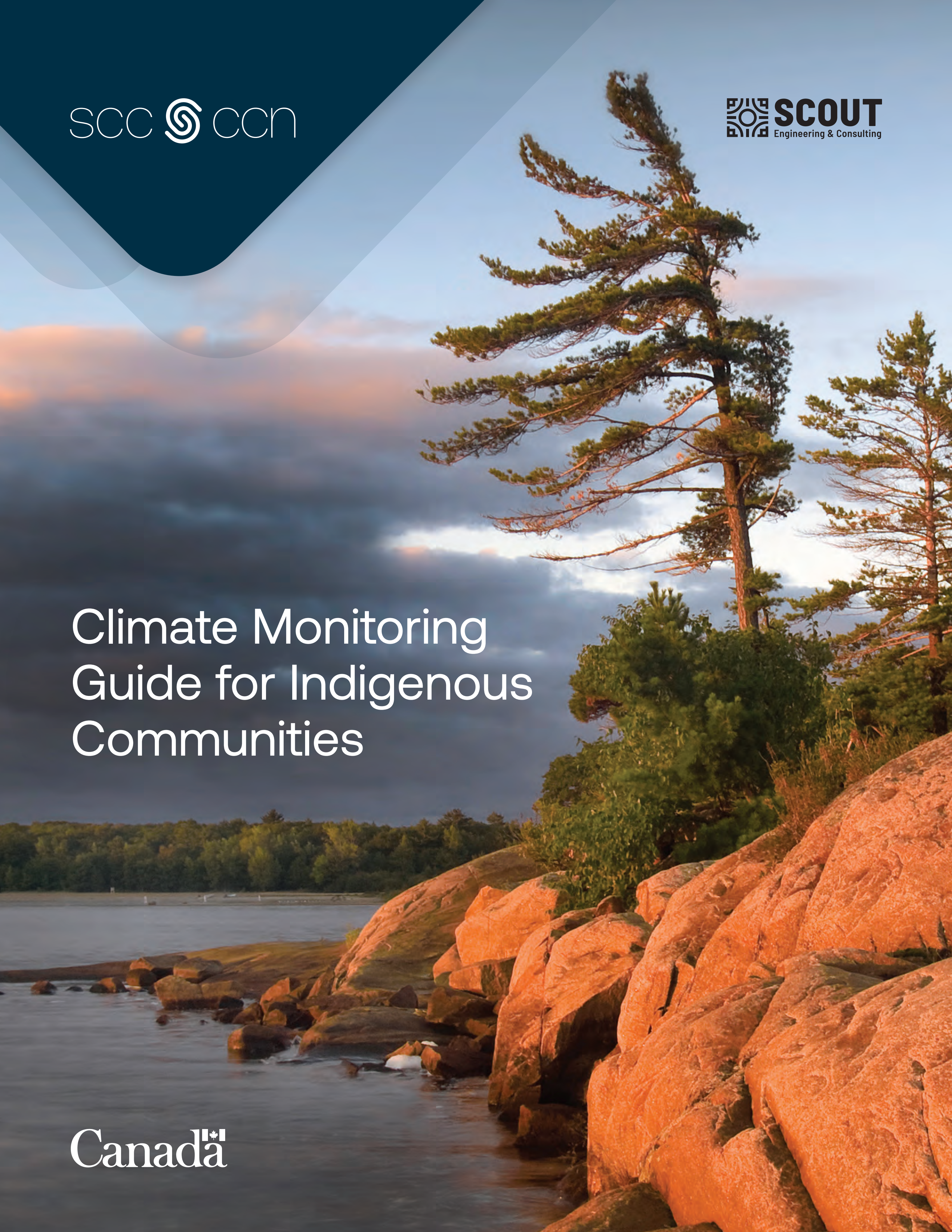

Climate Monitoring Guide for Indigenous Communities

Canada

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Aussi offert en français sous le titre *Guide de surveillance du climat destiné aux collectivités autochtones.*

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The Standards Council of Canada (SCC) and Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) funded this voluntary guidance document to support Indigenous communities that wish to participate in community-based physical climate monitoring.

Development of the guide was led by a steering committee with input from community representatives with varying levels of experience with community-based climate monitoring projects. The stories profiled throughout give insight into these communities' unique projects with the hope that other communities will benefit from the experiences and lessons learned.

CONTRIBUTING COMMUNITIES

We thank the following major contributors, who shared their time and experience to add valuable and relevant resources for communities across Canada:

Fort McKay Métis Nation

Mikisew Cree First Nation

Tuktoyaktuk Community Corporation

To develop the *Climate Monitoring Guide for Indigenous Communities*, SCC retained Scout Engineering and Consulting Ltd., Associated Environmental Consultants Inc., Integral Ecology Group, and Hoskin Scientific Ltd. (the project team).

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Supporting Indigenous communities affected by climate change

First Nation, Métis and Inuit communities across Canada are directly experiencing the impacts of climate change. In northern regions, permafrost thaw and changes to snow and ice conditions have made navigation more difficult and dangerous for land users. In southern regions, more intense and frequent droughts, floods and wildfires have led to emergency situations for many communities. In coastal regions across the country, rising sea levels and erosion threaten the safety of housing and infrastructure. In response, Indigenous communities are adapting and seeking solutions in their territories.

Since early 2018, Crown-Indigenous Relations and Northern Affairs Canada's (CIRNAC) Indigenous Community-Based Climate Monitoring (ICBCM) Program and the Standards Council of Canada's (SCC) Standards to Support Resilience in Infrastructure Program have worked together to develop voluntary guidance for Indigenous communities undertaking physical climate monitoring.

In November 2020, CIRNAC and SCC partnered with Scout Engineering and Consulting Ltd., an Indigenous engineering company, to lead the development of this guide. The project benefited immensely from a steering committee comprising Indigenous and non-Indigenous representatives, including Knowledge Holders and climate change monitoring and adaptation experts. Members provided valuable expertise and knowledge to help determine key climate variables, support the writing of the guide and provide feedback on its contents.

How to use this guide

This document offers voluntary guidance to Indigenous communities across Canada for implementing community-based climate monitoring projects. It shares advice on how to collect, record and validate data on key physical climate variables (e.g., temperature, precipitation, sea ice thickness, etc.) consistently and reliably using scientific methods. It also outlines best practices for recording, storing and sharing Indigenous Knowledge related to climate change while respecting Indigenous principles for data collection, analysis and management. This is vital to enable Indigenous communities and individuals who practice traditional activities to adapt to changes in their environment.

The guide is meant to support local, regional and national data collection and management and to reduce existing gaps in climate data. For example, climate data shared by communities could support Canadian climate models and weather predictions, which in turn will help communities plan for the future. This information could also benefit a variety of entities facing similar issues now and in the future, including co-management boards, governments, academics, northern businesses and international communities.

> “Indigenous community-based climate monitoring project” is referred to as “ICBM project” in this guide.
>
> ICBM projects usually include both Indigenous Knowledge and western science monitoring.

This document aims to:

- **Support Indigenous communities** looking to monitor climate variables
- **Outline tools and processes to record and validate** key physical climate variables
- **Reflect guidance and knowledge provided by** First Nations, Métis and Inuit Knowledge Holders; community-based monitoring practitioners; and representative Indigenous organizations
- **Provide guidance for recording climate variables** relevant to Indigenous communities
- Recommend key climate indicators relevant to Indigenous communities that can be readily measured and recorded
- **Recommend equipment to measure key climate** indicators
- **Provide recommendations** for measuring, understanding and recording key climate indicators
- **List best practices** for the management of physical climate datasets

There are three parts to this guide:

- **Part 1: Implementing an Indigenous community-based climate monitoring project.** Focuses on the development of a successful ICBM project and includes a list of key climate indicators Indigenous communities can readily monitor.
- **Part 2: Monitoring key climate indicators.** Focuses on how climate indicators are physically measured, monitored and recorded. Recommends data collection and management strategies, as well as ways to assess how reliable a given dataset is. Suggests different equipment options for each climate indicator across a range of price points, and lists infrastructure and training requirements for each. Also outlines cost considerations for infrastructure, operation, maintenance and monitoring.
- **Part 3: Recording, storing and sharing Indigenous Knowledge.** Gives guidance on how Indigenous climate knowledge can be recorded, stored and shared as part of community-based climate monitoring.

Why conduct a community-based climate monitoring project?

For generations, Indigenous Peoples have maintained strong relationships with the environment through cultural practices and traditions. From this comes a rich body of Indigenous climate knowledge that includes information about changes in weather patterns, the timing of freeze and thaw cycles, snow and ice conditions, and other climate-related phenomena. This knowledge is often passed down through generations and is incredibly valuable, as it can help us understand how climate change is affecting our planet.

Community-based climate monitoring is gaining traction across Canada as a way for Indigenous communities to better understand and respond to climate change. Compared to academic-driven monitoring, which looks at questions that come from outside the community, this approach enables Indigenous communities to come up with solutions and adaptations to climate change that address their own questions and concerns. Projects may be informed by scientific observations, Indigenous Knowledge or both.

Ultimately, community-based climate monitoring empowers Indigenous communities to collect and use their own traditional knowledge to respond to climate change. This approach can help strengthen awareness of environmental issues within a community and enhance trust in climate monitoring data among community members. It can also promote consideration of Indigenous Knowledge and worldviews in natural resource management and decision making.[1]

Any Indigenous community anywhere in Canada can start a community-based climate monitoring project to help understand environmental changes. Driven by community members, these projects reflect local priorities and are supported by the broader community. Benefits to Indigenous communities include:

- **Training and professional development opportunities for interested community members**
- **Tailored monitoring objectives**
- **Greater awareness of changes in local climate and environment**
- **A better understanding of how climate change is affecting traditional land and resources.**
- **A larger body of knowledge about climate change and its effects on Indigenous communities.**
- **Stronger community ties and capacity building through collaborative work.**
- **Opportunities for Indigenous youth to participate in environmental monitoring and stewardship.**
- **Holistic, place-based knowledge to inform decisions related to climate change adaptation and land stewardship.**

1 Hopkins, D., Joly, T. L., Sykes, H., Waniandy, A., Grant, J., Gallagher, L., Hansen, L., Wall, K., Fortna, P., & Bailey, M. (2019). “Learning Together”: Braiding Indigenous and Western Knowledge Systems to Understand Freshwater Mussel Health in the Lower Athabasca Region of Alberta. Canada. Journal of Ethnobiology, 39(2), 315–336.

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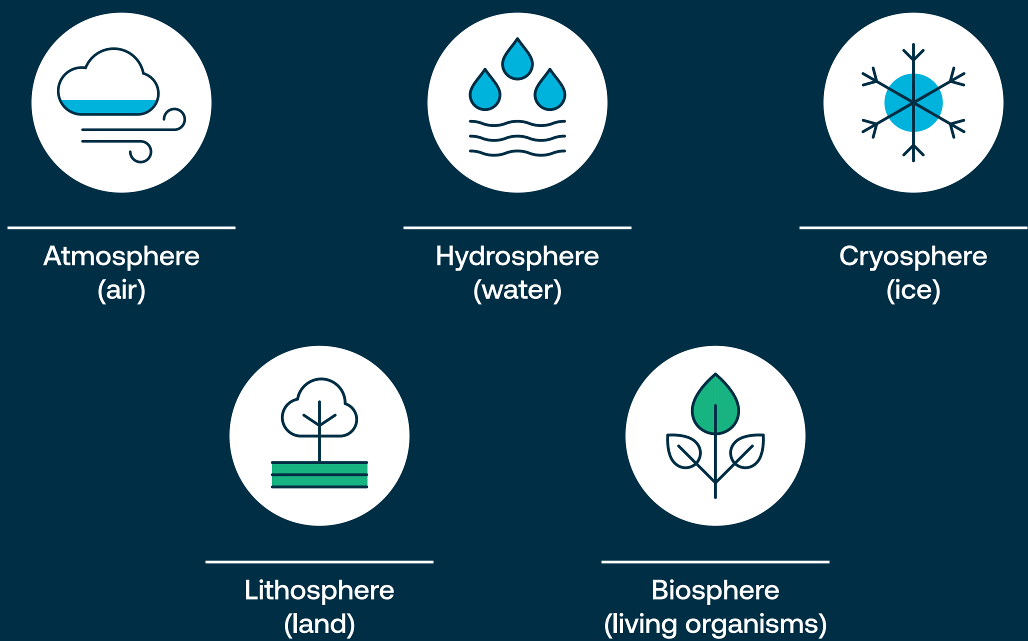
What is climate?

“Climate” refers to the long-term average weather conditions in a given region. This is distinct from “weather”, which typically refers to short-term atmospheric conditions. Climate conditions are generally averaged over a 30-year climate “normal” period. Climate normals are calculated and reported by national and international organizations (such as Environment and Climate Change Canada and the World Meteorological Organization) every 10 years.

Climate normal data typically focuses on direct measurement of atmospheric variables (e.g., precipitation and air temperature). However, monitoring other environmental variables can tell us a lot about changes to the climate system, which includes five major components, as well as the interactions among them:



Part 1: Implementing an Indigenous community-based climate monitoring project

There is no one-size-fits-all approach to community-based climate monitoring

Every ICBM project will look different, depending on where and how the community chooses to set it up. This chapter shares guidance on designing and launching an ICBM project. Projects may include Indigenous Knowledge, physical climate monitoring or both to better understand the climate system.

Key considerations for ICBM projects

The following tips can help in the early stages of ICBM project planning:

- **Clearly define the project purpose and goals:** What environmental changes or issues do you want to monitor, and how will you do it? Meet with community staff and members to define your project's overall purpose and goals. Consider sharing these with the broader community to be clear about what the project hopes to achieve, prevent misunderstandings, and promote education and awareness about the initiative.
- **Build relationships and trust:** Strong relationships and trust are vital to the success of any community-based climate monitoring project. Look for meaningful ways to build or deepen relationships between community staff, members, community monitors and external partners. Open houses with the community's lands and resources department, culture camps, and community field visits to monitoring sites are great ways to introduce monitoring team members to each other and strengthen trust and understanding within the project team.
- **Invest time in planning, but be prepared to adapt:** As a team, discuss project logistics and how you would respond to different situations or challenges. Try to allow for some flexibility when you're developing the project schedule. Unexpected winter storms, impromptu cultural events in the community, or changes in the availability of staff or community monitors may affect when you're able to go onto the land.
- **Identify and pursue ways to build capacity:** Community-based climate monitoring can be a first step for interested members to develop skills in environmental monitoring, from conducting interviews and surveys to recording and interpreting information collected through mapping and GIS applications.

