WEATHER MONITORING FOR TREE FRUIT IN BC

A Strategy for Network Renewal

Prepared by:
A. Nadler
Peak HydroMet Solutions

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EXECUTIVE SUMMARY

BC's Decision Aid System (DAS) is a suite of online decision support tools that assist the BC Tree Fruit industry with integrated management of insects and diseases. Tools like BC DAS require high quality local weather information for the models to produce accurate predictions. Since 2018, BC DAS has been operational in the Okanagan Valley using an existing network of weather stations. In the Central Kootenays, Creston does not have adequate weather monitoring to represent the variability of the region nor to support BC DAS. A renewal of the monitoring network is necessary, including modernizing the existing hardware and establishing new weather stations in Creston. This report provides an assessment of the existing weather monitoring network and a roadmap for its enhancement, expansion, and sustainable operation.

The existing tree fruit weather monitoring network in the Okanagan consists of aging equipment that is positioned inside of orchard canopies. These measurements are highly influenced by the management of the individual orchard, thus providing limited local or regional representativeness. A monitoring strategy that is intended to benefit multiple users requires that a station represent more than a single block or orchard. To avoid canopy effects and for consistency, weather stations should have adequate exposure so that they represent their local areas. A well-sited station can be applicable to a larger area and will provide benefits to stakeholders beyond just the tree fruit industry.

New stations should be installed and sited according to the detailed specifications that have been laid out in this report. Sites should be evaluated based on the proposed classification and tiering systems. How a station is classified helps to describe its data and its overall representativeness of the surrounding area. Sites that are classified as category 2 or better are recommended.

Metadata should be maintained according to the WMO Integrated Global Observing System (WIGOS) standard that is recommended by the Canadian Metadata Standard for Hydrometeorological Monitoring Stations. Siting information that is known and documented is important for both operational purposes and for any application or analysis of the data in the future.

There are certain sensors that are necessary for running the DAS models. These include air temperature, relative humidity, rainfall, and leaf wetness. Data from other sensors like wind and solar radiation can be used to generate additional value-added products that can be used for spraying, frost mitigation, and water management. To promote awareness and engagement, project partners should consider producing regular in-season updates that would provide the industry with timely information about weather, pests, and other relevant communications.

A priority for monitoring hardware is to limit the technical complexity so that servicing and maintenance can be performed by local personnel that have basic skills and training. The METER ATMOS 41 all-in-one weather sensor has been deployed in other mesonets, including Washington State's AgWeatherNet (AWN), which supplies data for the DAS program in Washington. This device is compact, easy to use and maintain, and is well-suited for the BC tree fruit network. The unit uses industry standard sensor protocols that are compatible with various telemetry options, including cellular or Low Power Wide Area Networks (LPWAN).

Stations should be visited at least once per season by a trained technician to ensure that all components are fully functional. Additional visits should occur every four to six weeks during the growing season. Maintenance, calibrations, and repairs should follow a systematic procedure and be recorded. Prior to the start of the 2022 growing season, the correct station coordinates need to be updated in BC DAS to reflect the actual locations of the weather stations. The known locations and site information are provided in a separate document.

Some basic quality control of the station data should be applied prior to it being sent to Washington State University (WSU) where it undergoes a thorough evaluation. Ideally, the final quality-controlled dataset should be acquired from WSU so that Farmwest and other users are providing tools that are based on a single consistent dataset. Both the raw and cleaned data should also be archived and made available for future use.

Since its inception, BC DAS has been administered and supported by the Sterile Insect Release (SIR) Program. SIR will continue to coordinate BC DAS and is well positioned to oversee the monitoring network in the Okanagan. In Creston, partners like Fields Forward and the Kootenay Boundary Farm Advisors (KBFA) will play important roles in promoting and supporting the expanded network and the BC DAS program. Climate & Agriculture Initiative BC (CAI) will continue to promote initiatives that support regional and provincial priorities.

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ABBREVIATIONS

AAFC	Agriculture and Agri-Food Canada
AEPI	Agriculture Environment Partnership Initiative
AFF	BC Ministry of Agriculture, Food and Fisheries
BCFGA	BC Fruit Growers' Association
BCTF	BC Tree Fruits
BMP	Beneficial Management Practices
CAI	Climate & Agriculture Initiative
CRMP	Climate Related Monitoring Program
DAS	Decision Aid System
DST	Decision support tools
ECCC	Environment and Climate Change Canada
EFP	Environmental Farm Plan
ET	Evapotranspiration
IoT	Internet of Things
IPM	Integrated Pest Management
KBFA	Kootenay Boundary Farm Advisors
LPWAN	Low power wide area networks
MSC	Meteorological Service of Canada
NOAA	National Oceanic and Atmospheric Administration
OSCAR	Observing Systems Capability Analysis and Review Tool
PCIC	Pacific Climate Impacts Consortium
PFCA	Pacific Field Corn Association
QA	Quality assurance
QC	Quality control
RDCK	Regional District of Central Kootenay
RH	Relative humidity
SIR	Sterile Insect Release Program
TAHMO	Trans-African Hydro-Meteorological Observatory
TBRG	Tipping bucket rain gauge
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization
WSU	Washington State University

INTRODUCTION

The climate of British Columbia is becoming increasingly variable, including changing trends in heat and moisture and increases in the frequency and severity of extremes. Such changes are bringing about new challenges for agricultural production in managing insects, diseases, water, nutrients, and agronomics. High-value crops like tree fruit are especially sensitive to weather conditions that are affecting the emergence, development, and prevalence of pests. Methods that may have worked in the past no longer apply.

Despite the increased risk, there may also be opportunities to take advantage of some of these changes. Shifting climate patterns may be favourable to certain types of production, allowing the cultivation of new varieties or cropping in areas that were previously not feasible. To adapt to current and future conditions, it is critical to be able to quantify the changes that are occurring and to recognize how these changes are affecting production. This can only be done through monitoring of the various phenomena that influence the development of crops and organisms.

Tree fruit production requires a delicate balance of providing the right amount of management to maximize yield and quality while considering environmental effects, input costs, and economic thresholds. Any input or intervention must be precisely timed so that it corresponds to crop requirements and maximizes efficacy. Anticipating and predicting crop and insect stages can be facilitated by models that inform decision support tools (DST). These models are highly reliant on accurate and complete local weather information. Key priorities that were identified in both the Okanagan[1] and the Kootenay & Boundary[2] Regional Adaptation Strategies were to develop decision support tools and resources linked to weather data.

In 2018, with support from Climate & Agriculture Initiative (CAI) BC's Regional Adaptation Program, several organizations partnered to adapt Washington State University's (WSU) Decision Aid System (DAS) for the BC Okanagan tree fruit industry. Partners included the Okanagan Sterile Insect Release Program (SIR), BC Tree Fruits (BCTF), BC Fruit Growers' Association (BCFGA), Agriculture and Agri-Food Canada (AAFC), and the BC Ministry of Agriculture, Food and Fisheries (AFF). DAS is an Integrated Pest Management (IPM) decision support platform that provides time-sensitive insect, disease, and crop phenology predictions to decision-makers in the tree fruit industry. The system provides a web-based toolset to help tree fruit producers better manage resources, thus improving their sustainability, profitability, and competitiveness. According to surveys in Washington, the DAS program saves growers an average of $75 per acre ($185 per hectare)[3]. Given the value and success of BC DAS in the Okanagan, there is a strong desire to continue offering this program and to expand its geographic coverage to include Creston.

The DAS tools rely heavily on accurate local weather information that is highly representative of the area to which it is being applied. In the Okanagan, there is an existing network of weather stations that provide the necessary data for DAS to operate. However, concerns about the reliability, longevity, and the overall management of this network have been raised by regional partners. In Creston, there is only one weather station that does not reflect any of the variability of the region. The purpose of this report is to evaluate the status of the existing monitoring network and to define a roadmap for monitoring as it applies to tree fruit production in the

Okanagan and Creston areas. The information and value-added tools will help farmers better cope and adapt to the climate, thus making them more profitable and sustainable.