This guide is intended to support First Nation, Métis and Inuit communities across Canada. As such, it does not propose examples specific to any one Indigenous group. Indigenous groups may approach community-based climate monitoring in different ways based on their distinct rights, priorities and traditions. That means some of the best practices this document mentions may not apply to every group or community. Each community should adapt this guidance to suit its own needs.

There are many factors that may affect how a community approaches community-based climate monitoring and that could impact Indigenous Knowledge recording, storing and sharing. These include:

- **Geographic location:** The core issues or priorities that guide climate monitoring project development often depend on geography. For example, northern communities will likely focus on climate change issues that affect northern regions, such as changes in snow and ice conditions and permafrost thaw. Coastal erosion, sea level rise, or changes in marine plants and animals will likely be priority issues for communities in coastal areas. Prairie communities may be most interested in, for example, water quantity and quality.
- **Access to technology:** Limited access to cell service or internet connectivity issues may influence how community-based climate monitoring is established. Satellite phones, radios and other non-cellular options may be more appropriate for field visits in remote areas. Planning meetings may be held in person if virtual meetings are not possible or desired.
- **Community capacity:** Capacity to engage in community-based climate monitoring will differ across Indigenous communities. Some communities have the capacity to hire permanent staff to oversee their monitoring initiatives, while others hire for seasonal positions and work with volunteers. Available funding may also dictate the duration and extent of a monitoring project.

Designing an ICBM project

There are four phases to an ICBM project:

- Identify the need for an ICBM project
- Develop a monitoring plan
- Implement the project
- Review and evaluate the project

Phases of an ICBM project

The following highlights key considerations communities should address at each phase.

01.

Identify the need for an ICBM project

Problem definition

- What are community members concerned about?
- What changes has the community observed?

System understanding

- What concerns did the community identify?
- What components of the climate system are of interest/concern?

Resource identification

- Are resources available to support a monitoring project?
- Are grants available to the community?

Objective definition

- What does the community hope to achieve through a physical climate monitoring project?

Monitoring purpose

- What is the purpose of the monitoring project?
  - Assess long-term impacts/changes
  - Better understand processes
  - Identify thresholds of change
  - Inform management decisionsw

02.

Develop a monitoring plan

Key climate indicators

- What questions do you want to answer with your project?
- How do these questions support the project's objectives?

Key data requirements

- How precise/accurate does the data need to be?
- How frequently does data need to be collected?
- Where/when does the data need to be collected?

Equipment requirements

- What equipment exists to meet key data requirements?
- What equipment will require training to use?

Preparation

- Are monitoring sites accessible?
- Is the required infrastructure in place?
- Is all necessary equipment available and in working order?

Have team members taken required?
Monitoring protocols

- How will data be collected?
- How will data be stored?
- Who will be responsible for maintaining and/or publishing the data?
- How will the data be shared?
- Who will be responsible for maintaining the equipment?

03.

Implement the project

Monitoring

- Install monitoring equipment
- Begin data collection

Data analysis and reporting

- Check data
- Analyze data
- Report/publish results for community users (and other community agreed-up users)

04.

Review and evaluate the project

Project assessment

- What is working well?
- What is not working as intended?
- Are the objectives being met?
- What components need to be revised?
- Does the project need to be expanded?

Project updates

- Update or amend the project as necessary

A successful ICBM project starts with a clear objective: a specific problem or need identified by the community. Because each community will have different concerns, there is no one-size-fits-all approach to project design. However, the following considerations can help develop an appropriate framework for a given community:

- **Defining the problem:** Project leaders should engage with the wider community to understand key concerns about the climate system. These concerns will likely be related to changes community members have observed/experienced in their lifetime. Be sure to capture all concerns (and supporting evidence) that community members share, even if an ICBM project is not the best course of action to address them.
- **Understanding key climate system components:** With community members' concerns documented, it is important to understand the climate system component(s) that may behind the observed changes. Recognizing that all components of the climate system are interconnected, identify the key component(s) that should be monitored to help better understand the community's concerns.
- **Defining a monitoring goal:** Based on community members' concerns, define a monitoring goal that specifies the key desired outcome of the ICBM project. At this stage, focus on the high-level goal of the project and what the community wants to achieve.
- **Identifying resources:** ICBM projects need a variety of resources, both financial and operational. Consider resources already available to the community, as well as potential external resources (e.g., federal financial grants). Recognizing that available resources and/or grant opportunities may include stipulations on how they can be applied, be prepared to adjust the project objective as needed to align with available resources.
- **Defining the monitoring objective:** To inform the development of the monitoring plan (identifying key climate indicators to monitor, determining monitoring frequency, etc.), define the long-term objective of the monitoring. This will be closely linked with the monitoring goal, but aims to identify the purpose of the ICBM project.

Community engagement is at the core of ICBM projects. Accordingly, ICBM projects are best designed based on input from a broad group. Approaches that can support this include:

- Holding a public meeting or open house to introduce the project and solicit input from community members
- Creating a survey to collect feedback from community members about the project
- Using focus groups to get feedback from community members about the project
- Working with community organizations to get input from community members about the project

No matter which approach is used, it is important to ensure community members have a voice in the design.

Key climate indicators

Climate indicators can include many environmental variables that help us understand the different parts of the climate system. Monitoring multiple components together allows us to better understand large-scale changes and, where appropriate, to plan, adapt or mitigate accordingly.

This document focuses on the monitoring of key climate indicators within three main components of the climate system:

- Atmosphere
- Land
- Water

Many partners helped identify these indicators, which were selected to provide the most versatile climate datasets that Indigenous communities can readily observe and monitor. However, Indigenous communities can consider any other climate indicators they deem relevant to their ICBM project.

Although this document focuses on physical climate indicators, many of the considerations presented throughout can also be applied to monitoring biological indicators, such as those related to plants and animals.

ATMOSPHERIC INDICATORS

- **Atmospheric pressure:** The force exerted by the weight of the atmosphere at any given location.
- **Humidity:** The amount of water vapour in the air. Indicates the likelihood of precipitation, dew or fog and is dependent on air temperature and atmospheric pressure.
- **Longwave radiation:** Radiant energy emitted by the Earth.
- **Precipitation (liquid):** Water vapour that forms in clouds and falls back to Earth once water droplets are heavy enough. Commonly referred to as "rain" or "drizzle".
- **Precipitation (solid):** Water vapour that forms in clouds and falls back to Earth once water droplets are heavy enough. If the cloud and underlying atmosphere is cold enough, the water droplets freeze to form snow or hail.
- **Shortwave radiation:** Radiant energy produced by the sun.
- **Surface air temperature:** The temperature of the air close to the Earth's surface.
- **Surface wind direction:** The direction from which a wind originates.
- **Surface wind speed:** How fast the air is moving

LAND INDICATORS

- **Permafrost:** A layer on or under the Earth's surface that has remained frozen for at least two years.
- **Snow depth:** The cumulative depth of snow on the ground at any given time.
- **Soil moisture:** The water content of the soil, representing the water contained in the land surface.

WATER INDICATORS

- **Groundwater level:** The level of water that exists underground in saturated zones beneath the land surface.
- **Ice cover:** The amount of ice covering a body of water. May be expressed in terms of ice thickness or area of cover.
- **Salinity:** The concentration of salts in water or soils.
- **Surface water level:** The level of water within surface water bodies (e.g., rivers, lakes, creeks).
- **Water temperature:** The temperature of a body of water.

See the Appendix for more detailed descriptions and recommended physical monitoring equipment for each key climate indicator.

Case study

How the Fort McKay Métis Nation stores and manages community-based monitoring data

The Fort McKay Métis Nation has collected a large amount of monitoring data through its community-based environmental monitoring programs. Effectively storing and managing this data is critical to protecting the information while ensuring it is accessible to the community.

Situated at the confluence of the McKay River and the Athabasca River in northeastern Alberta, the Fort McKay region is essential to the culture and way of life of the Fort McKay Métis. Growing pressures from oil and gas development, forestry and other industries have transformed the landscape in ways that affect members' ability to practise their rights as Indigenous peoples. Also concerning to community members are the current and future impacts of climate change in the region.

The Fort McKay Métis Nation has established several community-based monitoring programs to monitor environmental changes in Fort McKay and the surrounding region. These initiatives have produced vast amounts of data informed by both Indigenous Knowledge and scientific observations.

The community recognizes the need to improve the usability of the data members collect both internally to make decisions and externally with outside partners. While there is no one-size-fits-all approach to managing environmental monitoring data, the experience of the Fort McKay Métis Nation offers a few lessons:

- **Develop a vision and goals for data management:** It is important to develop a clear vision and goals for how data will be managed. Consider developing both short- and long-term goals to build a data management system and monitor your progress.
- **Establish selection criteria for a data management platform:** Develop a set of criteria for evaluating potential data management platforms. For example, is your data mainly numerical or is it text-based? Do you want to visualize or analyze your data within the platform? This will make it easier to prioritize and select platforms that suit your specific needs.
- **Consider how different data platforms can work together:** It is unlikely that one platform will be able to meet all data storage and analysis needs. Consider selecting data management platforms that can integrate with each other for better access and usability.
- **Determine how the data will be stored securely:** Consider how you will protect access to stored climate data, particularly Indigenous Knowledge information. Fire-proof safes or secure filing cabinets are options for physical data. For digital data, passwords and encryption can be used to control access.

Part 2: Monitoring key climate indicators

Best practices for collecting, managing and assuring the quality of climate data

This chapter focuses on the physical measurement, monitoring and recording of key climate indicators. By including physical climate monitoring in ICBM projects, Indigenous communities can collect high-resolution records of key climate indicators. These can better highlight changes to the climate system over shorter periods or in different places that may not be as effectively captured using Indigenous Knowledge.

Physical climate monitoring overview

Physical climate monitoring is the measurement and recording of indicators that provide information on climate and weather conditions and the non-living physical environment. There are many approaches to physical climate monitoring that **can help understand changes to the climate system**, but the two most common approaches are:

- **Automated monitoring:** Uses scientific sensors and instruments to measure climate indicators regularly or continuously, with limited community member involvement. Sensors and instruments vary in terms of cost and measurement accuracy/precision. Automated monitoring typically requires dataloggers (programmable units that store measurements internally as digital data files) and a power source (e.g., battery and solar panel).
- **Manual monitoring:** Relies on community members to measure climate indicators periodically using scientific sensors and instruments. This method provides immediate observations.

Manual monitoring usually costs less upfront, as installation hardware (e.g., monitoring tripods, batteries and solar panels) and dataloggers are not required. However, in some cases, such as projects that require frequent measurements or multiple measurement locations, automated monitoring may be a better long-term solution.

Depending on the data collection technique used, data collection and management strategies can be important to producing robust climate datasets and safely storing them.

Physical climate data collection techniques

Data can be collected using a notepad and pen or by fully automated dataloggers with telecommunications capability. Consider the following data collection techniques and choose the most appropriate ones based on your project requirements.

MANUAL DOCUMENTATION

Documenting measurement data manually is a simple, reliable way to record climate data and is typically associated with manual monitoring. Measurements should be recorded consistently in a notebook and stored securely. Key information to record includes:

- **Name of the person taking the measurement:** This allows others to follow-up if more information is required when interpreting the climate data in future.
- **Date and time:** A consistent format (e.g., YYYY-MM-DD HH:MM) should be used to record the date and time of each observation.
- **Climate indicator**: Each entry should specify the climate indicator being measured.
- **Unit:** Each entry should specify the unit the measurement is being taken in.
- **Value:** Each entry should specify the value of the measurement.
- **Method:** Each entry should note the method used to record the measurement.
- **Location:** If measurements are being taken in multiple locations, the location of each measurement must be recorded. Whenever possible, locations should be documented in geographic coordinates using a GPS (e.g., latitude and longitude coordinates). However, anecdotal information (e.g., “outside ranger’s hut”) can be used if geographic coordinates are not available.
- **Weather conditions:** A simple record of weather conditions can be useful when interpreting the climate data later.

Table 1 shows an example of manual documentation of physical climate measurements.

For greater data security, periodically convert all manual documentation to a digital form. This way a backup exists if a notebook gets lost or damaged, and digital data is easier to analyze and report on.

Table 1. Manual documentation of physical climate measurements

Name	Date / time	Climate indicator	Unit	Value	Measurement method	Location of measurement	Weather conditions
First Name, Last Name	2022-06-20 08:42	Air temperature	°C	12.6	Mercury thermometer	Latitude: 45.422176° Longitude: -75.696149°	Dry, overcast, light wind
First Name, Last Name	2022-06-21 08:30	Air temperature	°C	10.8	Mercury thermometer	Latitude: 45.421773° Longitude: -75.696115°	Light rain

STANDALONE DATALOGGER

Standalone dataloggers provide autonomous data collection, usually at very frequent intervals. Dataloggers record measurements on internal hard drives from which data can be periodically downloaded. Some scientific sensors come with integrated standalone dataloggers and computer software to communicate with the devices. In other cases, multiple scientific sensors can be connected to one standalone datalogger to harmonize data storage and data download processes. The choice of standalone dataloggers often depends on the choice of scientific sensor(s) and climate indicators being measured.

Advantages

- Standalone dataloggers can be programmed to automatically collect measurements at specific intervals (e.g., every 30 seconds), as required to meet the project's needs.
- Standalone dataloggers are very reliable, ensuring measurements are collected consistently at each scheduled interval.
- No additional effort is required to digitize data records.

Drawbacks

- Unlike with telecommunications (see next section), standalone dataloggers require manual data downloading to retrieve the measurements, which means community members must visit the monitoring station from time to time.
- Although very reliable, standalone dataloggers can fail as with any electronic device. This can lead to large periods of lost data if records have not been downloaded recently.
- Whether standalone dataloggers are integrated into individual sensors or common units are used for multiple sensors, a power source is required. Often this is a battery connected to a solar panel, increasing installation costs.