The ensuing report provides recommendations that will improve and modernize agricultural weather monitoring in the Okanagan and Creston regions. Throughout the report, there are certain key recommendations that are emphasized in **bold** font. While the primary objective of this work is to improve and expand the availability of weather information and tools for the tree fruit industry, a reliable and representative monitoring network will also benefit other commodities and stakeholders. A network that has many users will gain more support that will help to ensure long-term sustainability.

EXISTING WEATHER MONITORING NETWORKS

Throughout the major free fruit growing areas, there are many weather monitoring stations and networks that serve a diverse range of applications. There are also privately owned stations that are located on farms, businesses, and homes. There are various characteristics that determine whether these stations might be suitable for use with a program like BC DAS. The networks and stations are discussed below.

ENVIRONMENT AND CLIMATE CHANGE CANADA

Environment and Climate Change Canada (ECCC) provides a high-quality monitoring network across the country. Most of the stations are reasonably well-sited to represent regional weather conditions. The sites and instruments are generally well-maintained. Most stations have been operational for long periods of time, providing reliable historical climate records. All automated stations report air temperature, relative humidity (RH), barometric pressure, precipitation (both liquid and non-liquid), and wind speed and direction. Hourly and daily data from these stations is freely available for download from the Meteorological Service of Canada (MSC) Open Data Server (Datamart).

From Osoyoos to Salmon Arm, there are seven automated ECCC stations. Two are located at airports (Kelowna and Penticton), three are somewhat within urban centres (Salmon Arm, Kelowna UBCO, Osoyoos), and two are located just outside of urban centres (Vernon and Summerland). A map of the stations is shown in Figure 1.

Observations from the automated ECCC stations in the Okanagan are being retrieved by WSU and are used for BC DAS. Most of these stations provide good representation of their surroundings and provide some coverage of tree fruit growing areas. Although some stations, such as Penticton and Salmon Arm, are located quite far from any orchards. The Salmon Arm station is also located close to the Shuswap Lake, whose elevation is much lower than any surrounding agricultural land. In the absence of viable alternatives, stations like these will address certain coverage gaps. Over time, it would be preferable to have stations that are more representative of the orchards in their respective areas.

In Creston, there is one ECCC station that is located centrally on Connel Road. This station is somewhat unique in that it is surrounded by orchards but situated in a very specific climatic area (Figure 2). This station does not provide good representation of farmland beyond its immediate vicinity. Most agricultural production areas around Creston have no relevant weather information that is publicly available.

There are some manually operated ECCC stations within the region, but these are not suitable for operational purposes due to the lack of current time-series data. These manual stations do however provide valuable historical data.

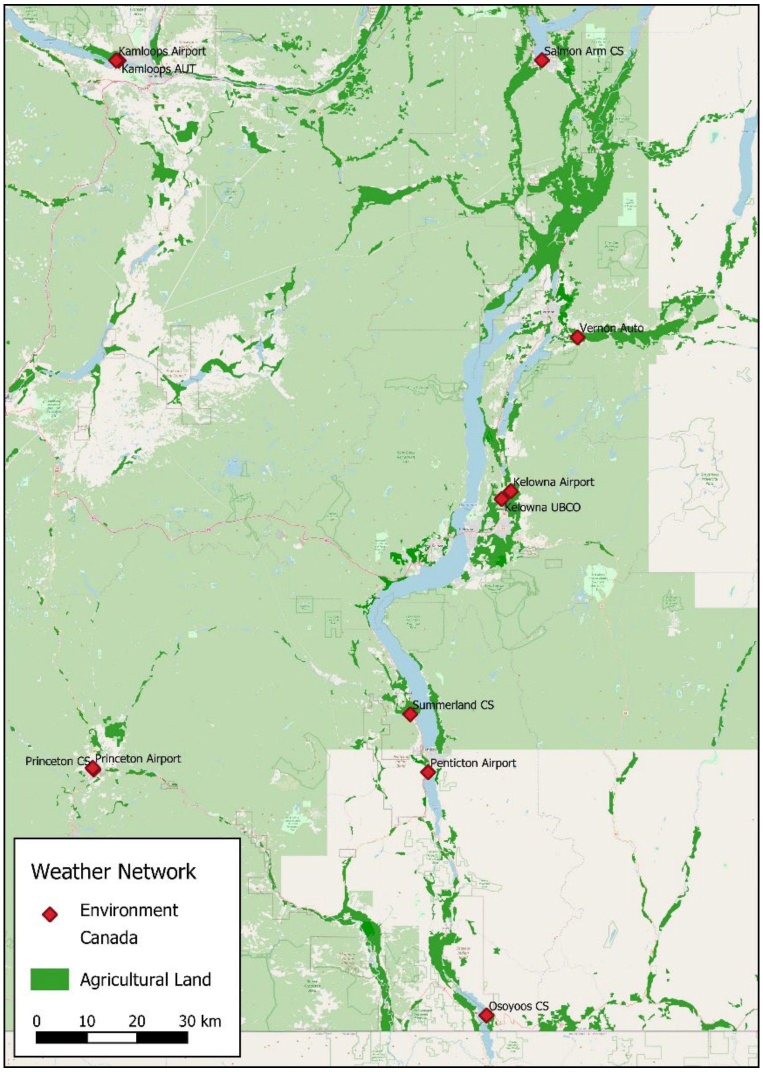

Figure 1: Environment and Climate Change Canada stations in the Okanagan

Figure 2: Creston Environment and Climate Change Canada weather station

GROWERS SUPPLY

Most weather data that goes into the BC DAS program comes from a network of 20 stations that are owned and operated by Growers Supply. The network was established between 2002 and 2004 with funding through the federal-provincial Agriculture Environment Partnership Initiative (AEPI). The intent of the network was to provide pest management support for the tree fruit industry.

The weather stations are manufactured by ADCON Telemetry of Austria. These stations are well suited to orchards and vineyards as they are robust and have flexible communications options. Data is transmitted wirelessly, either by radio to a central gateway or over the cellular network. The data is compiled and managed within addVANTAGE Professional, ADCON's data visualization, processing, and distribution software. The ADCON equipment is quite expensive, being two to four times the price of many viable alternatives that are now available. Growers Supply is an ADCON Telemetry distributor.

All the weather stations in this network have been installed within the orchards themselves. The temperature, RH, and leaf wetness sensors are at heights of between 1.3 and 1.8m and are entirely within the canopy. This results in measurements that are highly specific to these canopies and their architecture. They are also quite influenced by how the orchards are managed. This limits the representativeness of a station and the transferability of the information to a wider area.

The weather station rain gauges are mounted above the canopy, at a height of between 4.0 and 5.0m. Standard meteorological monitoring guidelines specify that the top of the gauge should be as low to the ground as possible. Wind speed increases with height, which can introduce considerable errors in rainfall measurement.[4] Wind speed is the single largest source of rainfall loss for rain gauges.[5] One study found that gauges at 1.5m caught an average of 5% less than a lower gauge. Gauges at heights of 6m caught 10% less.[6]

Figure 3: Typical Growers Supply orchard station in the Okanagan

Despite regular replacement of components over the years – mainly upon failure or damage, the stations are aging and approaching the end of their useful lives. This raises concerns about their reliability, data accuracy, and maintenance costs. **The renewal of this network needs to be addressed, including modernizing the hardware, standardizing station siting to improve spatial representation, and ensuring that the network meets stakeholders needs.**

Growers Supply has shown a renewed interest in the monitoring network and in becoming an active partner in the program. They acknowledge the limitations of the existing stations and are open to reviewing hardware options and working towards a new operational model. Prior to the 2022 growing season, Growers Supply intends to install 10 new weather stations whose data will be available for BC DAS. The new stations will be located close to some of their existing stations but outside of the orchards and sited according to the guidelines that are set forth in this document. The specific locations of the stations are yet to be determined.

Part of this assessment includes location surveys to evaluate individual monitoring sites and the status of the instruments. Geographic coordinates were supplied, based on what is shown in addVANTAGE Professional and what is being used in BC DAS. When navigating to the supplied coordinates, it became evident that many of the locations were incorrect. Presumably, when certain stations had been relocated or removed, the information did not get updated. In some cases, the coordinates were tens of meters off, which is of little consequence for the models. In other cases, the stations were hundreds of meters from where the coordinates indicated, which is significant and prevented some stations from being located altogether. **Prior to the start of the 2022 growing season, the station coordinates in BC DAS need to be updated to reflect the actual locations of the weather stations.** The known locations are provided in a separate document. Growers Supply has committed to assist with providing the coordinates of any stations that were not found.