TELECOMMUNICATIONS

Typically combined with standalone dataloggers, telecommunications devices allow measurements to be transmitted electronically to a remote data storage location (e.g., cloud-based server) over radio, cellular or satellite. This allows community members to view and monitor data remotely.

Depending on the specific scientific sensors or instruments being used, it may be possible to upgrade standalone dataloggers to include telecommunications functionality later.

Advantages

- Standalone dataloggers can be programmed to automatically collect measurements at specific intervals (e.g., every 30 seconds), as required to meet project needs.
- Standalone dataloggers are very reliable, ensuring measurements are collected consistently at each scheduled interval.
- No additional effort is required to digitize data records, as measurements are stored in digital format by default.
- Measurements can be viewed and downloaded in "real time" (i.e., as they are taken) remotely. This way, community members can observe climate conditions without having to visit the monitoring site. In addition, erroneous data records make it possible to quickly identify issues with the monitoring equipment.

Drawbacks

- Whether standalone dataloggers are integrated into individual sensors or common units are used for multiple sensors, a power source is required. Often this is a battery connected to a solar panel, increasing installation costs.
- There may be transmission and/or data hosting fees depending on the telecommunication method used (e.g., radio, cellular or satellite).

Physical climate data management techniques

No matter what monitoring techniques are used, data management and security are important considerations. It is recommended that communities develop climate data management protocols to support these practices. These protocols can be as simple or as complex as needed to ensure data collected within the ICBM project is adequately documented, stored and protected.

Data management protocols should consider:

- Data storage and back-up solutions
- Metadata documentation
- Data formats and file naming conventions
- Data analysis approaches

DATA STORAGE AND BACK-UP

Physical climate monitoring often yields large volumes of data, particularly when using dataloggers or when projects last multiple years. Even measurements collected manually should be digitized periodically to support back-up, analysis and sharing. At its simplest, data back-up involves duplicating data records/files to one or more additional storage locations. For any ICBM project, it is important to consider how and where data will be stored and how data back-ups will be built in.

There are various options for storing and backing up digital climate data:

- **Local computer hard drive:** At a minimum, climate data records should be stored on a local computer hard drive (e.g., an office desktop or laptop computer). This hard drive should have enough storage space for the volume of data anticipated throughout the project.
- **External computer hard drive(s):** If a local computer hard drive is the primary data storage location, it is good practice to periodically copy data from there to least one external storage device that is stored separately (ideally at another site).
- **Cloud-based storage solution:** Cloud-based storage solutions (i.e., remote internet-hosted servers) can provide both data back-ups and remote access to climate data. Examples include Dropbox, Google Drive and Microsoft OneDrive. Many allow local storage to be "synced" to cloud-based storage, so all climate data can be backed up instantly. Alternatively, community members may periodically copy local datasets to cloud-based storage in the same way they would an external computer hard drive.
- **Cloud-based data portal:** Often associated with the use of telecommunications, a cloud-based data portal provides a cloud-based storage solution through a web-based interface for easy access to climate data. Many also offer features such as data visualization, mapping, automated quality assurance and quality control (QAQC) checks, and customized user access via multiple user accounts. Depending on the telecommunications options in use, data portals may be readily available. If not, customized data portals can be developed.

Consider the following when selecting a storage solution:

- How much physical climate data is anticipated to be collected throughout project?
- What storage resources are already available?
- How many people will need access to the climate data, and where is access required (e.g., remote or local)?
- How will data be shared with the wider community?
- Who will be responsible for ensuring data is properly backed up?
- How often should data be backed up?

METADATA DOCUMENTATION

Metadata is information that describes the data (such as where and when it was collected, by whom and for what purpose). Metadata can be as simple or as complex as necessary and should be documented for both manual and automated climate records. Metadata worth documenting includes:

- Who collected the data and/or downloaded the data from the datalogger?
- What are the data records?
- When was the data collected?
- Where was the data collected?
- How was the data collected?
- Who reviewed the data for quality control?
- When was the data reviewed for quality control?
- Photographs of the measurement location/equipment setup

Metadata can be specific to each monitoring location (e.g., each monitoring station has its own metadata), or generalized to the whole project.

DATA FORMAT AND FILE NAMING CONVENTIONS

Data files should be stored and consistently named according to a standard file naming style and format established at the project outset. This supports logical data organization and makes it easier to find specific data records, improving the community's ability to access and analyze collected data.

For example: *LocationName_DownloadDateTime_Version.csv*, where:

- *LocationName* is the pre-assigned name/unique identifier for the location where the data was collected.
- *DownloadDateTime* is the date and time at which data was downloaded or collected.
- *Version* is the version number of the data file.

According to this naming convention, the first version of a file downloaded from Station 1 on July 10, 2013, at 2:02 p.m. would be named *Station1_2013-07-10_14:02_V1.csv.*

Each file or set of files (e.g., all files with data collected at Station 1) should be accompanied by a file documenting metadata information.

It is recommended that data records be stored in a tabular format. Dataloggers typically use this approach by default, regardless of data collection platform or software. For manual data collection, computer software such as Excel allows data to be easily digitized and tabulated.

Table 2 shows an example of tabulated data, collected from a standalone datalogger recording multiple climate indicators at 10-minute intervals.

Table 2. Tabulated data collected from a datalogger

Date / time (YYYY-MM- DD HH:MM)	Battery (V)	Air temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Precipitation (mm)
2013-07-10 12:20	14.68	9.4	54.86	5.006	0
2013-07-10 12:30	14.54	10.23	53.71	5.016	0
2013-07-10 12:40	15.36	10.96	50.4	5.49	0
2013-07-10 12:50	14.39	10.85	49.92	5.483	0
2013-07-10 13:00	14.55	11.88	44.63	5.588	0
2013-07-10 13:10	15.13	11.66	48.89	5.387	0
2013-07-10 13:20	15.8	11.5	48.08	5.455	0
2013-07-10 13:30	16.8	11.84	45.3	4.667	0
2013-07-10 13:40	16.77	11.55	46.85	4.81	0
2013-07-10 13:50	14.68	11.73	48.29	4.919	0
2013-07-10 14:00	14.62	10.95	50.45	4.871	0

Tabulated data can be stored in spreadsheets (e.g., .csv or xlsx file extensions) or plain-text documents (e.g., .txt file extensions), with data points separated by spaces or tabs. There are also advanced file formats (e.g., NetCDF, HD5) that can support larger, more complex datasets.

DATA ANALYSIS APPROACHES

There are a variety of ways to analyze physical climate data. Depending on the project purpose, options may include:

- Developing long-term statistics for each climate indicator (e.g., daily, monthly, seasonal and annual minimum, mean and maximum values)
- Developing timeseries visualizations (e.g., plots) of data records to show how climate indicators have changed over time
- Calculating climate "normals" to demonstrate long-term average climate conditions (for projects spanning 30 years or more)

Various computer software programs can support data analysis and visualization (e.g., Excel, R, Python). The software that comes with some monitoring equipment may also have these functions built in.

Physical climate data quality assurance and quality control

Quality assurance and quality control (QAQC) activities can help ensure the quality of the physical climate data communities collect. QAQC ensures measurements are of equal quality, representative of environmental conditions, and accurate and precise enough to meet project objectives.

With different indicators being monitored for different purposes, QAQC needs can vary significantly from one project to the next. The sections that follow share some guiding climate data grades and QAQC activities that communities can use.

CLIMATE DATA GRADES

Many factors can affect the quality of climate data measurements, including:

- Instrumentation accuracy and/or precision
- Recording interval (e.g., daily, hourly, etc.)
- Recording techniques (e.g., manual or automatic recording)
- Monitoring location/site (e.g., height of instrumentation, proximity to obstacles, etc.)

Communities should develop data grades that consider the purpose of the physical climate monitoring, climate indicators being measured and the intended use for the data. The following four climate data grades can serve as a starting point:

Excellent

Data can reliably be used to assess sub-daily climate conditions and trends.

Good

Depending on the purpose of data collection, data can be used to assess sub-daily climate conditions and trends and/or daily (or less frequent) changes to climate conditions. Manual collection typically enables good data to be collected at lower cost but higher effort than automated collection.

Fair

Depending on the purpose of data collection, data may be used to assess sub-daily climate conditions. Caution should be used to ensure medium or low instrument accuracy or precision is appropriately accounted for. In general, fair data can be used cautiously to assess long-term changes to climate conditions.

Poor

In general, poor data should not be used to assess sub-daily climate conditions. In some cases, climate monitoring equipment limitations and infrequent data records may force the use of poor data. While this data remains valuable, great caution should be used when analyzing and applying it.

Table 3. Example data grades for climate data quality

Record interval	Instrument accuracy or precision		
Automated recording	**High**	**Medium**	**Low**
< Hourly	Excellent	Excellent	Good
Hourly	Excellent	Good	Fair
≥ Daily	Good	Fair	Poor

Record interval	Instrument accuracy or precision		
Manual recording	**High**	**Medium**	**Low**
< Hourly	Good	Good	Fair
Hourly	Good	Fair	Poor
≥ Daily	Fair	Poor	Poor

Table 3 shows examples of data quality grades for various combinations of collection techniques, recording intervals and instrument accuracy and precision. These data grades are meant as guidance on the quality of climate data that can typically be expected, but they do not cover all possibilities. For example, automated data collection is not subject to human error, so it tends to offer a better data grade. Despite this, excellent quality is possible with manual monitoring approaches, as well as daily data records, depending on the purpose of the monitoring and the climate indicator being measured.

In addition, monitoring locations and sites can themselves affect data quality. These effects are not included in Table 3 since they can be complex and are outside the purpose of this guide. The World Meteorological Organization offers detailed standards regarding monitoring site selection for surface meteorological stations.[2]

QUALITY ASSURANCE AND QUALITY CONTROL ACTIVITIES

Quality assurance (QA) refers to processes followed to maintain the quality of a dataset so the data can be used with confidence and with an understanding of any limitations. Quality control (QC) is the process of ensuring errors or gaps in datasets are highlighted and documented. The World Meteorological Organization provides detailed guidance on QAQC activities for surface meteorological monitoring stations.[3]

Different communities and ICBM projects may require different QAQC activities, depending on the purpose of the project and the indicators being measured. At project onset, communities should identify relevant QAQC activities and how they will be carried out. Equipment suppliers may be able to help integrate QAQC checks into data collection. Whatever QAQC activities a community chooses to carry out and however they choose to conduct them, all should be clearly documented.

Following are two examples of QAQC requirements.

2 World Meteorological Organization. (2018). Guide to Instruments and Methods of Observation. Volume I – Measurement of Meteorological Variables. 2018 edition.

3 World Meteorological Organization. (2021). Guidelines on Surface Station Data Quality Control and Quality Assurance for Climate Applications. 2021 edition.

Example 1

Community A is monitoring snow depth at one easily accessible location. The project requires only one measurement each day, which is typically recorded at 12:00.

Recommended QAQC activities include (at a minimum):

- **Consistency checks against previous measurements:** Does the measurement seem reasonable compared to the previous? If not, is there a reasonable explanation for why a large change may be recorded?
- **Reasonability checks:** Does the measurement appear reasonable for the given climate indicator?
- **Variable calculations:** All manual calculations (e.g., for relative humidity) should be confirmed.
- **Customized checks:** Communities may include additional checks they feel are necessary.

These activities can be completed manually by the person taking the measurement or by another community member. The process should be impartial and documented once complete.

Example 2

Community B is monitoring five different climate indicators at four independent monitoring sites using standalone dataloggers.

Recommended QAQC activities include (at a minimum):

- **Consistency checks against previous measurements:** Does the measurement seem reasonable compared to the previous measurement? If not, is there a reasonable explanation for why a large change may be recorded?
- **Consistency checks against other parameters at the station:** Does the measurement appear reasonable given changes observed in other parameters measured at the station?
- **Consistency checks against other stations:** Does the measurement appear reasonable given changes observed at other stations?
- **Reasonability checks:** Does the measurement appear reasonable for the given climate indicator?
- **Data volume checks:** Is the expected volume of data available? Are there measurements for every expected timestep? Are there data gaps?
- **Customized checks:** Communities may include additional checks they feel are necessary.

When using automated data collection, QAQC is also typically automated, usually based on established thresholds, constraints and dataset volume expectations. With standalone dataloggers, QAQC activities are typically completed when the data is retrieved, while dataloggers connected via telecommunications can complete these checks in near real time whenever data is transmitted. QAQC checks can also be set to trigger notifications or alarms to alert community members to any issues.

The process of conducting these checks should be impartial and documented once complete.

Physical climate monitoring equipment

“Physical climate monitoring equipment” can refer to a broad range of equipment covering many applications and varying significantly in accuracy and precision, costs, installation requirements and integration options. This section covers equipment options for each climate indicator to help communities select appropriate equipment.

Generally, climate monitoring equipment can be categorized into the following components:

- **Scientific sensors and instruments:** Components that detect or measure the climate indicator
- **Dataloggers and telecommunications devices:** The (optional) components that collect, store and/or transmit measurements made by the sensors or instruments
- **Installation hardware:** Additional hardware required to install sensors, dataloggers and telecommunications hardware in the environment.
- **Data storage equipment:** Hardware (physical or cloud-based) that stores climate data records.

Because each sensor and each monitoring site has different installation requirements, this section includes only high-level guidance on installation and infrastructure considerations. Site-specific installation requirements should be assessed at the start of the project.

In addition, automated datalogger and telecommunications are generally independent of associated sensors or instruments (unless they are directly integrated), so they do not usually affect measurement accuracy or precision. This section focuses primarily on sensors and instruments for that reason, though high-level guidance on datalogger and telecommunications device costs and options is also provided.

SENSORS AND INSTRUMENTS

Table 4 lists equipment options for each climate indicator, including an overview of cost ranges and the level of accuracy/precision possible with different options. It also recommends monitoring equipment, highlighting the minimum equipment required to collect useful data. However, many ICBM projects will need higher-resolution data records.

This information is not exhaustive. Communities should consult with suppliers to ensure their equipment meets their monitoring requirements.