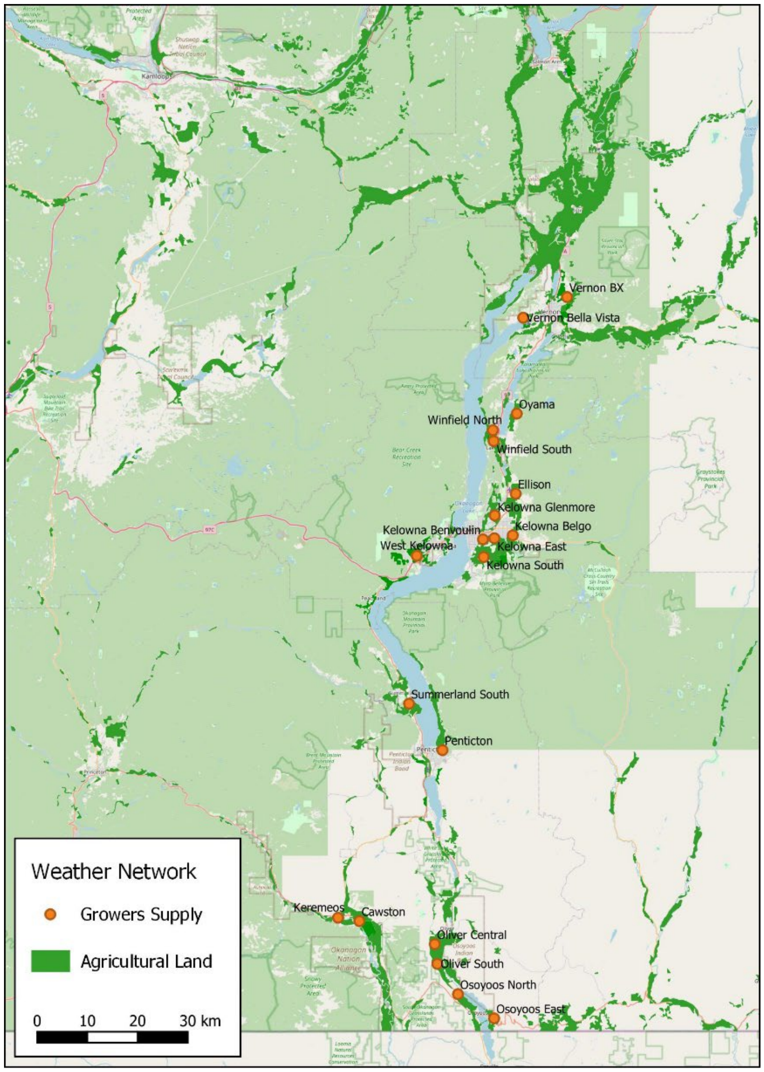

Figure 4: Growers Supply weather stations in the Okanagan

FARMWEST

Farmwest is a province-wide initiative that is administered by the Pacific Field Corn Association (PFCA) with operational and financial support from AFF, and AAFC. The program's mandate is to provide weather, irrigation, and nutrient management tools to support BC farmers. The Farmwest website does provide some tools for tree fruit production, including summaries of degree days as they relate to the development of codling moth populations. This information is used to determine the proper timing to apply control products.

The Farmwest weather stations are Davis Instruments VantagePro2, an economical all-in-one weather station that records temperature, RH, barometric pressure, rainfall, and wind speed/direction. The stations send data mainly using cellular connections provided by ROM Communications. The stations record hourly measurements that normally get transmitted once per day. More frequent transmission intervals are possible at additional communications costs.

Across the province, there are approximately 25 Farmwest stations. In the Okanagan, there is one station in West Kelowna and four in the North Okanagan, clustered around Enderby and Grindrod (Figure 6). None of the Okanagan Farmwest stations are close to free fruit production areas so incorporating the data from these stations would not provide a great deal of additional value. There are no Farmwest stations near Creston.

Normally, a few new Farmwest weather stations get added each year. Many of these stations have been purchased by individual farms through the Environmental Farm Plan (EFP) Beneficial Management Practices (BMP) funding. Participants who receive funding for weather stations must agree to share their data with Farmwest.

Figure 5: Farmwest station at Grindrod (North Okanagan)

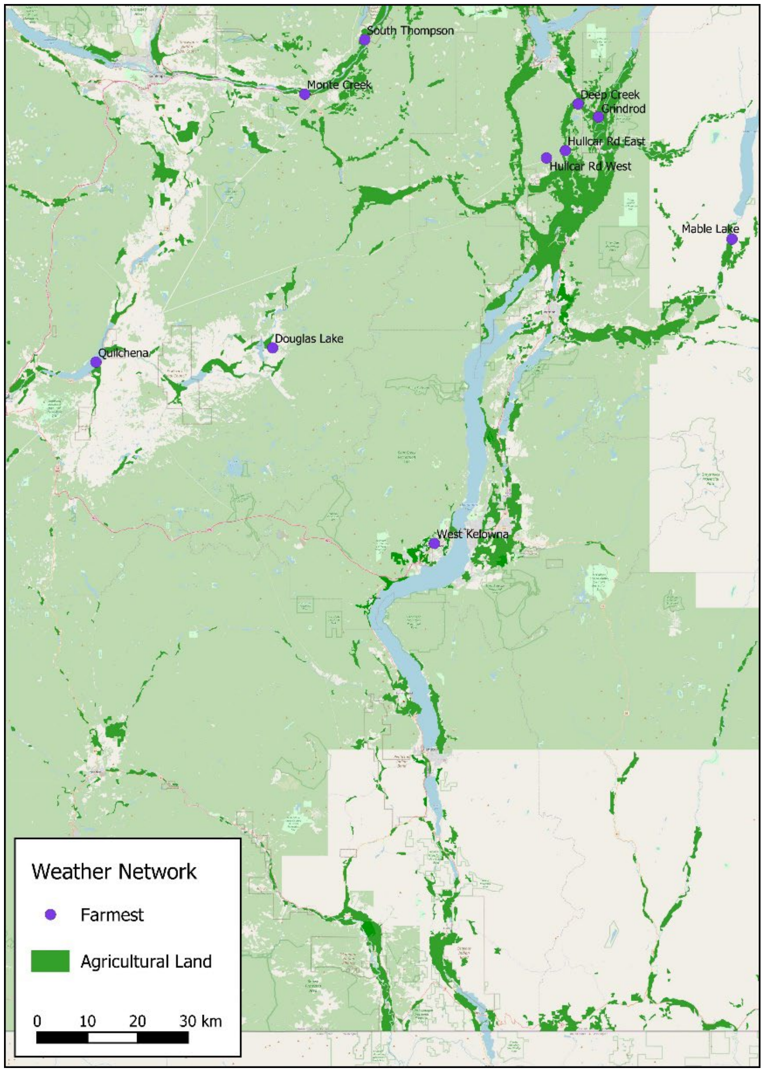

Figure 6: Farmwest weather stations in the Okanagan

OTHER WEATHER STATIONS

Across BC, there are some other networks that operate and have stations within the Okanagan and Creston regions. Several of these networks are part of the Climate Related Monitoring Program (CRMP), a formal collaboration between network operators. This agreement promotes the sharing of data and methods.

The BC Ministry of Transportation and Infrastructure operates stations to monitor highway conditions. Due to the siting of these stations along highways, including mountain passes, the data is not conducive to agricultural risk models. Other ministries and organizations, including BC Wildfire Service, Environment and Climate Change Strategy, and BC Hydro also operate and maintain networks. These stations are generally located outside of the main agricultural production areas and would be of little use to the tree fruit industry.

Apart from the established networked stations, there are many private stations that are located on farms and vineyards whose data is not shared beyond the farm itself. While these additional monitoring points could be a valuable resource and provide excellent coverage, there are many unknowns that come with them. Private weather stations are often not installed according to defined standards, maintenance schedules and protocols are unknown, and data is handled differently between operators. At some point, amalgamating these data sources would provide benefits to the program and to the growers. However, this would require considerable investment and as such, is not a current priority.

WEATHER MONITORING STRATEGY

Monitoring of environmental conditions is highly dependent on the siting and exposure of the individual sensors. How and where the equipment gets installed is the most important factor determining the quality and representativeness of that station – more so than the accuracy of the sensors themselves. Even the highest-grade equipment with suboptimal siting will result in poor quality information that is of little value to end-users.

When establishing a monitoring program, it is critical to identify the scale of measurement that is required. If the in-crop microclimate is to be monitored, then sensors should be placed within that crop. However, the user must recognize that those conditions are not necessarily representative beyond that specific location – certainly not representative of the wider region. Likewise, the conditions in one block can differ from those in a nearby block that may have slightly different management, vegetation, or site characteristics.

Weather conditions that are observed inside a crop will differ significantly than those experienced in an open and unobstructed area. Conditions will further vary by slope, aspect, exposure, and nearby features, all contributing to the complex nature of climate. What gets measured in one part of a field is likely to be different than that of another part of the field or a nearby field. **Therefore, monitoring of conditions within the crop will limit any sort of local or regional benefit from a station. A station or sensors that are in a microclimate will provide excellent information for that exact location - but have little applicability anywhere else.**

The World Meteorological Organization (WMO), the global body that oversees climate monitoring, publishes weather station siting criteria that describe a station's representativeness of its surroundings.[7] According to the WMO, a well exposed station provides regional coverage while one that is less optimally sited may only accurately represent a very small area. In the context of a tree fruit monitoring network, a station with representative siting would be relevant to several orchards in an area provided that the elevation and exposures are somewhat consistent.

WSU has been evaluating the magnitude of orchard effects on air temperature, RH, and wind speed using paired monitoring instruments located inside and outside of orchards.[8] Their initial findings suggest that air temperature is on average more than a centigrade cooler, RH is 35% higher, and wind speed is 4.3km/hr lower inside the orchard. The cooler in-canopy temperatures results in a lag in the accumulation of GDD compared to well-exposed stations. Further, microspray irrigation events tend to cause noticeable and abrupt reductions in temperature by up to 5.5°C and increases in RH by up to 20%. Such discrepancies highlight the importance of having standardized station placement.

To avoid canopy effects and to maintain consistency, the weather station should be well exposed so that it will represent the local area. A monitoring strategy that is intended to benefit multiple growers requires that a station represent more than a single block or orchard. A representative station can be applicable to a larger area and benefit more users.

STATION SITING CLASSIFICATION

Depending on the makeup of the area, stations should normally be on level ground, freely exposed to sunshine and wind, and not be influenced by small scale features like waterbodies or objects like buildings, trees, or pavement that could emit or reflect heat. Nearby obstacles or obstructions can affect measurements by casting shade over sensors, blocking prevailing winds, or by preventing rain from entering the gauge. To avoid such effects, stations should be installed at an adequate distance from any obstructions.

Practical implications will often restrict where a weather station ultimately gets installed. Factors like landowner permission, equipment access, convenience, and security must all be considered. Regardless of whether a station is on private or public property, it must be in a location that has low risk of damage or loss from nearby equipment, animals, vandalism, or theft. At the same time, convenient access to a site is important to allow for maintenance, repairs, and inspections.

A classification system is helpful for determining the extent to which a site adheres to the set guidelines. If there are deviations, they must be known to the end user. How a station is classified helps to describe its data and its overall representativeness of the surrounding area.

The WMO uses a classification system to help determine a station's representativeness of a wide area. A wide area is described as at least tens of square km's. A class 1 site, one that perfectly adheres to all guidelines, is considered a reference site and has minimal measurement uncertainty. Whereas a class 5 site, one with nearby obstacles is considered to have an uncertainty of up to 5°C for temperature and up to 100% uncertainty for precipitation. A class 5 site is not considered appropriate for representing a wide area. The WMO Classification is summarized in Table 1.

To establish monitoring stations that provide some degree of wider representation, not just of the orchard within which they were installed, siting classifications of 2 or better are recommended. This means that ideally, the station should be on flat, horizontal land, surrounded by an open space. The ground surrounding the station should be covered with natural and low vegetation that is maintained below 10cm. Stations should never be installed over pavement, gravel, or water. Stations should never be installed on or against buildings. Other areas to be avoided include tops of hills, hollows, or at the bottom of narrow valleys.

Any heat sources, reflective surfaces, or expanses of water should be more than 30m away. If the features are not large (i.e. a small building or car park), less than 30m may be acceptable. Stations should be installed further than at least twice the height of the nearest obstruction (Figure 7). The obstruction's height is measured in reference to the sensor height. An obstruction is defined as an object that subtends a horizontal angle of 10° or more from the station (Figure 8).

Table 1: World Meteorological siting classification

CLASS	TEMPERATURE UNCERTAINTY	PRECIPITATION UNCERTAINTY	DESCRIPTION
CLASS 1	Minimal	Minimal	Flat, horizontal land, surrounded by an open space Obstacles at a distance at least four times their height Ground covered with natural, low vegetation (<10cm) >100m from heat sources or reflective surfaces >100m from an expanse of water
CLASS 2	Minimal	Up to 5%	Flat, horizontal land, surrounded by an open space Obstacles at a distance at least twice their height Ground covered with natural, low vegetation (<10cm) >30 m from heat sources or reflective surfaces >30 m from an expanse of water
CLASS 3	Up to 1°C	Up to 15%	Obstacles at a distance of at least their height Ground covered with natural, low vegetation (<25cm) >10m from artificial heat sources or reflective surfaces >10m from an expanse of water
CLASS 4	Up to 2°C	Up to 25%	Obstacles at a distance greater than half their height Close, artificial heat sources, reflective surfaces, or expanse of water occupy: • <50% of the surface within a 10m radius or • <30% of the surface within a 3m radius
CLASS 5	Up to 5°C	Up to 100%	Obstacles at a distance closer than half their height Site not meeting the requirements of class 4

Stations that do not conform to certain guidelines are assigned the appropriate class and their data is treated accordingly. If a station's siting is deemed inappropriate, for example a class 4 or 5, the location should be reviewed, and remedial action should be performed. If this is not possible at the existing site, relocation of the station may be required. Relocation is not ideal as any moves will disrupt the continuity of record.