Table 4. Physical climate monitoring equipment

	Key climate variable	Recommended monitoring equipment	Accuracy/ precision range	Record frequency range	Approximate cost range ($)
Atmospheric	**Atmospheric pressure**	Barometer for manual daily atmospheric pressure readings. For less accessible sites, automated measurement may be required.	± 0.02%	Daily to less than seconds	2,500
	Humidity	Psychrometer ($50) for manual daily relative humidity readings. For less accessible sites, automated measurement (e.g., capacitive hygrometer) may be required.	±3%	Daily to less than seconds	100–1,500
	Precipitation (liquid)	Rain gauge ($50) for manual daily rainfall readings. For less accessible sites, automated measurement (e.g., tipping bucket) may be required.	± 2%	Daily to less than seconds	50–1,000
	Precipitation (liquid and solid)	Automated all-season precipitation weighing gauge ($5,000).	± 0.01%	Daily to less than seconds	5,000–10,000
	Longwave radiation	Pyrgeometer ($1,000) for manual longwave radiation readings. For less accessible sites, automated measurement may be required.	± 5 %	Daily to less than seconds	1,000
	Shortwave radiation	Silicon cell pyranometer ($250) for manual shortwave radiation readings. For less accessible sites, automated measurement may be required.	± 3 – ± 10 %	Daily to less than seconds	250–500
	Surface air temperature	Thermometer ($50) for manual daily temperature readings. For less accessible sites, automated measurement may be required.	± 0.05 °C to ± 2°C	Daily to less than seconds	50–1,000
	Wind speed and wind direction	Automated vane anemometer ($1,000) for wind speed and wind direction measurements.	±0.05 m/s - ±0.5 m/s (wind speed) ±2° - ±3° (wind direction)	Daily to less than seconds	500–2000

Table 4. Physical climate monitoring equipment (continued)

	Key climate variable	Recommended monitoring equipment	Accuracy/ precision range	Record frequency range	Approximate cost range ($)
Land	**Permafrost temperature**	Calibrated thermistor ($10,000) lowered into a borehole at specific depths for monthly readings.	± 0.1 °C	Hourly to annually	10,000–100,000
	Snow depth	Survey level ($500) for manual daily depth measurement. For less accessible sites, automated measurement may be required.	± 0.01 m - ± 0.001 m	Daily to seconds	100–5,000
	Soil moisture	Electromagnetic moisture meter ($500) for manual readings. For less accessible sites, automated measurement may be required.	± 0.03 m3/m3	Daily to minutes	500–1,000
Water	**Groundwater level**	Piezometer ($2,000) and water tape ($200) for manual groundwater level readings. For less accessible sites, automated measurement (e.g., pressure transducer) may be required.	± 0.001 m	Daily to minutes	2,000
	Ice cover	Buoys or ice-tethered platforms for collecting time-series data from remote regions. These buoys can autonomously measure the physical properties of sea ice, snow and the upper layer of the ocean.	± 0.05 m	Daily to seconds	45,000–100,000
	Salinity	Handheld manual units or unattended monitoring sensors. Installation of unattended monitoring sensors can be complex.	± PPT	As required to less than seconds	5,000–50,000
	Surface water level	Pressure transducer ($500) for automated readings.	± 0.001 m - ± 0.0005 m	Daily to seconds	500–2,500
	Water temperature	Submersible temperature strings based on the thermistor method. Thermistor strings are designed and built to the specifications of each installation location.	± 0.5 °C to ± 0.002 °C	Daily to seconds	100–5,000

For more equipment options and key monitoring considerations for each climate indicator, see the Appendix to this guide. A range of equipment options is given where possible, though some indicators are difficult to measure without high-end equipment.

ADDITIONAL MONITORING EQUIPMENT

In general, automated monitoring requires more infrastructure (including dataloggers, power sources and data storage) than manual monitoring. Table 5 overviews key infrastructure that can support physical climate monitoring within an ICBM project.

Every project and site is different, so communities should seek advice from equipment suppliers about project-specific requirements.

Table 5. Infrastructure required to support ICBM projects

Installation hardware			
Infrastructure	**Key considerations**	**Required for**	**Approximate cost range ($)**
Monitoring tripod	Depending on the climate indicator and monitoring technique, it may be necessary to mount hardware (e.g., solar panels, weatherproof enclosure, scientific sensors/instruments) off the ground. A monitoring tripod can be used for this. The tripod should be large enough to support all the components that must be mounted.	Automated monitoring (and manual monitoring)	500
Weatherproof enclosure	The enclosure should be large enough to enclose all dataloggers and telecommunications components. Depending on community/public access to the monitoring equipment, a locking mechanism may be necessary. Mounting hardware may be required to mount the weatherproof enclosure onto a monitoring tripod.	Automated monitoring	500–5,000
Power source (battery / solar panel)	Most automated dataloggers can accept an external power source. If mains power is not accessible, battery and solar panel setups can effectively power monitoring equipment. Batteries and solar panels should have enough capacity to support all devices being used.	Automated monitoring	500–5,000
Cable armoring	To prevent damage to cables connecting monitoring equipment, cable armouring should be installed.	Automated and manual monitoring	100–500

Dataloggers			
Infrastructure	**Key considerations**	**Required for**	**Approximate cost range ($)**
Datalogger(s) / telecommunications	For automated monitoring using sensors/instruments without integrated dataloggers, external dataloggers are required. Dataloggers must be able to accommodate the number of sensors/instruments being used to monitor climate indicators.	Automated monitoring	1,500–15,000

Data storage			
Infrastructure	**Key considerations**	**Required for**	**Approximate cost range ($)**
External computer hard drives	External hard drives can be used for climate data back-ups. Hard drives should be selected based on compatibility with local computers and to ensure enough storage space for the expected data volume.	Automated and manual monitoring	50–200
Cloud-based storage	Communities should select a service that best integrates with any existing cloud-based services. Many services offer small storage volumes (e.g., 15 GB) free of charge. Higher data volumes typically require annual subscription fees.	Automated and manual monitoring	Free–5,000/yr.
Cloud-based data portal	If telecommunications are part of the project, the service will likely include cloud-based data access. However, custom options are available.	Automated and manual monitoring	Free–5,000/yr.

Installation, operation and maintenance considerations

It is not possible to prescribe specific installation requirements given the range of monitoring equipment available and the variety of monitoring purposes and locations. Still, the key considerations in this section can help communities select monitoring locations and install monitoring equipment. This section also recommends operational and maintenance tasks to keep the equipment running smoothly and improve data quality.

INSTALLATION OF MONITORING EQUIPMENT

The climate indicator being monitored, the installation location and the equipment being used will all affect the installation. Following are high-level considerations that are broadly applicable to manual and automated monitoring. Equipment suppliers can provide guidance specific to the installation of their equipment.

Site selection

Where possible:

- Equipment should be installed on dry, stable land, in areas not prone to flooding and away from large obstacles (e.g., buildings and trees).
- Sites should be easily accessible year-round. Consider year-round weather conditions and accessibility options to ensure data can be retrieved at all times of the year.
- Solar panels should be located to maximize sunlight exposure to optimize battery charging.
- Sites should be representative of the surrounding landscape to ensure the data collected is representative of larger-scale conditions.
- Fencing should be installed around the monitoring equipment to prevent access by wildlife and the public, where necessary.

Equipment placement

Where equipment is placed and installed will depend on the climate indicator and purpose of monitoring. General considerations include:

- When monitoring atmospheric variables, the 10:1 rule can serve as a rule of thumb for instrument height placement: If the measuring area is 10 metres wide, sensors should be placed at least 1 metre above the ground.
- The 10:1 rule may also apply to nearby obstacles: Instruments should be placed at 10 times the height of any nearby obstacles.
- Sensor accessibility for maintenance purposes should be weighed against protection from wildlife interference.
- Sensors should be installed securely so wind, rain and other environmental conditions do not move them.

Infrastructure considerations

Where possible:

- Guy wires should be used to ensure monitoring tripods are stable and securely anchored.
- Lightning rods/grounding rods should be installed on all automated monitoring stations to prevent damage from lightning.
- In snowy areas, solar panels should be positioned on an angle to minimize snow cover during winter months.
- Desiccant (a substance that absorbs moisture and promotes a dry environment) should be included in all weatherproof enclosures.
- Batteries should be insulated to minimize power loss during cold months.

MAINTENANCE AND OPERATION

After installing monitoring equipment, communities can focus on operation and maintenance. Operation includes data collection, QAQC tasks, and data analysis and reporting. Maintenance includes ensuring equipment remains accessible and operational, which promotes a higher quality of collected data.

An operation and maintenance plan can support an ICBM project by documenting key tasks for operating and maintaining climate monitoring equipment. How often each task should be carried out will depend on the monitoring equipment, required data quality and the purpose of monitoring. However, maintenance tasks will likely include:

- Ensuring all infrastructure and installation hardware remain secure
- Checking desiccant activation and replacing as necessary
- Ensuring battery voltage is sufficient to keep sensors and equipment in operation
- Ensuring all equipment is operational
- Ensuring all equipment is accessible
- Performing any sensor-specific maintenance tasks outlined in user manuals

Keeping replacement equipment (e.g., batteries, solar panels and installation hardware) on hand can help ensure faulty components are replaced quickly

Case study

How the Mikisew Cree First Nation records Indigenous Knowledge about climate change

The Mikisew Cree First Nation (MCFN) community-based monitoring program combines Indigenous Knowledge and science to monitor changing conditions in the Peace-Athabasca Delta region. The program uses innovative data collection tools to promote education and adaptation to environmental change within the community.

At the heart of the MCFN's traditional territories in northeastern Alberta is the Peace-Athabasca Delta, a large freshwater delta that supports a diversity of plants and wildlife. The delta is intimately linked to MCFN culture and identity. Hunting, trapping, fishing and other harvesting practices have sustained the MCFN community for generations.

With the rise of industrial development and increasing impacts of climate change in the region, MCFN Elders and community members are concerned about the health of the Peace-Athabasca Delta. To address these concerns, the MCFN Government and Industry Relations Department established a community-based monitoring program in 2008. The program is driven by the MCFN community and is focused on environmental change indicators informed by Indigenous Knowledge and science, including the health of wild foods, water quality and quantity, and the safety of winter travel conditions. MCFN Elders, along with the Chief and Council, provide guidance for the program. MCFN members are employed as Environmental Guardians to conduct monitoring and research activities.

The program uses innovative tools, such as a smartphone-based application that enables community monitors to record observations in an electronic field book during site visits. The application also tracks the routes used to reach monitoring sites, which provides insight into the safety of snow and ice conditions throughout the year. Monitoring data is stored in a data management portal linked with other platforms and databases the MCFN uses, improving access to information. By using these tools, the MCFN promotes education and adaptation to environmental change within the community, and educates decision makers about changing conditions in the Peace-Athabasca Delta.

Physical climate monitoring considerations

This section presents some key considerations for physical climate monitoring, including costs, site requirements, equipment availability, data storage needs and maintenance requirements.

SENSOR COSTS

While average sensor costs have come down thanks to changes in technology and increased production capacity, costs are still highly dependent on the data being collected, the complexity of the measurement and the environment they are designed for. Organizations should carefully examine the technical specifications to determine whether a sensor will meet the requirements of the monitoring platform. Typically, low-cost sensor suites are best for high-density monitoring networks, rather than one concentrated climate monitoring station. Canada's remote, rugged and challenging environments often make these low-cost options unsuitable, and communities can end up paying multiple times over the lifespan of the project for repeated repairs and replacements. In these cases, higher-cost sensors that meet local site requirements will be more cost-effective in the long run.

MANUAL DATA COLLECTION COSTS

Typically, sensors designed for manual data collection cost much less than those intended to be left unattended for long periods. That makes labour itself usually the biggest cost associated with manual data collection, and it varies with the level of effort required. For example, if monitoring is conducted locally by someone already required to be in the area as part of their day-to-day operations, the manual data collection costs will be lower than if someone has to travel to the monitoring site to take measurements. Organizations may also need to account for the labour costs of having field staff away from their normal duties. These costs may lead organizations to supplement their manual data collection with remote, unattended climate monitoring stations.

DATALOGGER/RECORDING

A variety of dataloggers are available that are designed specifically for monitoring surface climate and other climate variables. The choice of datalogger is mostly driven by local site conditions, complexity of the sensor suite and the total number of sensors being deployed. Preferences related to familiarity or ease of use may also play a role in the choice.

Some dataloggers include embedded telemetry options that support real-time integration and make deployment and operation easy. Understanding these options helps ensure a community chooses the right datalogger for their needs.

Package pricing usually includes both datalogger and power control. Communities should choose an appropriate power system for the load (current draw from the sensors and telemetry package), the expected weather conditions of the station and any other elements that could harm the physical infrastructure.

SITE REQUIREMENTS

Site requirements and installation costs depend largely on the surface of the installation (e.g., bedrock vs. loose sand and gravel vs. open water). Ideally, monitoring stations should be on dry, stable land that is flat and open, not prone to flooding conditions, free of subsurface irregularities (such as melting permafrost), and out of the public eye.

Monitoring climate over open water is possible but poses a variety of risks and challenges, including buoy size, mooring line capacity, stress from local currents on anchor points and tethered lines, potential hazards in the water (e.g., debris, ice floes, marine traffic). These add to the costs of installation and engineering required for monitoring platforms.

Case study

Lessons learned about sharing climate monitoring data through the Tuktoyaktuk Community Climate Change Resilience Project

The Tuktoyaktuk Community Corporation (TCC) has gathered a large amount of climate monitoring data through the Tuktoyaktuk Community Climate Change Resilience Project. The TCC has taken steps to safeguard its data to ensure the knowledge remains protected and under the control of the community.

The Inuvialuit community of Tuktoyaktuk is located north of the Arctic Circle on the shores of the Arctic Ocean. Climate change impacts such as rising sea levels, coastal erosion and permafrost thaw threaten the safety of homes and buildings in the community. Changes in snow and ice conditions are also affecting the day-to-day realities of community members, such as when they can safely travel on the ice.

In 2018, the TCC launched the Tuktoyaktuk Community Climate Change Resilience Project to better understand these changes and their impacts on the community and the environment they depend on to sustain their livelihoods and culture. The program includes community-based monitoring, where community members lead data collection activities and participate in training with researchers to build their scientific monitoring skills. The program looks at and assesses climate change indicators that reflect the values and concerns of the community, such as ice thickness, turbidity (cloudiness) of water, permafrost depth, and the leaf and bloom dates of edible plants. The project is designed to act as a knowledge-sharing platform to bridge Indigenous Knowledge and scientific knowledge, although to date the program has focused on collecting scientific data.