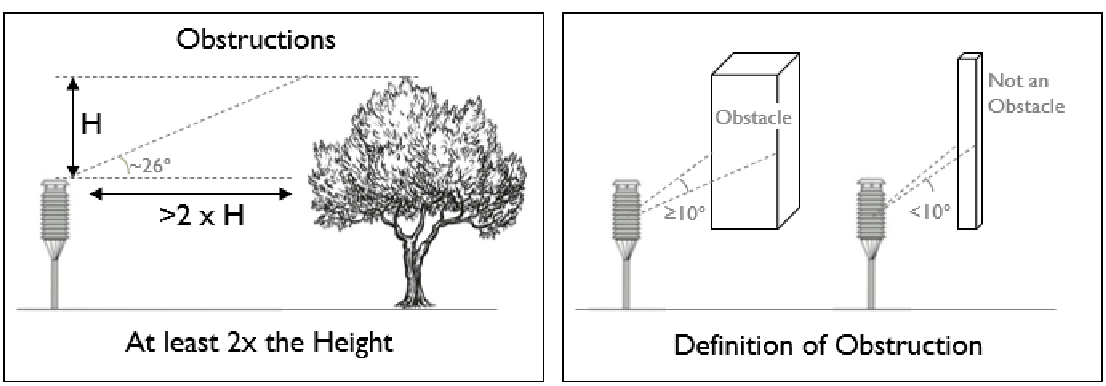

Figure 7: Obstruction guidelines for weather stations

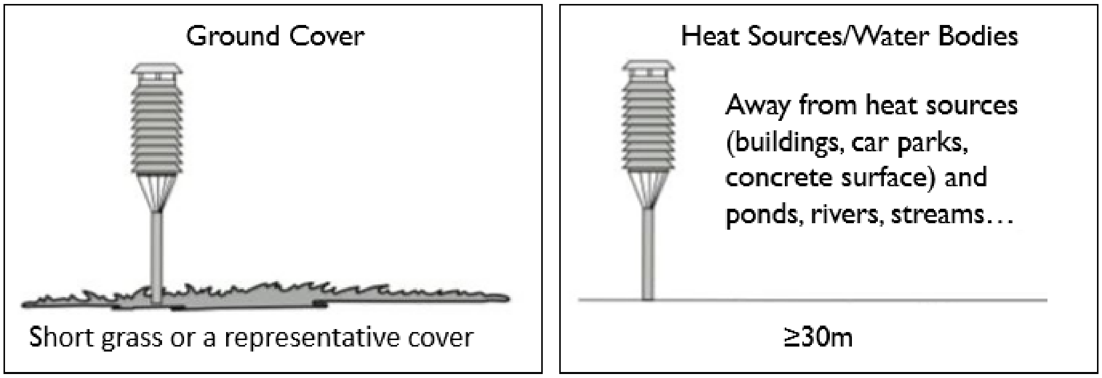

Figure 8: General siting guidelines for weather stations

Siting information that is known and documented is important for both operational purposes and for any application or analysis of the data in the future. Sites should be visually reviewed annually as environmental circumstances can change over time. These could include changes in nearby vegetation, structures, or land cover. Stations that have been in operation for many years can be affected by gradual changes in vegetation or by structures that get added.

STATION TIERS

The weather stations used by AWN and DAS in Washington are categorized on a tiered system that is based on the types of monitoring equipment, station siting, and equipment ownership. Like the siting classifications, the tiers help the user to identify the data source and its suitability for various applications. The AWN tiers are described in Table 2.

Table 2: AgWeatherNet station tier system

TIER	DESCRIPTION
TIER 0	Stations that are operated by federal government organizations like the National Oceanic and Atmospheric Administration (NOAA). Stations consist of high-quality components and are generally well-maintained. Siting is meant to capture regional conditions. In Canada, these would be equivalent to ECCC station.
TIER 1	High-accuracy, professional/research-grade hardware, duplicate temperature sensors, towers to monitor wind, and soil sensors. Tier 1 stations are well-sited and provide regional coverage. They are not intended to represent individual farms or orchards.
TIER 2	Tier 2 stations have similar siting to Tier 1 stations – perhaps with some concessions that limit their regional representativeness. The hardware consists of more economical all-in-one stations. The data is intended for local to regional agricultural monitoring. These stations are owned and operated by AWN.
TIER 3	Tier 3 stations are the same all-in-one units and are expected to conform to the same standards as Tier 2 stations but are privately owned. This setup enables cooperators to connect their stations to the AWN network to access site-specific conditions and tools. The data from these stations is not being used for DAS.
TIER 4	These are privately-owned stations and sensors that are installed within orchards and canopies to monitor microclimates. The data is also not shared with other uses as the information limited use beyond the orchard that is being monitored. The data from these stations is not being used for DAS.

IMPLEMENTING SITING CLASSIFICATION AND TIERS

Currently in Washington, only Tiers 0, 1, and 2 are being used by DAS. This means that the DAS models have been developed and are being ground-truthed based on those well-exposed stations – not in-canopy stations. In contrast, the weather stations in the Okanagan that are being used for BC DAS are located within the canopies and are collecting temperature and RH measurements that are influenced by those canopies.

The WMO-based classification system describes the siting of a station. The WSU tier system addresses siting in addition to equipment type and ownership. For the proposed network, there is merit in referencing both systems to characterize weather stations. This helps to identify the representativeness of a station as well as the intended use.

Based on these classification systems, the entire Growers Supply network is considered Tier 4, Class 5, indicating that the stations are privately owned, located within orchards, and provide a high degree of uncertainty in representing a wide area. **To become consistent with AWN and DAS and to improve the representativeness of the network, all stations' siting should be upgraded to meet Class 1 or 2 (possibly 3) siting designations. This will require a complete transformation of the existing network.** A strategy to achieve this objective is described in the next section.

NETWORK RENEWAL

In the Okanagan, the aging equipment and its inappropriate siting presents an opportunity for network renewal with modern monitoring hardware in locations that provide reliable and representative data for decision makers. The intention is to design and establish a network that is fit for purpose while also considering additional uses**. The network can also increase its sustainability by generating engagement among its stakeholders.**

STATION LOCATIONS

The existing monitoring network is a logical starting point to begin the network renewal. The current locations of the Growers Supply stations provide reasonable coverage across the main growing areas. These stations also provide valuable historical data as some of these stations have been in operation for nearly 20 years. Except to comply with the proposed siting classifications, stations will need to be relocated outside of the orchards.

Finding a nearby site that is more representative and appropriate for a weather station will require cooperation from the landowner. To maintain historical continuity, despite the siting change, the new location should be no more than a few hundred meters from the existing in-field location. Ideally, a station would be shifted from its current location inside the canopy to an open area just outside of that orchard block.

There will be situations where the existing or potential landowner is not interested in hosting a weather station due to the inconvenience. In these cases, a new landowner will need to be identified – ideally, close by. **While not always possible, it is preferable to work with landowners who are engaged and who recognize the value of the network and BC DAS. In no situations should a landowner need to receive payment for hosting a station as they are the ones**

receiving the most benefit. Most growers will recognize the advantages of having site-specific risk management data. Furthermore, a cooperator who uses the information is more likely to take care of the station and to notice if something is not right, whether it be sensor issues or other problems with the station or data. Suitable and engaged cooperators can be identified by consulting with local horticulturalists and advisors.

In Creston, there are several important production areas that are lacking local coverage. Some of these locations have been identified in a 2020 report that provided an assessment of monitoring networks in the Kootenay & Boundary.[9] Within Creston, the report identified three main areas – Wynndel, Erickson, and Canyon.

As resources may allow for more than three new stations around Creston, there are several additional areas that would benefit. For example, Erickson has many orchards and varied topography that experience diverse climatic conditions. Two or three stations would better characterize this variability. There is a large amount of agricultural land, including some existing and some potential orchard production south of Creston towards Lister (Figure 9). There are also very large tracts of grain, oilseed, and forage production land along the Kootenay River. While not in orchard, these areas and commodities would benefit from improved monitoring. Of the eight new stations in Creston, four or five would be specific to tree fruit production.

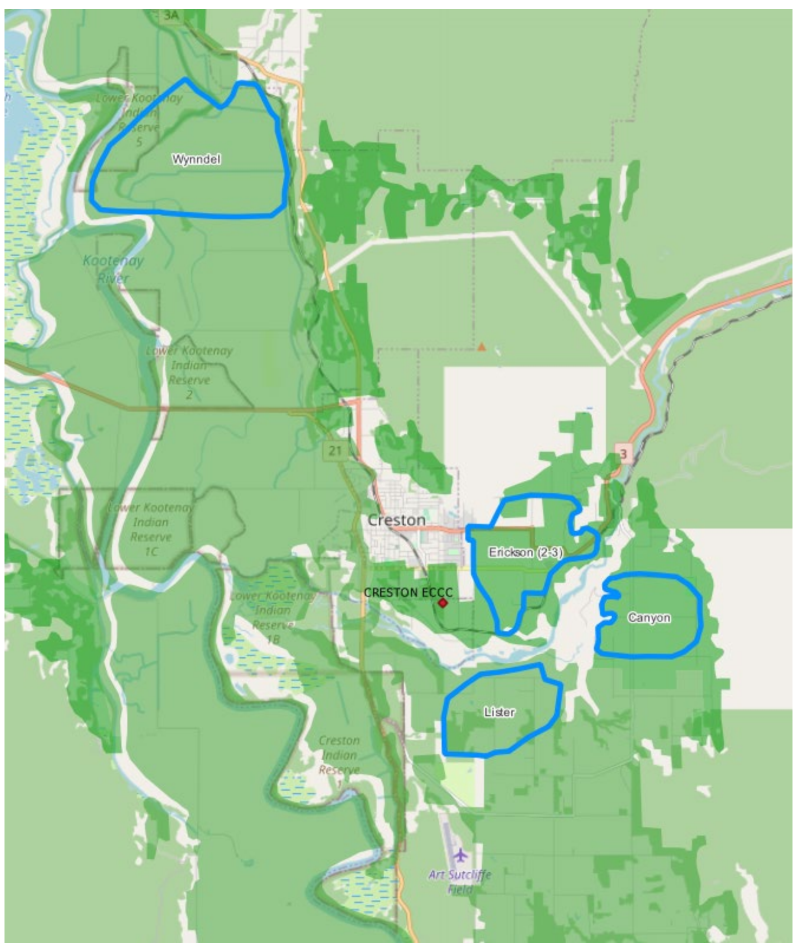

Figure 9: Areas for additional monitoring around Creston

A basic land-sharing agreement should be developed and shared with landowners. The purpose of this agreement would not be to hold the landowner responsible for any damages to a station nor to prevent them from deciding not to host a station. Rather, the agreement would restrict any liability, either to the landowner or to the network operator that could result from having the station at that location. Technicians should also be covered under an insurance policy that protects them in case of injury or property damage.