The TCC has gathered a large amount of climate monitoring knowledge through the project. As the project moves toward the collection of Indigenous Knowledge, one of its key principles is the protection of knowledge shared, ensuring its use remains under the control of the community and that it will not be shared or accessed without permission. For example, community monitors use a digital app to collect monitoring data in the field. The app is password protected, and the data is only accessible to the community. Some data is also collected using field data sheets, which are stored as physical data in the TCC office and are not handled by a third party. The TCC also plans to store digital data in servers on site in the future.

At the discretion of the TCC, selected data may be shared with external partners to enable those partners to be part of community-driven monitoring and research and to advance the interests of the community. The TCC also actively shares knowledge about environmental monitoring internally with community members to promote community interest and involvement in the program. Sharing knowledge also helps build awareness in the community of the impacts of environmental change.

MAINTENANCE

Regular preventative maintenance of climate monitoring stations, sensor components and all related infrastructure is critical to extend the life of the stations, ensure data collected is accurate and reliable, and data flow is continuous from all sensors. Each sensor is unique and has its own maintenance schedule and requirements, which should be outlined in its user manual. Failure to carry out maintenance as directed could affect the validity of collected data.

Maintenance tasks could include preparing an all-season precipitation gauge for winter with antifreeze and mineral oil according to the manufacturer's recommendation, or clearing the optics of a radiation sensor that has been exposed to months of cumulative dirt and dust build-up.

In addition to sensor-specific maintenance, visual and physical inspections of all site infrastructure should be completed every year. This includes all mounting equipment, ground anchors, concrete bases for towers and other installation components.

CLIMATE MONITORING SYSTEMS TELECOMMUNICATIONS

Advances in telecommunications capabilities mean more real-time data is available from climate monitoring stations. This data is invaluable as it provides regular data updates and validation, sends alarms and alerts on abnormal conditions, and delivers continuous insight into the station's condition.

Telecommunications options include radio telemetry, cellular data transmission and satellite telemetry.

- **Radio telemetry** is recommended when all equipment is relatively close together. Spread-spectrum radio technology may allow a range as far as 20 kilometres (line-of-sight) or up to 100 meters (non-line-of-sight). The radio base station serves as a central hub for all dataloggers in range and can send the collected data to a project computer. In a typical system, sensor data is stored locally on a datalogger or network of dataloggers before being forwarded to the project computer.
- **Cellular data transmission** is the most inexpensive option, including both upfront costs for the hardware and ongoing transmission costs (usually priced per kilobyte). However, the lack of network reliability in remote areas may make this option unsuitable.
- **Satellite telemetry** can be used for remote applications where radio and cellular communications are not feasible. The Iridium communications network maintains a dynamic, cross-linked constellation of Low Earth Orbiting (LEO) satellites that provide coverage all over the world. This means dataloggers with an Iridium satellite modem can transmit data in real time from anywhere on Earth. The data is sent to a central gateway, which then transfers the data over the internet to a project computer or cell phone. In a typical climate monitoring system, sensor data is stored locally on a datalogger and sent to an email server via the Iridium satellite network. A cloud-based data centre then pulls the data out of the email server according to a schedule set by the project team.

CLIMATE DATA STORAGE AND SHARING

The easiest way to share and view climate monitoring data is through a web-based data centre, which offers 24/7 instant access to project data via any web browser. Climate data can be exported into the data centre directly from a datalogger or through any project software. The service can be password protected or public and allows real-time access to the collected data. In addition to project-specific information, the online interface may offer dynamic area maps overlaid with weather information, recent and historical data, time series graphs, and statistical summaries, which enable users to interact with project maps and view real-time monitoring data or parameter trends over time.

Data storage costs can vary from free to over $5,000 per year, depending on the amount of data that needs to be stored. This will be determined by the type of sensor and sampling frequency.

Part 3: Recording, storing and sharing Indigenous Knowledge

Best practices for recording Indigenous Knowledge in community-based climate monitoring

What follows are best practices for recording Indigenous Knowledge to support community-based climate monitoring. Depending on how the community-based climate monitoring work has developed within your community, you may have enlisted external partners (e.g., academic or government researchers, consultants, NGOs etc.) to support the monitoring. Regardless of the partners involved, a thoughtful approach to the collection, management, sharing and safekeeping of Indigenous knowledge, guided by community protocols and knowledge holders, is critical.

There are many things to consider when deciding how to record Indigenous Knowledge. The planning stage of any ICBM project must include an open conversation with community knowledge holders to confirm how Indigenous Knowledge will be collected, how it will be used, how it will be shared and how participants' contributions will be acknowledged.

Guidelines or protocols for recording Indigenous Knowledge will vary by community, and there is no one best practice. All ICBM projects must follow the guidelines set by your community.

Indigenous Knowledge can be recorded and used in different ways to inform community-based climate monitoring, including:

- Informing indicator development
- Guiding data collection methods (e.g., protocols for respecting land)
- Contributing unique and integrated information toward understanding climate change
- Guiding the interpretation of outcomes and their meaning
- Framing the purpose and relationships around the monitoring process (e.g., guiding how participants should work together)[4]

Whether your monitoring work is being done entirely by community resources, or with the help of external partners, the same principles apply to recording Indigenous Knowledge about climate as to documenting other types of Indigenous Knowledge, including:

- **Be transparent about why Indigenous Knowledge is being recorded and how it will be used.** Inform knowledge holders about the project in an accessible manner. For example, have conversations about what the project intends to monitor, how the information will be used and how the project will benefit the community.
- **Determine how knowledge holders will be acknowledged for their contributions.** Ask knowledge holders whether they want to be recognized for participating or remain anonymous. Examples of ways to recognize those who wish to be acknowledged include crediting participants in meeting presentations or research reports, or listing them as co-authors on publications.

4 Parlee (2018, p. 15). Parlle, B. (2018). A Best Practices Guide : Indigenous Knowledge and Citizen Science – Lessons for Indigenous Community-Based Climate Change Monitoring in Canada. Crown-Indigenous Relations and Northern Affairs Canada. Ottawa, Canada. https://brendaparlee.ca/climate-monitoring

- **Get consent to record Indigenous Knowledge.** If you have external partners supporting your community in your climate monitoring, they should seek formal oral or written consent to record Indigenous Knowledge from participants, even if the external partners already know the participants, or are friends. Written consent forms usually specify the benefits and/or risks of participating as well as emphasize that participation is voluntary, with consent able to be withdrawn at any time. An example of a consent form used as part of community-based research can be found at the Tracking Change project.
- **Take care when recording sensitive observations or information.** Unique customs may dictate how knowledge is held and transferred from one generation to the next. Some cultures may not allow some types of information to be recorded or disseminated outside the community. If your community has engaged an external partner, you should make sure they are aware of your requirements. For example, members may not want to talk about harvesting rates or hunting ground locations for sensitive species such as caribou. They may request to remain anonymous when providing some information or have certain details not recorded. Care should be taken by external consultants to honour these requests when recording sensitive information.

Although incorporating Indigenous languages into an ICBM project is not required, it can be helpful. Many words and phrases in Indigenous languages reflect cultural understandings of the environment that may not be easily translated into non-Indigenous languages. Ways to incorporate Indigenous languages include:

- **Including Indigenous words or phrases in the project name.** For example, the Tłı̨ cho-led Boots-on-the Ground Caribou Monitoring Program is also called the Ekwò Nàxoèhdee K'è program, a phrase in the Tłı̨ cho language that refers to the movement of the caribou herd throughout the year.[5] Using local language within these programs helps retain the traditional concepts, cultural elements and rich meaning these words or phrases convey instead of inadequate translations or loan words.
- **Conducting project meetings or interviews in Indigenous languages.** Consider having meetings conducted in local languages, either by a community member responsible for the climate monitoring program speaking the local dialect, or with the help of translators and interpreters..
- **Translating project materials into Indigenous languages.** Translating project-related materials (e.g., newsletters, brochures, web pages) into Indigenous languages can promote language learning and generate interest in the project.
- **Encouraging knowledge holders to speak Indigenous languages or share key words and phrases during monitoring activities.** Monitoring can be an opportunity to promote language learning and literacy among community monitors. Speaking local languages during monitoring activities or sharing words or phrases related to climate, weather, place names and other aspects of the environment can help knowledge holders maintain, renew and share Indigenous Knowledge with younger generations.

5 Detas'eetsa: Tłı̨chǫ Research and Training Institute (2017). "We Watch Everything:" A Methodology for Boots-on-the Ground Caribou Monitoring. Behchokǫ̀, NT.

Methods for recording Indigenous climate knowledge

Some of the most common methods of recording Indigenous Knowledge as part of ICBM projects include interviews, surveys, mapping, photography and videos. This section describes these methods and identifies best practices for applying them.

Note that Indigenous Knowledge can provide both qualitative and quantitative information for monitoring climate change:

- **Qualitative information** is based on words and their meaning. For example, a monitor might note that caribou appear unhealthy or make other observations about herd behaviour.
- **Quantitative information** is based on numbers and statistics. For example, a hunter might note how many unhealthy caribou he saw on his last hunting trip or share other observations such as estimates of cow–calf ratios or predator distribution within a territory.

Together, both types of observations provide insight into caribou health and movement and can inform climate monitoring.

ORAL STORYTELLING, TALKING CIRCLES, INTERVIEWS

Among the many ways to document Indigenous Knowledge are oral storytelling, talking circles and interviews. These approaches involve discussing key topics or questions with one or more knowledge holders. The format can range from a formal set of questions or a casual conversation with more open-ended questions.

Storytelling

Storytelling is an important way of transferring Indigenous Knowledge and continuing cultural traditions. Stories can help provide context to a process or phenomenon or attribute additional meaning to events.

To support the collection of Indigenous climate knowledge through storytelling:

- **Be physically present on the land where changes are occurring.** Being on the land presents unique opportunities for storytelling compared to being in an office. Engaging in storytelling at a monitoring site (e.g., by the side of a river, in a berry patch) gives life and meaning to the story, particularly for youth or less experienced members.
- **Use visual materials to elicit responses or support recollection.** Using visual materials (e.g., drawings or photos) can encourage storytelling. Symbols and metaphors can foster discussion and learning about critical values, community wellbeing, resources and environmental changes.[6]

Talking or sharing circles

Talking or sharing circles can be used to mediate, problem-solve or heal, or simply to provide a space for sharing with no tight agenda or facilitation. Participants can express themselves freely and honestly, and focus on fostering a supportive environment that promotes the sharing of Indigenous Knowledge, observations and stories.

6 Parlee. (2018).

To support the collection of Indigenous Knowledge through a talking or sharing circle:

- **Uphold community values and protocols.** It is important to follow community values and protocols during a talking or sharing circle. For example, the Mi'kmaw pass around a token (e.g., a special feather or talking stick) to ensure there is only one speaker at a time. The person holding the token may speak for as long as they wish.[7]
- **Create a comfortable setting for participants.** A comfortable setting can help set the tone for the talking or sharing circle. Providing seating, food and refreshments can make knowledge holders feel more at ease and willing to contribute.[8]

Interviews

Another important method for documenting Indigenous climate knowledge, interviews can range from formal discussions to more casual conversations. Formal interviews are more structured, with a fixed list of questions or topics that are discussed with every knowledge holder. Less formal interviews use more open-ended questions or rely on input from knowledge holders to guide the conversation, and may not all cover the same topics.

To help collect Indigenous Knowledge through interviews:

- **Be clear about the purpose of the interview and obtain consent.** Knowledge holders must provide their informed consent. Explain the purpose of the interview and the monitoring project beforehand. If photos or videos are being taken of the interview, ensure the knowledge holder has given written or oral consent. Due to the age or health status of some knowledge holders, it may be appropriate to have a family member or trusted individual witness the interview.
- Consider the role of Indigenous language in the interview. In some cases, interviews may need to be conducted with the presence of an interpreter. For example, external partners supporting the community-based climate monitoring could consider working with trusted interpreters from within your community wherever possible.
- Consider including a community support person. Knowledge holders may feel more comfortable or willing to share knowledge if a trusted individual (e.g., a relative or friend) is present.

Surveys or questionnaires

Made up of pre-determined questions listed in a set order, surveys and questionnaires are useful for gathering observations from a subset of people in the community. They can be delivered at a low cost to efficiently gather information from a large group or about a specific weather event.

To increase the chances a survey will generate information that fulfills ICBM project objectives:

- **Make the survey easy to understand.** A short summary at the top of the survey can help orient participants to the survey's purpose and how their participation will benefit the community. Clear categories or sections can also help guide participants through the questions. Consider how to best phrase the questions. For example, "Why do you think moose are not as healthy today as they were in the past?" may yield better responses than "What are some of the environmental stressors that cause moose mortality?"

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7 Mi'kmaw Spirit (2016). Mi'kmaw Spirituality – Talking Circles. Retrieved from http://www.muiniskw.org/pgCulture2c.htm#:~:text=The%20sharing%20circle%20is%20also,kinship%20in%20those%20who%20participate

8 Łutsel K'e Dene First Nation (LKDFN) & Trailmark Systems (2022). Mobilizing Indigenous Knowledge in Resource Management Settings: A Practical Guide.

- **Deliver surveys in person or with a facilitator.** A facilitator can help participants overcome barriers to completing a survey. For example, a facilitator might read the questions aloud or provide more explanation for each question. Conducting surveys in person can also help participants feel more at ease and willing to share.
- **Use an online survey platform.** Online or web-based surveys can be shared over email, websites and social media. This can help reach more people, particularly younger people. In addition, many platforms can automatically tabulate responses and are compatible with other programs (e.g., Microsoft Excel) for visualizing results.
- **Test the survey to ensure it reads well and records responses correctly.** Take the time to test the survey and edit it based on feedback. Make sure the survey uses accessible, neutral language and avoids leading questions. Test every question and response option to ensure it appears and records data correctly. A mixture of closed and open-ended questions will produce a richer dataset, so also consider if the survey includes both types of questions.

MAPPING TOOLS AND APPLICATIONS

Map-making involves recording how community members interact with the land in a specific geographic region. Created as hard-copy or digital versions (e.g., Google Earth), maps are typically marked up with codes and notes to describe how the land is used or viewed by the community (e.g., land use areas, place names, sacred sites).

Mapping exercises should be kept simple when recording spatial information and focus on what is most useful for the community and the project.[9]

Map biographies

A map biography is a research method that gathers space- and time-based information about Indigenous land use and occupancy from individual harvesters and land users. Generally, questions focus on land users' direct personal activities and experiences over their lifetime.10 Map biographies are useful for documenting past and present hunting, fishing, trapping and gathering patterns; relationships to the land; history; place names; linguistics; subsistence techniques; campsites; and other cultural information.11 Creating a map biography with an individual involves interviewing the person about how they use the land broadly or at specific sites, and marking these areas on the map (on paper or using digital software).[12]

When conducting map biographies:

- **Limit map biography interviews to one or two participants.** Individual interviews will usually yield more detailed information than group interviews or workshops with multiple knowledge holders.[13]
- **Be clear on what you are documenting and use consistent methods for recording spatial knowledge.** If this work is being done by an outside consultant to support the community, ensure the person leading the interview is familiar with the region and is clear on what types of Indigenous Knowledge observations to record. A standard set of map codes or notes can help ensure consistency within and across interviews.

9 Tobias, T. (2000). Chapter 3: Map Biographies and Composites in Chief Kerry's Moose: A Guidebook to Land Use and Occupancy Mapping, Research Design and Data Collection. Union of British Columbia Indian Chiefs.
10 Tobias. (2000).
11 Chapin, M., Lamb, Z., & Threlkeld, B. (2005). Mapping Indigenous Lands. Annual Review of Anthropology. 34: 619-638.
12 Tobias. (2000).
13 LKDFN & Trailmark Systems. (2022).

GPS applications

GPS devices or platforms are efficient tools for collecting spatial information and seeing trends across time and space. These technologies capture local observations, which can then be represented visually to present relevant findings to decision makers.[14] Software applications for smartphones, tablets and other electronic devices are becoming more common in community-based monitoring. With some initial training, community monitors can go onto the land and independently record observations, relieving some pressure and capacity issues for community staff.

To make the most of GPS applications:

- **Get familiar with existing applications.** Several applications for recording community spatial knowledge already exist, such as, Arc GIS Survey 123 and Trailmark. Consider the costs and benefits of existing applications to determine whether one is suitable for your project or if a custom application is required.
- **Invest in training.** To take full advantage of all features of a new application, community staff and members will need training. Make sure the project plan includes time for that training.
- **Review accuracy and completeness of data submitted by community monitors.** Verifying observations is important to confirm they contain the appropriate level of detail and are relevant before they are added to the dataset.[15] Consider appointing a specific person trained to review data submissions for errors or inconsistencies.
- **Create a community place names map.** A place names map can serve as an educational and storytelling tool to build familiarity with the region and its significance to the community. For example, the Gwich'in Place Names Atlas is an interactive, web-based map that tells the story of Gwich'in culture and history within their traditional territory.

Digital storytelling

Communities can present their knowledge narratively or artistically using a variety of digital media. Through artistic media (e.g., photography, video, etc.), communities can explore social and ecological change by mirroring these changes in the environment or depicting a social-ecological event in the community in a captivating, meaningful way for the audience and content creators.[16] Participatory video is a newer approach to documenting climate change observations and stories, where a community or group creates their own film by mobilizing stories and collective knowledge to inform climate adaptation.[17]

CONSIDERATIONS FOR STORING INDIGENOUS CLIMATE KNOWLEDGE

Indigenous climate knowledge can be stored either as physical material (e.g., paper copies of maps and monitoring data sheets) or electronically (e.g., on a computer or in a web-based platform). No matter the storage method, it is essential to consider how community knowledge will be protected.

14 Johnson, N., Behe, C., Danielsen, F., Kruemmel, E., Nickels, S., & Pulsifer, P. (2016). Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic: A Review for the Sustaining Artic Observing Networks. Final report to Sustaining Artic Observing Networks. Ottawa, ON: Inuit Circumpolar Council.

15 Parlee. (2018).

16 Parlee. (2018).

17 First Peoples Group. (2022). Indigenous Climate Monitoring Toolkit. Retrieved from https://indigenousclimatemonitoring.ca/

When considering how to store Indigenous climate knowledge:

- **Uphold protocols for storing Indigenous Knowledge.** All storage locations and methods must be approved by your community. The community may wish to store the data at its own office, as physical records or on private servers. Data may also be stored with a third party, such as a regional monitoring network or provincial or federal government partner.
- **Determine who will be able to access the stored data.** Establish protocols to govern data access permissions. Consider appointing a designated data steward within the community or group to oversee access to the data and respond to information requests.
- **Determine how stored data will be protected.** Passwords, encryptions and other safeguards may need to be put in place to ensure Indigenous Knowledge is protected and safely stored.

Selecting a platform for storing Indigenous climate knowledge

Data management is critical to community-based climate monitoring projects. Ideally, data should be stored in a way that ensures it is protected and stored safely but remains accessible to the community.

When assessing a platform for storing Indigenous climate knowledge, consider:

- **How much storage capacity does it offer?** Does the platform offer enough capacity to handle the amount of data that will be collected?
- **What types of data can it store?** Can the platform store different types of data (e.g., spatial data, community land use data)?
- **What analytical features does it offer?** Does the platform have built-in tools to query, analyze or interpret data?
- **Does it have data visualization features?** Are there ways to visualize data within the platform, such as graphs, maps or word clouds?
- **Where is the data stored?** Can the data be stored on the community's server or can it only be stored by a third party?
- **How accessible is it?** Is the program only accessible by community staff, or can you control access for various users?
- **Is it compatible with other platforms?** Can stored data be exported and brought into other platforms? Can data from other sources be brought in?
- **Is it compatible with different electronic devices?** Is the platform only accessible on a desktop computer, or can it be accessed on other devices such as laptops, tablets and mobile phones?
- **Is it secure?**
- **Is it easy to use?**

CONSIDERATIONS FOR SHARING INDIGENOUS KNOWLEDGE IN COMMUNITY-BASED CLIMATE KNOWLEDGE PROJECTS

Sharing Indigenous Knowledge about climate or environmental change is a core purpose of any monitoring project. It ensures the information can enhance decision making to the benefit of the community. Sharing knowledge within the community includes sharing it with your Chief and Council, community leadership, knowledge holders, and/or community members.

Communities may use a combination of methods to share knowledge and information. Examples of communication methods include:

- Presentations to Chief and Council and/or community leadership
- Community meetings
- Open houses
- Community newsletter updates
- Social media posts
- Other community forums

Check out these other important resources

[Mobilizing Indigenous Knowledge in Resource Management Settings: A Practical Guide]

[Indigenous Climate Monitoring Toolkit]

[Guidance Document for Community Knowledge Protocols (CKP) and Data Sharing Agreements (DSA)]

Indigenous Knowledge about climate or environmental changes may also be shared outside the community if appropriate or desired by the community. This is most often done in cases where knowledge and information may influence decisions outside the community. However, a history of appropriation or misuse of Indigenous Knowledge by external researchers and governments may make some communities hesitant to share their knowledge and concerned that, once shared, the community would be less able to protect it. If your community has engaged an external partner to support your work, data sharing protocols, guidelines and agreements can help you maintain control over shared knowledge.

Before any monitoring data is collected, answer four key questions:

- Who owns the data?
- Who controls it?
- Who has access to it?
- Who holds it?[18]

These questions are particularly important if your community has engaged an external partner to support your monitoring efforts.

- **Develop data sharing protocols within the community.** If an external partner has been engaged to help the community with the monitoring project, ensure they are aware of data sharing protocols. If community data sharing protocols don't currently exist, consider the need to develop them (with the development of protocols being done by the community). If local sharing protocols exist determine how the nature, role and functionality of existing data sharing protocols could support the climate-monitoring work. The Łutsel K'e Dene First Nation, in partnership with Trailmark Systems, offers a variety of useful templates for knowledge sharing. These documents are meant to be modified and to guide Indigenous communities in the development of legal documents that reflect their knowledge sharing laws and principles.
- **Determine who owns and can access data.** Use and ownership protocols for Indigenous Knowledge vary by community. A community may have established principles or guidelines governing how its data is used and shared or it may vary case by case. Many First Nations communities apply the ownership, control, access and possession (OCAP) principles developed by Ontario's First Nations Information Governance Centre.[19] These principles advocate for the inclusion of Indigenous Peoples in research that involves their knowledge and data. External partners supporting a community to do conduct a community-based climate monitoring project should be made aware of these.

18 Parlee. (2018).

19 First Nations Information Governance Centre. (2022). The First Nations Principles of OCAP. Retrieved from https://fnigc.ca/ocap-training

- **Consider the significance and sensitivity of the information or materials being shared.** Appropriate measures must be taken to protect culturally sensitive and sacred knowledge, especially when the knowledge is exchanged in person. Strategies include designating a regional organization to act as a data steward that holds the data while allowing local authorities to control who can access it and for what purpose.[20] This may include restrictions on the research material for an agreed period or simply keeping certain data confidential.[21]
- **Meet with knowledge holders to share the findings.** Before knowledge is shared broadly within the community, validate whether information was interpreted correctly and is appropriate to release within the community, or to broader monitoring partners, third-party consultants or the public. Individually or in a group, participants must have time to review the information they contributed and discuss how findings were interpreted. This helps ensure accurate representations of participant experiences.
- **Build capacity to store, manage and access your own data.** Investing in technical infrastructure or getting training in research methods and data management can enable communities to achieve long-term data ownership and maintain data sovereignty.[22] To offset the high costs of these technologies and data software, it might be helpful to involve a third-party developer or manager to distribute costs across multiple users within your region.[23]

DATA SHARING AGREEMENTS

The following principles for data sharing agreements are particularly important if a community's climate-based monitoring is being supported by an external partner.

Data sharing may involve documenting, exchanging, collecting and/or disclosing Indigenous Knowledge. All data-sharing activities should be conducted under the assumption that the community has ownership of its knowledge and disclosure of that information may require a data sharing agreement.

Data sharing agreements are fundamental to ensuring an ethical standard is upheld to secure Indigenous ownership of and access to traditional knowledge. Data sharing agreements should:

- **Describe the project and the data being collected.** Participants need to be aware of the purpose, objectives and intent behind the research and data sharing. Any expected outcomes and potential impacts should be addressed. It is equally important to describe the types of information being collected and how information will be included.
- **Outline how the data will be accessed and used.** Detail how and when the data will be accessed, how these permissions will be granted, who can access the data and for what purpose, and how confidentiality measures will be upheld.
- **Set parameters for data storage, retention and disposal.** Agreements should describe how data will be managed, timeframes and plans for long-term data storage, related risks and security procedures (e.g., how data will be backed up).

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20 Canadian Institutes of Health and Research, Natural Sciences and Engineering Research Council of Canada, and Social Sciences and Humanities Research Council. (2018). Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans. Secretariat on Responsible Conduct of Research.

21 Yukon Research Centre. (2013). Protocols and Principles for Conducting Research with Yukon First Nations. Yukon Research Centre, Yukon College, Whitehorse, YT.

22 Łutsel K'e Dene First Nation (LKDFN) & Trailmark Systems. (2022). Mobilizing Indigenous Knowledge in Resource Management Settings: A Practical Guide.

23 Johnson, N., Behe, C., Danielsen, F., Kruemmel, E., Nickels, S., & Pulsifer, P. (2016). Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic: A Review for the Sustaining Artic Observing Networks. Final report to Sustaining Artic Observing Networks. Ottawa, ON: Inuit Circumpolar Council.

- **Protect the collective ownership and intellectual property rights.** An agreement is only a license to share a community's knowledge, granting permission to access and steward the data. Agreements should protect each community's intellectual rights while being mindful that treating knowledge as "property" rather than a gift to be shared can present problems between knowledge holders and data stewards in a position of trust.[24]
- **Re-assess sharing agreements periodically and keep protocols up to date.** Agreements should be revisited periodically, particularly when new requests are either unanticipated or were not discussed thoroughly during the project design phase.[25]

STRATEGIES FOR SHARING MONITORING DATA AND RESULTS

Despite the challenge of maintaining control over their data, Indigenous communities can benefit from comparing and compiling data to inform local, regional and national decision-making.[26] Creating opportunities to celebrate and share traditional knowledge with a wide audience can be a show of respect for the knowledge being collected.[27]

Data sharing strategies may include the use of:

- Networks, usually focused on shared experiences and common resources and concerns
- Knowledge commons
- Cooperative knowledge sharing
- Open-access data hubs
- Web portals or distribution lists
- In-person exchanges (e.g., fieldwork, workshops, working groups)
- Funding source coordination or sharing

A few ways to develop a strategy for sharing monitoring results include:

- **Developing standard data collection methods.** Regional monitoring networks (e.g., Tracking Change) can standardize aspects of data collection while continuing to prioritize community needs and goals. This often involves commitments from community programs to incorporate some non-local monitoring goals into their existing local programs.[28]
- **Participating in regional monitoring and data sharing networks.** National environmental monitoring programs (e.g., Mackenzie DataStream, CABIN, Indigenous Climate Hub and CoCoRaHS) can develop systems that enable widespread communication across community-based monitoring programs to identify and distribute relevant information.[29]
- **Increasing accessibility of data to monitoring partners.** For example, the Mackenzie DataStream is openly accessible to communities, researchers and government. No password is required to access the data and there are no restrictions or data downloads, facilitating collaboration and knowledge sharing.

24 Parlee. (2018).
25 Johnson et al. (2016).
26 Johnson et al. (2016).
27 Parlee. (2018).
28 Johnson et al. (2016).
29 Johnson et al. (2016).