MONITORING EQUIPMENT

Over the past several years, monitoring technology has improved dramatically. Like most other electronics, weather instruments have become more user-friendly, compact, and affordable. At the same time, communications technologies have become inexpensive and are very reliable. These innovations are enabling users to monitor at a higher degree of granularity, both spatially and temporally. In agriculture, this includes having better insight into the soil-plant-atmosphere continuum, providing information that can help decision makers manage their crops more precisely and effectively.

There are a variety of quality weather stations that would be suitable for this network. Some specific features to consider include the following:

- Parameters: Must have the appropriate sensors to run the required models
- Near real-time data: Stations should transmit data at least every 15 minutes
- Accurate: Must have acceptable accuracy and resolution specifications
- Economical: Must be cost effective to purchase and to maintain
- Durability and longevity: Equipment must last for several years
- Not overly technical: Installation, maintenance, and repair should require minimal specialized training
- Compact: A station with a small footprint takes up less space and is less likely to be damaged by equipment

For consistency, inventory management, and ease of maintenance, the proposed core network of tree fruit weather stations should be of one single type. This allows for easier interchange of sensors and parts. As additional types of instruments get used, field technicians must be familiar with more systems, they must stock more parts, and carry more tools.

There are many high-quality instruments that produce excellent data - but are also highly complex. Such instruments require a great deal of expertise and training to deploy, maintain, and troubleshoot. Manufacturers like Campbell Scientific, as used by ECCC, have many features and functionality. Yet, having them serviced and maintained by a layperson would not be appropriate. Furthermore, the cost to purchase and maintain these stations is quite high.

A priority of this network is to limit the overall technical complexity of the equipment. This reduces the need for technicians that have specialized skills and training. With equipment that is relatively easy to install and configure, a local contractors or landowners themselves could potentially swap out a malfunctioning unit with a replacement that is couriered to their location.

SENSORS

There are certain sensors that are necessary for running the DAS models. These include air temperature, RH, rainfall, and leaf wetness. There are additional measurements that can also be useful. Wind sensors can be used to help with spray application timing to avoid spray drift. Derived parameters like Delta-T can help predict spray droplet survival. The rate of crop water loss, or evapotranspiration (ET), can be used for irrigation scheduling. ET is a function of energy, vapour pressure deficit, and air turbulence. The energy portion is represented by air temperature and solar radiation; the vapour pressure is derived from RH; and the air turbulence is the velocity of the wind. A solar radiation sensor (pyranometer) and a wind sensor (anemometer) can be included with any weather station.

Monitoring hardware must be of reasonable quality. The instruments' specifications will provide sensor resolution and accuracy that can be used to determine if the margin of error is acceptable for the intended use. Though, since the margin of error associated with sensor accuracy is less than the error caused by suboptimal siting or inadequate maintenance, requiring sensors that are of high precision and accuracy is somewhat secondary to good station siting and proper upkeep.

Air temperature sensors are relatively straightforward in terms of technical specifications. Most quality temperature sensors provide an accuracy of ±0.1°C. For consistency, the network should use a single height standard. A height of 1.5m is recommended.

The amount of moisture in the air, as represented by RH, is often used as input for diseases risk models. Most RH sensors have accuracies between ±1% and ±3%, which is adequate. All RH sensors are also prone to gradual drift, meaning that over time, the accuracy diminishes. For this reason, it is important that easily replaceable RH sensors or chips be readily available at a reasonable cost. Swapping out the RH sensor at least every two years reduces any effects of sensor drift. The RH sensor is collocated with the temperature sensor.

Precipitation is the sum of all liquid expressed as the depth that it would cover on a flat surface. While precipitation is very important for agriculture, it can vary tremendously over a small area. For irrigated crops, local precipitation amounts are less important as soil moisture is more heavily influenced by irrigation. Therefore, while rainfall should certainly be monitored, its importance is somewhat secondary. Typical rain gauge accuracy ranges from ±1% to ±5%.

A leaf wetness sensor is used to mimic the amount of moisture that is retained on a generic leaf surface. As most fungal diseases require free moisture to propagate, the duration of leaf wetness, as measured from this sensor, is often used to predict the onset of certain diseases and infections.

There are many different leaf wetness sensors on the market. In addition to the sensor technology, readings are sensitive to placement, exposure, and angle. In Washington, AWN uses and recommends the METER PHYTOS 31 and the Campbell Scientific 237 leaf wetness sensors (Figure 10). Ideally, the sensor should be installed within the actual canopy, typically at an angle of 45°. However, chemical sprays have been found to coat these sensors and raise the baseline, making them less sensitive to wetting or causing faulty readings. On the other hand, out-of-orchard sensors were found to not accurately capture actual conditions. Thus, any leaf wetness output should be used with caution.

Figure 10: METER Group PHYTOS 31 (left) and the Campbell Scientific 237 (right) leaf wetness sensors

Wind speed and direction are commonly monitored using mechanical sensors. One of the main issues with mechanical sensors is that they are subject to wear and failure. Over time and depending on conditions, the bearings within the sensors become worn, which causes friction, thus reducing the reported wind speed. Wind sensors must be serviced regularly.

Ultrasonic wind sensors are a major improvement to mechanical designs. These sensors have no moving parts and determine instantaneous wind speed and direction by measuring sound waves traveling between transducers. These sensors are highly accurate, not subject to wear, and require minimal maintenance. Over the past few years, the cost of ultrasonic wind sensors has gone down considerably, making them a viable and affordable option for weather stations.

DATA TRANSMISSION

All stations must be equipped with a datalogger and a communication module to enable data to be acquired and transmitted on a regular basis. Data should be sent a minimum of every 15 minutes to correspond with AWN's protocol. Higher reporting frequency allows users to take advantage of current information such as temperatures for frost mitigation, wind speed/direction and Delta-T for spraying, and rainfall for irrigation decisions.

While there are several different communication options that can be used to transmit data, two technologies are well-suited for monitoring orchards in these regions. For stations that are spread out, more than 10-15km apart, cellular is ideal. The region has reliable 4G/LTE coverage (Figure 11) and data transmission is relatively inexpensive. Throughout BC, Telus, Bell, and Rogers are the main cellular carriers. Telus and Bell share cellular towers and claim to cover 19.4% of BC. Rogers covers 10.3%.[10] Using multi-network SIM cards, devices will connect to whichever network has the best coverage in the area.