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Appendix: Physical climate monitoring guides

Atmospheric indicators

ATMOSPHERIC (BAROMETRIC) PRESSURE

Definition

Atmospheric pressure (also known as air pressure) is the weight of the air pressing down on the Earth. An atmosphere (atm) is a unit of measurement equal to the average air pressure at sea level at a temperature of 15 degrees Celsius (59 degrees Fahrenheit). The number of atmospheres drops as altitude increases because the density of air is lower and exerts less pressure. As altitude decreases, the density of air increases, as does the number of atmospheres. Low atmospheric pressure means the air is rising, while high atmospheric pressure means the air is sinking. Atmospheric pressure is typically reported in inches of mercury or in millibars (1 inch of mercury equals about 33.9 millibars).

Why measure atmospheric pressure?

Atmospheric pressure has important effects on water chemistry and weather conditions. High atmospheric pressure means sunny, clear and favourable weather conditions, while lower atmospheric pressure leads to rainy and cloudy weather conditions.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Capacitive barometer	Two parallel conducting plates separated by a small gap. One plate acts as a diaphragm that is displaced by atmospheric pressure, changing the capacitance of the circuit. The change in capacitance is translated as a change in atmospheric pressure.	Measurement technique: Manual or automated Approximate accuracy: 0.02% Measurement frequency: As required (up to <1 sec)	Manual: Temperature readings recorded in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$2,500

Key monitoring considerations

Site selection:

- Equipment should not be installed under direct sunlight, as temperature changes can affect the readings.

Maintenance:

- Equipment, particularly the pressure inlet, must be kept clean and free from obstructions.
- The height of sensing instrument and mounting must be checked regularly.
- Equipment must be calibrated regularly.
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.

HUMIDITY

Definition

Humidity (water vapour) is the amount of water in vapour form in the air. It indicates the likelihood of precipitation, dew or fog and is dependent on air temperature and atmospheric pressure. It is typically recorded as relative humidity, or the actual amount of water vapour in the air compared to the total amount of vapour that can exist in the air at its current temperature. Relative humidity is typically recorded as a percentage.

Why measure humidity?

Along with temperature and wind, near-surface water vapour influences the movement of moisture and plays a role in the energy and hydrological cycles. The humidity of air near the surface of the Earth affects the comfort and health of humans, livestock and wildlife; the swarming behaviour of insects; and the occurrence of plant diseases.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Psychrometer	Two calibrated thermometers, or bulbs: one dry and one kept moist with distilled water on a sock or wick. A psychrometer measures humidity by taking both a wet-bulb and a dry-bulb temperature reading. With those two values known, the relative humidity in the air can be determined digitally or by reading a psychrometric chart.	Measurement technique: Manual Approximate accuracy: ±3% RH, ±1.0°C Measurement frequency: As required	Readings (temperature of the dry bulb and the wet bulb on an analog psychrometer) or relative humidity (on a digital psychrometer) recorded manually in the field (pen and paper) and digitized later Data format: Tabular	Mounting hardware Simple installation; no special training required	$100
Capacitive hygrometer	Thin strip of non-conductive material placed between two metal plates. The change in capacitance of the non-conducting material due to humidity is measured as an output voltage. This can be displayed via an analog dial, output into another system or converted into a digital reading that indicates the amount of water vapour in the air.	Measurement technique: Automated Approximate accuracy: ±2% RH Measurement frequency: As required (up to <1 sec)	Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$1,500
Resistive hygrometer	Thin strip of conducting material placed between two metal plates. The change in electrical resistance of the conducting material due to humidity is measured as an output voltage. This can be displayed via an analog dial, output into another system or converted into a digital reading that indicates the amount of water vapour in the air.	Measurement technique: Automated Approximate accuracy: ±3% RH Measurement frequency: As required (up to <1 sec)	Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$1,500

Key monitoring considerations

Site selection:

- Humidity measurements should reflect the humidity of the general atmosphere of the site. Equipment should be located at least 15 metres away from the nearest tree or body of water.
- Equipment should be installed and mounted in a sheltered area that is protected from precipitation.

Maintenance:

- Dirt and debris that have accumulated on the sensor must be removed. During the winter, snow and ice should also be checked for and removed.
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.
- Recalibration every two years is recommended to maintain accuracy.

LONGWAVE RADIATION

Definition

Longwave radiation is radiant energy emitted by the Earth. It is typically recorded in Watts per square metre (W/m^2).

Why measure longwave radiation?

Longwave radiation can be used as a tool to measure climate sensitivity.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Pyrgeometer	Measures the resistance/voltage changes in a material that is sensitive to the net energy transfer by radiation that occurs between itself and its surroundings. By also measuring its own temperature and making assumptions about the nature of its surroundings, it can infer the temperature of the local atmosphere with which it is exchanging radiation.	Measurement technique: Manual or automated Approximate accuracy: ± 5 % Measurement frequency: As required (up to <1 sec)	Manual: Readings recorded manually in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting platform Mounting hardware More complex installation; some training required	$1,000

Key monitoring considerations

Site selection:

- Equipment should be installed at a height of 3 metres to avoid debris contamination. These sensors should be mounted with a clear field of view (i.e., free from obstructions).

Maintenance

- Lens/sensor cover must be periodically cleaned to remove dust, dirt and debris.
- Screw connections and mounting hardware must be checked periodically.
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.
- Recalibration is recommended every two years to maintain accuracy.

PRECIPITATION (LIQUID AND SOLID)

Definition

Precipitation is any form of water that falls to the Earth's surface, including rain, freezing rain, sleet, snow and hail. Precipitation is water vapour that forms in clouds and falls back to Earth once water droplets are heavy enough. Liquid precipitation is commonly referred to as "rain" or "drizzle". Solid precipitation is typically referred to as "snow" or "hail". Liquid precipitation is typically recorded as a cumulative amount in millimetres. Solid precipitation is typically recorded as a cumulative amount in millimetres of water equivalent. This amount is typically added over a certain period of time, such as millimetres per day.

Why measure precipitation?

Precipitation measurements provide essential information for monitoring water levels in lakes and reservoirs, forecasting potential droughts and floods, as well as assessing long-term water supply/demand and water quality.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approximate cost
Manual rain gauge	A simple acrylic or glass tube, closed on one end and with a scale in metric or imperial units to indicate the amount of liquid. Must be emptied by hand after each precipitation event to ensure correct measurements. Rainfall amounts are described as the depth of water reaching the ground, typically in inches or millimetres (25 mm equals one inch).	Measurement technique: Manual Approximate accuracy: ±2% Measurement frequency: Daily Type of precipitation measured: Liquid	Gauges should be read between 5:00 a.m. and 9:00 a.m., preferably at the same time every day Readings recorded manually in the field (pen and paper) and digitized later Data format: Tabular	Mounting hardware Simple installation; no special training required	$50
Tipping bucket rain gauge	A collector funnel with stainless steel leaf filter, an integrated siphon control mechanism, an outer enclosure with quick release fasteners and a base that houses the tipping mechanism. The bucket tips when precipitation of 0.2 mm, 0.5 mm or 1.0 mm has been collected. Each tip activates a reed switch closure, which is detected by a datalogger and/or telemetry system.	Measurement technique: Automated Approximate accuracy: ±2% Measurement frequency: As required (0.2–1 mm) Type of precipitation measured: Liquid	Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$500–$1,000

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approximate cost
All-season precipitation weighing gauge	A storage bin, which is weighed to record the precipitation mass. Some models measure the mass using a pen on a rotating drum or by using a vibrating wire attached to a datalogger. The advantages of this type of gauge over tipping buckets are that it does not underestimate intense rain and it can measure other forms of precipitation, including hail and snow. Its disadvantages are that it is more expensive and requires more maintenance than tipping bucket gauges.	Measurement technique: Automated Approximate accuracy: ±0.1% Measurement frequency: As required Type of precipitation measured: Liquid and solid. Gauge can also include water quality sensors (e.g., greenhouse gas concentration)	Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$5,000
Disdrometer	Precipitation type and intensity are estimated based on an optical principle using a laser beam (786 nanometres) that is scattered by falling particles (such as rain). The strength and duration of this scattering lets it measure the diameter and velocity of the falling particles, allowing precipitation type to be estimated.	Measurement technique: Automated Approximate accuracy: ±5% (liquid precipitation), ±20% (solid precipitation) Measurement frequency: As required Type of precipitation measured: Liquid and solid	Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$10,000

Key monitoring considerations

Site selection:

- Equipment should be installed in an open area, away from vegetation or buildings that may interfere with precipitation. It is recommended that instruments be placed at least twice the distance away from the height of the nearest obstruction.
- Equipment should be installed away from sources of artificial precipitation that can affect the readings, such as sprinklers.

Installation

- Gauges should be placed at least 0.6–1.5 metres (2–5 feet) off the ground on the side of a pole, with the top of the cylinder at least 0.15 metres above the top of the pole to prevent splash back.
- The top of the rain gauge should be level.

Maintenance

- Manual rain gauges, tipping buckets and weighing rain gauges must be periodically checked for debris, insects, bird's nests, etc., and cleaned as required.
- Self-emptying rain gauges must be checked for any obstructions in the exit path.

- Gauges must be wiped of dust using a soft, damp cloth. If possible, buckets and collector funnel should be cleaned gently with water and a mild liquid detergent, and rinsed thoroughly.
- The gauge must be checked to ensure it is level before and after reassembly.
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.

SHORTWAVE RADIATION

Definition

Shortwave radiation is radiant energy produced by the sun. It includes the wavelengths in the visible, near-ultraviolet and near-infrared spectra. Each of these wavelengths has a different impact on the environment. The amount and intensity of radiation a location or body of water receives depends on a variety of factors, including latitude, season, time of day, cloud cover and altitude. Shortwave radiation is typically recorded in Watts per square metre (W/m^2).

Why measure shortwave radiation?

Shortwave radiation provides light and heat for the Earth and energy for photosynthesis, making it essential for the metabolism of the environment and its inhabitants. Shortwave radiation is also essential for determining evapotranspiration rates, energy balance and net radiation.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approximate cost
Silicon cell pyranometer	Produces an output current similar to that produced when a solar panel converts the sun's energy into electricity. When the current passes through a shunt resistor, it is converted to a voltage signal, which is then translated to W/m^2.	Measurement technique: Manual or automated Approximate accuracy: ± Manual 3–±10% Measurement frequency: As required (up to <1 sec)	Manual: Readings recorded manually in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting platform Mounting hardware More complex installation; some training required	$250
Thermopile pyranometer	Uses a series of thermoelectric junctions to provide a signal proportional to the temperature difference between a black absorbing surface and a reference. The reference may be either a white reflective surface or the internal portion of the sensor base. The black surface uniformly absorbs solar radiation across the solar spectrum.	Measurement technique: Manual or automated Approximate accuracy: ±3% Measurement frequency: As required (up to <1 sec)	Manual: Readings recorded manually in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting platform Mounting hardware More complex installation; some training required	$500

Key monitoring considerations

Site selection:

- These sensors should be installed at a height of at least 3 metres (10 feet), or high enough to avoid radiation from reflective surfaces (e.g., buildings, roads, vegetation, etc.) or shading from obstructions.

Installation

- Equipment should be positioned at the angle that will enable them to receive the maximum amount of solar radiation throughout the year. This angle will be different for each site.

Maintenance

- The lens/sensor cover must be cleaned periodically to remove dust, dirt and debris.
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.
- Recalibration every two years is recommended to maintain accuracy.

SURFACE AIR TEMPERATURE

Definition

Surface air temperature is the temperature of the air close to the Earth's surface. It is typically measured at a height of 2 metres from the ground and recorded in degrees Celsius.

Why measure air temperature?

Air temperature affects the growth and reproduction of plants and animals, with warmer temperatures promoting increased biological growth. Air temperature also affects nearly all other observed climate variables, including relative humidity, evaporation rates, wind speed and direction, and precipitation patterns and types.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Mercury/alcohol thermometer	A glass tube filled with mercury or alcohol and marked with a standard temperature scale. With changes in temperature, the liquid expands and contracts, and the temperature can be read from the scale.	Measurement technique: Manual Approximate accuracy: ±1°–2° C Measurement frequency: As required	Thermometer readings recorded manually in the field (pen and paper) and digitized later Data format: Tabular	Mounting hardware Simple installation; no special training required	\$50–\$250

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Thermocouple	Device that consists of two metallic wires joined together to form a junction. When the junction temperature changes, a small voltage is generated, and that is translated as temperature.	Measurement technique: Manual or automated Approximate accuracy: ±0.50 °C Measurement frequency: As required (<1 sec–24 hrs)	Manual: Temperature readings recorded in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	\$50–\$100
Resistive temperature detector (RTD)	Wire windings or thin-film serpentines of pure metals (commonly platinum) that exhibit changes in resistance with changes in temperature. An external electronic device measures the resistance of the sensor by passing a small electrical current through the sensor to generate a voltage. The resistance vs. temperature relationship is well known and is repeatable over time.	Measurement technique: Automated Approximate accuracy: ±0.05 °C Measurement frequency: As required (<1 sec–24 hrs)	Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	\$500
Thermistor	Semiconductor materials pressed into a small bead, disk or wafer shape and coated with epoxy or glass. Similar to RTDs, an electrical current is passed through the thermistor to generate a voltage across the thermistor and determine its temperature.	Measurement technique: Automated Approximate accuracy: ±0.05 °C Measurement frequency: As required (up to <1 sec)	Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular data	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	\$100–\$1,000

Key monitoring considerations

Site selection:

- Equipment should be installed 1.2–1.8 metres off the ground to prevent ambient ground temperature from affecting readings.
- Equipment should be placed at a distance approximately four times the height of the nearest building.
- Equipment should not be located under direct sunlight and should receive proper ventilation.

Installation:

- Temperature measurements are very sensitive to exposure and are affected by the state of surrounding vegetation, ground cover, buildings and other objects. Equipment should be enclosed by a radiation shield or screen to maintain a uniform temperature that is the same as the surrounding outside air, and to protect the temperature sensor from radiant heat (solar radiation), precipitation and other variables that could influence the measurements.

Maintenance:

- Equipment and enclosure must be kept clean.
- Equipment must be calibrated regularly. For automated equipment, field checks can be performed between calibrations.
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.

WIND SPEED AND DIRECTION

Definition

Wind speed describes how fast the air is moving past a certain point. This may be averaged over a given unit of time, such as kilometres per hour, or an instantaneous speed, which is reported as a peak wind speed or wind gust. Wind speed is typically recorded in metres per second. *Wind direction* describes the direction on a compass from which the wind comes. Wind direction is typically recorded in degrees relative to north. Typically, wind speed and wind direction are measured at a height of 2 metres above the ground.