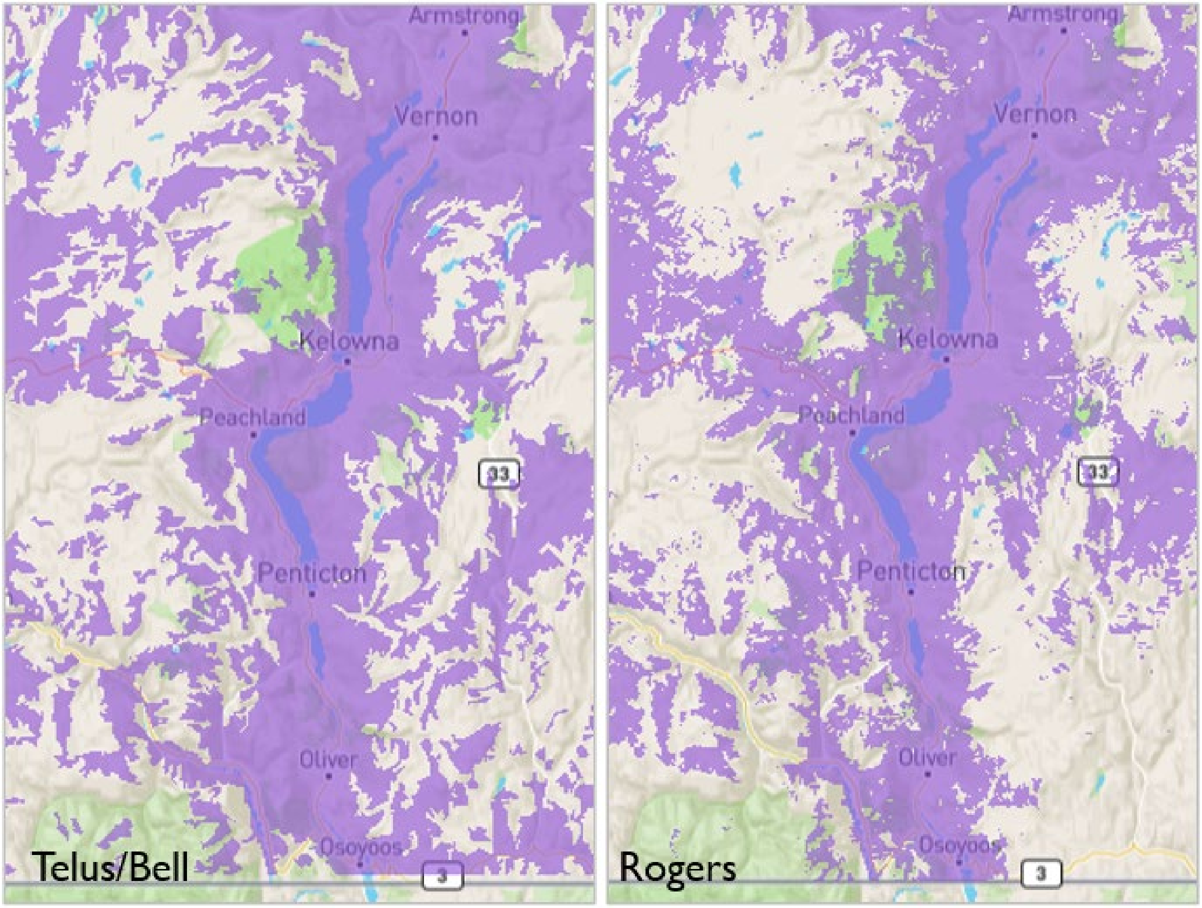

Figure 11: 4G/LTE cellular coverage across the Okanagan Valley

For areas that have clusters of stations or various other types of monitoring, there are wireless network technologies that are ideal for agricultural monitoring, such as low power wide area networks (LPWAN), technology often associated with 'smart cities' and 'smart farms.'

An LPWAN enables communication between Internet of Things (IoT) devices through one or more central gateways. A single gateway can receive data from thousands of monitoring devices (nodes) at distances greater than 10kms, line of sight. Data from the gateway is uploaded to the cloud via an internet and/or cellular connection. The per-device data cost ends up being very low – a few dollars per device per month. Low power means that nodes draw very little current, allowing batteries to last 5-10 years. Nodes can also be very small and are generally inexpensive.

In addition to the weather stations, there are many other on- and off-farm measurements that can leverage an LPWAN. This would enable individual farms to purchase their own stations or sensors that could communicate over the same network. Some use-cases include:

- **Microclimate Monitoring** – In canopy temperature, RH, and leaf wetness, allowing for site-specific data that can be compared across the farm and to local DAS weather stations.
- **Soil Monitoring** – Soil moisture probes for improved irrigation management.

- **Spray Advisory** – Local and on-farm wind speed and direction sensors to advise on appropriate times to spray.
- **Temperature Inversion**: Sensors at different heights to determine inversion status.
- **Water Infrastructure Monitoring** – Flow, pressure, and level sensors to remotely monitor operation and performance of pumps, pipelines, wells, waterways, and reservoirs.
- **Asset Tracking** – Location, movement, and speed of equipment (tractors, sprayers, trucks) or product (location and temperature of bins and cold storage). Custom alerts based on location (geofences) or thresholds (temperature).

A region-wide LPWAN would provide very affordable near-real-time communications to support a wide variety of agricultural and other sensors. Such a concept would provide a template of a regional participatory monitoring network and put the region at the forefront of becoming a '*smart agricultural community*'.

A combination of cellular and LPWAN communications will fulfill many of the regions' needs. In the Okanagan, regional networks could be established around some of the denser monitoring areas like Kelowna, Oliver, and Osoyoos. A network will also be established in Creston. Both technologies are seamlessly interchangeable. From a user's perspective, the technology that is used to transmit the data is of little consequence, so long as it works.

WEATHER STATIONS

In Washington, AWN's Tier 1 stations consist of Campbell Scientific dataloggers configured with research-grade sensors (Figure 12). A typical Tier 1 station costs approximately $12,000 to install and nearly $2,000 annually to maintain. In comparison, AWN's Tier 2 station, the METER ATMOS 41 and ZL6 datalogger (Figure 12), are approximately one third the cost of the Tier 1 and maintenance is much cheaper and far easier. For these reasons, AWN is moving more towards Tier 2 stations.[11]

Other networks have also started using the ATMOS41. Montana has adopted this device for their state mesonet. The sensor is also used throughout Africa under the Trans-African Hydro-Meteorological Observatory (TAHMO). Currently with approximately 1,000 weather stations, the goal of this initiative is to install 20,000 stations across Africa. According to TAHMO, the ATMOS 41 was chosen for having no moving parts, which greatly reduces the maintenance burden. They also claim that the stations are optimal in terms of high-quality measurements and price. Campbell Scientific Canada uses this same sensor rebranded as the ClimaVUE50.

The all-in-one-style METER ATMOS 41 is an ideal sensor-suite for the tree fruit network. Its compact form, ease-of-use, and simple maintenance make it well suited for a mesonet. Consistency with AWN's DAS network enables seamless integration of data and a direct comparison of model output.

The ATMOS 41 sensor suite uses the industry standard SDI-12 communication protocol, which makes it compatible with many types of dataloggers/modems. Or it can use METER Group's matching ZL6 datalogger. The ZL6 has an integrated 4G modem that sends data over the cellular network. In areas with marginal cellular coverage, the ZL6 is not an option. The ZL6 also requires a subscription to the ZENTRA Cloud data management platform. This platform provides some data analysis capabilities as well as functionality to automatically export the raw data. An annual subscription, which includes 15-minute data transmission costs USD $230 (~$300 CAD).

Figure 12: Washington's AgWeatherNet Tier 1 (left) and Tier 2 (right) stations

An advantage of using third-party data acquisition systems is that they offer more capacity for customization (with some sacrifice in simplicity). In areas with marginal cellular coverage or with several nearby stations, options like LPWAN can be used. In addition, network costs, whether for cellular or LPWAN, can be quite low, generally a few dollars per month. Hardware costs also vary. Some datalogger/modem options are listed in Table 3. The prices provided are approximate retail for a single unit and converted to Canadian dollars. Prior to equipment procurement and once funding has been secured, distributors will be invited to provide competitive bids.