Why measure wind speed and direction?

Wind speed and direction are important for monitoring and predicting weather patterns and global climate. Wind speed and direction have numerous impacts on surface water level and water quality by affecting rates of evaporation, mixing of surface waters, and the development of seiches and storm surges.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Mechanical anemometer	Cups mounted on a horizontal arm on top of a vertical shaft. The air flow past the cups rotates them at a rate proportional to the wind speed. For manual readings, a standard wind speed scale is marked on the tube.	Measurement technique: Manual or automated Approximate accuracy: ±0.5 m/s (wind speed) Measurement frequency: As required (up to <1 sec)	Manual: Readings recorded in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$500

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Vane anemometer	Vanes and a tail mounted on a horizontal axis to obtain accurate and precise wind speed and direction measurements from the same instrument. The speed of the fan is measured by a revolution counter and converted to a wind speed by an electronic chip.	Measurement technique: Manual or automated Approximate accuracy: ±0.3 m/s (wind speed) ±3° (wind direction) Measurement frequency: As required (up to <1 sec)	Manual: Readings recorded in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$1,000
Ultrasonic anemometer	Transducers mounted on a vertical axis. Measures wind speed and direction by detecting the difference in time for an ultrasonic pulse to travel in each direction between pairs of transducers caused by movement of the air. Allows accurate measurement even at low wind speeds, as there is no mechanical inertia (e.g., from cups or vanes) to overcome.	Measurement technique: Automated Approximate accuracy: ±0.05 m/s (wind speed) ±2° (wind direction) Measurement frequency: As required (up to <1 sec)	Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$2,000

Key monitoring considerations

Site selection:

- Equipment should reflect the wind patterns as if the instrument were placed in a large field.
- Equipment should be mounted 2 metres above the ground.

Maintenance:

- Free rotation of the anemometer (mechanical and vane) must be checked by observing equipment under light wind conditions.
- The sensor must be inspected annually, and its bearings cleaned and lubricated.
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.
- Recalibration every two years is recommended to maintain accuracy.

Land indicators

PERMAFROST

Definition

Permafrost is a permanently frozen layer on or under Earth's surface. That is, ground that remains completely frozen (0 degrees Celsius/32 degrees Fahrenheit or colder) for at least two straight years. It consists of soil, gravel and sand, usually bound together by ice.

Why measure permafrost?

Permafrost affects terrain stability, coastal erosion, surface and subsurface water, the carbon cycle, and vegetation development. Permafrost measurements are also essential to understanding how permafrost conditions are changing, to improve predictions of future changes, and to calibrate and verify regional and global climate change models.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approximate cost
Thermistor strings	A calibrated thermistor is lowered into a borehole and the temperature at the desired depths is recorded. Alternatively, multi-sensor cables permanently or temporarily installed in the borehole can be used.	Measurement technique: Manual or automated Approximate accuracy: ±0.1 °C Measurement frequency: As required (annually–hourly)	Manual: Permafrost temperature readings recorded in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source PVC pipe More complex installation; some training required	$10,000–$100,000

Key monitoring considerations

Site selection

- Borehole sites should be selected to avoid the influence of non-climatic factors such as land-use change, anthropogenic disturbance and wildfires.

Installation

- Thermistors should be installed at multiple depths, typically at intervals of 2 metres.

Data recording

- Data should be recorded at least monthly for shallow ground temperatures (up to 15 metres) and at least annually for deeper temperatures (up to 50 metres).

Maintenance

- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.

SNOW DEPTH

Definition

Snow depth refers to the cumulative depth of snow on the ground at any given time. Snow depth is typically measured in millimetres.

Why measure snow depth?

Snow depth provides important information for determining snowpack, predicting water levels and streamflow conditions, estimating sea ice thickness, and assessing climate change effects.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approximate cost
Snow ruler	A simple ruler with metric gradations allowing snow depth to be reliably recorded to the closest 0.005 m.	Measurement technique: Manual Approximate accuracy: 0.005 m Measurement frequency: As required	Ruler readings recorded manually in the field (pen and paper) and digitized later Data format: Tabular	Mounting hardware Simple installation; no special training required	$100
Ultrasonic depth sensor	A sensor mounted facing down toward the ground. The distance from the sensor to the ground or top-of-snow is measured reliably to the closest 0.001 m. The depth of snow is calculated as the difference between the sensor height and the distance to the ground or top-of-snow.	Measurement technique: Automated Approximate accuracy: 0.001 m Measurement frequency: As required	Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$5,000

Key monitoring considerations

Site selection:

- Snow depth can be affected and altered by wind conditions that cause snow drifts (i.e., the piling up of blown snow). A site secluded from strong or frequent winds is critical to obtain reliable and representative measurements of snow depth.
- Equipment should be installed in an open area, away from vegetation or buildings that may interfere with snowfall. It is recommended that instruments be placed at least 10 metres away from nearby obstructions.

Maintenance:

- The surface of ultrasonic depth sensors must be cleaned with a damp cloth at regular intervals to maintain sensor accuracy.
- Screw connections and mounting cables must be checked periodically.
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.

SOIL MOISTURE

Definition

Soil moisture is the water content of the soil, including water vapour. It represents the water in land surfaces that is not in rivers, lakes or groundwater, but instead resides in the pores of the soil. Soil moisture is typically measured as a percentage of water in the soil relative to the total volume.

Why measure soil moisture?

Soil moisture is an important variable in land–atmosphere feedback at both weather and climate timescales. Soil moisture is closely involved in the feedback between climate and vegetation, as both local climate and vegetation influence soil moisture through evapotranspiration, while soil moisture is a determining factor of the type and condition of vegetation in a region. Changes in soil moisture can have substantial impacts on agricultural productivity, forestry and ecosystem health.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approximate cost
Electromagnetic moisture meter	Sensors that detect changes that alter electrical currents or temperature in the soil. These sensors indirectly measure volumetric soil moisture content based on the (dielectric and electric) properties of the soil that determine the storage and dissipation of the magnetic and electric energy of soil components, which is related to soil moisture content.	Measurement technique: Manual or automated Approximate accuracy: ±0.03 m^3/m^3 Measurement frequency: As required (5 minutes–daily)	Manual: Readings recorded in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Sensors to be installed at several depths (e.g., 4, 10 and 20 cm) Automated datalogger, enclosure and power source More complex installation; some training required	$500
Tensiometer	Airtight, water-filled cylindrical tubes with a porous cup attached on the lower end and a vacuum gauge on the top. They measure the soil matric potential, which is also referred to as soil water suction or soil water tension (negative pressure).	Measurement technique: Manual or automated Approximate accuracy: ±0.03 m^3/m^3 Measurement frequency: As required (5 minutes–daily)	Manual: Readings recorded in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Sensors to be installed at several depths (e.g., 4, 10 and 20 cm) Automated datalogger, enclosure and power source More complex installation; some training required	$1,000

Water indicators

GROUNDWATER LEVEL

Definition

Groundwater is water that exists underground in saturated zones beneath the land surface. Groundwater is typically recorded as groundwater depth below a reference point (e.g., top of well casing) in metres.

Why measure groundwater?

Groundwater level provides essential information on identifying and monitoring aquifers. It can support long-term aquifer maintenance and planning by detecting possible changes in groundwater and surface water flow and groundwater flow path changes, and alerting to potential surface level flooding.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Piezometer	Pressure transducers installed beneath the ground. The bottom of the piezometer is perforated to allow soil water (under positive hydrostatic pressure) to enter the tube. Water enters the tube and rises to a height equal to that of the unconfined water table. The elevation of the water table is measured relative to the soil surface using a water tape with a bell sounder or other electro-optic devices that indicate water table depth.	Measurement technique: Manual or automated Approximate accuracy: ±0.001 m Measurement frequency: As required	Manual: Groundwater level readings from water tape recorded manually in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting tripod Mounting hardware More complex installation; some training required	$2,000

Key monitoring considerations

Maintenance:

- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.

ICE COVER

Definition

Ice cover is the amount of ice covering a water body. It can be expressed as a thickness of ice or an area of cover.

Why measure ice cover?

Ice cover is an important indicator of changes in global climate because warmer air and water temperatures are reducing the amount of sea ice.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Ice-profiling sonar	An upward-looking sonar device, mounted on the ocean or water body floor, designed to measure ice draft.	Measurement technique: Automated Approximate accuracy: ±0.05 m Measurement frequency: As required (up to 2 Hz)	Data continuously stored in a datalogger Data format: Tabular	Automated datalogger, enclosure and power source, typically installed on a sub-surface float or bottom-mounted frame or platform Mounting hardware Very complex installation; high level of training required	$45,000–$100,000

Key monitoring considerations

Site selection:

- Understanding of the depth and type of deployment, along with typical ice characteristics, is required before a system of this nature can be deployed. This includes:
- Movement of ice and what drives the transport of this ice in the system (e.g., currents, wind)
- Whether the ice freezes to depth
- Marine vs. freshwater systems

Installation:

- Systems are typically installed on a permanent or long-term basis, depending on site logistics.
- An appropriate bottom mount must be chosen, depending on a variety of factors, including sub-surface currents.
- A lithium battery pack is recommended for extended deployment durations.

Maintenance:

- Limited maintenance is required once deployed.

SALINITY

Definition

Salinity refers to the concentration of salts in water or soils. It is typically expressed in parts per thousand or as a percentage.

Why measure salinity?

Salinity is a strong contributor to conductivity and helps determine several aspects of the chemistry of natural waters and the biological processes within them. Salinity, along with temperature and pressure, determines physical characteristics of water and soils.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approximate cost
Water quality meter	May vary from simple handheld units to unattended monitoring sensors. Water and soil salinity are measured by passing an electric current between two electrodes in a sample of soil or water.	Measurement technique: Manual or automated Approximate accuracy: ±1 part per thousand Measurement frequency: As required (up to <1 sec)	Manual: Water quality readings recorded manually in the field (pen and paper) and digitized later Automated: Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Mounting hardware More complex installation; some training required	\$5,000–\$50,000

Key monitoring considerations

Maintenance:

- The sensor must be periodically calibrated to produce accurate readings.
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.

SURFACE WATER LEVEL

Definition

Surface water level is the level of water within surface water bodies (e.g., rivers, lakes, creeks). It is typically recorded as surface water depth above a reference point (e.g., streambed). Water levels can be monitored in various bodies of water, including reservoirs, lakes, rivers, streams and coastal waters.

Why measure surface water level?

Surface water levels provide information on extreme events (such as droughts and floods), long-term assessment and planning of water resources, and climate change effects.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Rod and level	Rod and level can be used to survey the elevation of the surface water in relation to benchmarks.	Measurement technique: Manual Approximate accuracy: ±0.001 m Measurement frequency: As required	Surface water level readings recorded manually in the field (pen and paper) and digitized later Data format: Tabular	Benchmarks to be installed near the surface water point of interest Some level of training required to conduct surveys	$2,500
Pressure transducer	Pressure sensing devices, typically installed at a fixed depth in a body of water, sense the change in pressure against a membrane. Pressure changes occur in response to changes in the height, and thus in the weight, of the water column in the body of water above the transducer.	Measurement technique: Automated Approximate accuracy: ±0.001 m–±0.0005 m Measurement frequency: As required (up to <1 sec)	Data continuously stored in a datalogger; periodic site visits required for data retrieval Data format: Tabular	Automated datalogger, enclosure and power source Stilling well Mounting hardware More complex installation; some training required	$500

Key monitoring considerations

Site selection:

- Pressure transducers should be installed in pools where turbulence is minimal, sensors are less likely to freeze or go dry, and sensors will stay submerged during low flows.
- In the case of rivers and streams, the pool should have a downstream hydrologic control, such as a riffle or bedrock outcrop, that allows for a stable water level–discharge relationship.
- Sites with extensive aquatic vegetation, beaver activity, or unstable streambeds and banks should be avoided.

Installation:

- Pressure transducers should be installed as far below the water surface as possible but above the streambed to prevent sediment build-up around the sensor.
- Pressure transducers should be installed inside a stilling well to protect them from debris and minimize wave action above the sensor.
- Stilling wells can be installed in any orientation within a stream channel but must be affixed securely to prevent movement.

Maintenance:

- Periodic field visits and manual water level surveys are required to verify pressure transducer readings.
- O-rings must be checked and replaced if damaged.
- The outside casing, the circulation holes and the optical eye(s) of pressure transducer sensors must be cleaned using a soft, clean cloth or cotton swab to gently wipe away any debris and dry the eye(s).
- The desiccant that keeps the instruments dry internally must be periodically checked and replaced.

WATER TEMPERATURE

Definition

Water temperature refers to the temperature of a parcel of water.

Why measure water temperature?

Water temperature influences the physical, chemical and biological properties of water. It also affects the amount of dissolved oxygen in the water, what kind of organisms live in it, and the rate of chemical and biological reactions.

Monitoring equipment options

Instrument name	Description	Measurement information	Data recording	Equipment and installation requirements	Approx-imate cost
Thermistor string	Multi-point over-moulded temperature string suitable for permanent submersion in water measuring temperature at pre-defined depths from the surface. Other measurement parameters (e.g., dissolved oxygen) may also be built into the temperature string.	Measurement technique: Automated Approximate accuracy: ±0.5–± 0.002 ˚C Measurement frequency: As required (up to <1 sec)	Data continuously stored in a datalogger Data format: Tabular	Automated datalogger, enclosure and power source, typically installed on a surface buoy or floating platform Mounting hardware More complex installation; some training required	\$100–\$5,000 (cost per node)

Key monitoring considerations

Site selection:

- Year-round deployment strategy must be considered, including whether ice formation in the water body is of concern.
- When choosing depth intervals for thermistor placement in the temperature string, an understanding of the thermal layers of the water body before deployment will provide a more useable dataset.
- Surface termination (buoy or floating platform) will be the greater challenge when deploying this sensor.

Installation:

- Protection from surface ice and knowledge of the total water body depth along with currents can help when determining if bottom weights are required to ensure the temperature string maintains its vertical deployment.

Maintenance:

- Limited maintenance required once deployed. If including additional parameters in the temperature string, calibration could become a consideration.

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