Table 3: Comparison of certain compatible datalogger/modems

	Manufacturer	Model	Communication	MSRP (approx.)
	METER Group	ZL6	Cellular	$900
	DecentLab	DL-DLR2-001	LoRaWAN	$725
	Zenseio	CSMP-4103	Cellular	$710
		LSMP	LPWAN	$560
	Infinite	ADS-300	Cellular	$600
		ADS-270	LPWAN	$575
	Ellenex	RS1 LTE Cat M1	Cellular	$500
		RS1 LoRaWAN	LPWAN	$500
	Digital Matter	Eagle 4G	Cellular	$500

NETWORK OPERATION

Since the inception of BC DAS, SIR has been the administrator and a champion of the program. Therefore, **SIR should continue to coordinate BC DAS, including the coordination and operation of the monitoring network. SIR works closely with the tree fruit growers throughout the Okanagan and has the field resources to support a network. SIR's field personnel can be trained to perform basic maintenance and troubleshooting of weather stations.**

In Creston, Fields Forward Society will administer the establishment and operation of network. The Regional District of Central Kootenay (RDCK) will be responsible for the equipment and its upkeep. The Kootenay Boundary Farm Advisors (KBFA) provide services for agricultural producers within the region. As these individuals are visiting farms and working with farmers, they are well positioned to both promote the program, support the tools, and provide some basic maintenance to the equipment.

STATION MAINTENANCE & UPKEEP

No matter the type or quality of monitoring equipment, regular maintenance is essential for ensuring reliable operation of instruments. The quality of the data provided by a sensor is greatly affected by its maintenance, which depends mainly on frequency of visits and the actions that are performed. Maintenance can be preventive (such as inspection and cleaning), corrective (when malfunctions occur), or adaptive (in response to changed requirements or obsolescence). Preventative maintenance reduces but does not eliminate corrective requirements. Rodents, livestock, accidents, vandalism, or any natural events can damage a station at any time. Corrective maintenance is the most expensive as it normally requires a special unscheduled station visit.

Maintenance frequency depends on the required quality of the observations, the equipment, and factors that influence the rate at which the equipment and exposure deteriorate. For example, a location with rapid vegetation growth may need more frequent visits during the summer. Or a location that is exposed to blowing soil or dust may need more frequent cleaning. **Stations should be visited at least once per season by a trained technician to ensure that all instruments are fully functional and that all elements are recorded properly. Additional visits should occur every four to six weeks during the growing season.** Some of these tasks can be performed by landowners or orchard employees. Maintenance recommendations are provided in Table 4.

The network operator should have a systematic procedure fully documented in the form of inspections and maintenance checklists that contain details of each site visit. Such forms, whether hardcopy or electronic, should be archived. Photo-documentation of 'as found' and 'as left' site conditions are useful for recording maintenance history.

Table 4: Recommended station maintenance

FREQUENCY	DESCRIPTION
Every 4 to 6 weeks during the growing season	Cut grass around station (2m radius) Remove any branches or foliage that may interfere with sensors Clear any debris from rain funnel, clean funnel Clean dirt, dust, and debris from around temperature and RH sensors Clean leaf wetness sensor. Apply UV protectant. Clean pyranometer with isopropyl alcohol using soft cloth Clean solar panel (if applicable) and radiation shield
Annual – at beginning of growing season	Complete all regular maintenance tasks (above) Confirm temperature, RH values using calibrated handheld unit. Replace sensor if necessary. Check rain gauge calibration. Adjust if necessary. Inspect enclosure, housing, and brackets Replace datalogger batteries (if applicable) Confirm station pole is plumb and proper orientation (pointing north) Confirm instruments are level (especially rain gauge) Review siting and note any changes, new obstructions, or concerns Confer with landowner. Confirm participation. Note any concerns.
Every 2 years	Replace RH sensor chip Replace/recalibrate pyranometer (every 2-3 years)

DATA QUALITY ASSURANCE/QUALITY CONTROL

All measured data are imperfect. However, knowing the quality of the data, including factors like uncertainty, resolution, continuity, homogeneity, representativeness, timeliness, and format, can help to ensure that data gets used appropriately. If the quality of data is unknown, its usefulness is limited. The purpose of quality management is to ensure that measurements meet specific requirements. These requirements vary by the intended use.

Quality assurance (QA) includes processes and procedures related to the collection and processing of data. For meteorological monitoring, this includes equipment selection, configuration, siting, maintenance, inspection, calibration, redundancy, and training. This also extends to data handling, including transmission protocols and data storage. Quality assurance generally operates in non-real time.

Quality control (QC) occurs on the data processing side (not at the actual weather station) and consists of processes to verify that the data are consistent and to detect errors so that the data may be either flagged as unreliable or corrected. A certain degree of automated QC must occur in near-real-time so that erroneous readings are less likely to reach the user and to prevent those readings from being ingested into models. When errors are detected, the system should have mechanisms to inform the network operator for follow-up. Subsequent and more in-depth quality control may be performed later to identify more subtle errors and refine the archives. Both QA and QC should be iterative processes that evolve to catch errors that may have previously been undetected.

The data that is collected from the existing Okanagan network undergoes minimal QC prior to being accessed by WSU as input to BC DAS. A thorough QC is performed by WSU to detect errors and to fill any data gaps that may be present. This ensures that the model output and subsequent recommendations are as accurate as possible. WSU will continue to perform QC on submitted data.

An issue that has arisen is that while the data in BC DAS undergoes an extensive QC process, the raw station data also goes to Farmwest. Farmwest has minimal QC capabilities and does not correct errors nor fill missing values. For cumulative indices like degree days, this tends to result in discrepancies where the values shown on Farmwest are different than those on BC DAS, despite them both being based on the same weather stations. **For this reason, SIR, WSU, and Farmwest should work towards having a single quality-controlled dataset that is common across all platforms. Ideally, WSU can share the final QC'd dataset for the various stakeholders to use. Both the raw and cleaned data should also be archived and made available for future use.**

As the tree fruit weather monitoring network becomes established, there should be less reliance on WSU for QC. Some preliminary data checks should be implemented prior to the data being sent to WSU. This would ensure that station or network issues can be caught and addressed sooner. Implementing this preliminary QC is contingent on having an established system to view and manage this data and having one or more personnel who can oversee its operation.

METADATA

It is essential for a monitoring program to have detailed information on the observing system itself and on all changes that occur during the time of its operation. For every station, having a proper description of the monitoring system is critical to identify and explain any abnormalities that may exist in the data. Metadata (data about data) should be kept concerning anything that may affect the measurements.

Metadata can help to explain inhomogeneities within the datasets. These can occur when changes are made to instrumentation, calibrations, methods of calculation, exposure of sensors, station location, or when the immediate area has been altered. The effects can appear as abrupt shifts, gradual trends, or even change in variability in the time-series. Without metadata that contains a detailed history of each station, any resulting inhomogeneities could avoid detection and be falsely attributed to natural changes in the weather.

In November 2020, the Standards Council of Canada published a Canadian Metadata Standard for Hydrometeorological Monitoring Stations. This document is the first of four national standards that will focus on data collected by hydrometeorological monitoring stations. The standards will define methods, procedures, techniques, and practices that are intended to help standardize observations across Canada and to make them more easily accessible. The remaining three standards, Siting and Operations, Data Quality, and Data Transmission, are expected to be released mid-2022.

The metadata component recommends best practices that follow the WMO Integrated Global Observing System (WIGOS)[12] standard. These guidelines are intended to accurately describe the conditions under which an observation or measurement was made. WIGOS metadata is divided into 10 categories (Table 5), each consisting of one or more elements.

Table 5: WIGOS metadata categories

CATEGORY	DESCRIPTION
1. OBSERVED VARIABLE	Specifies the basic characteristics of the observed variable and the resulting datasets. Describes the spatial representativeness of the observation and what the observation describes.
2. PURPOSE OF OBSERVATION	Specifies the main application area(s) of the observation and the observing programme(s) and networks the observation is affiliated to.
3. STATION/PLATFORM	Specifies the observing facility, including fixed station, moving equipment or remote-sensing platform, at which the observation is made.
4. ENVIRONMENT	Describes the geographical environment within which the observation is made. Also provides additional information that is considered.
5. INSTRUMENTS AND METHODS	The method of observation and characteristics of the instrument(s) used to make the observation.
6. SAMPLING	Specifies how sampling/analysis are used to derive the reported observation or it is collected.
7. DATA PROCESSING AND REPORTING	Specifies how raw data are transferred into the observed variables and reported to the users.
8. DATA QUALITY	Specifies the data quality and traceability of the observation.
9. OWNERSHIP AND DATA POLICY S	Specifies who is responsible for the observation and owns it
10. CONTACT	Specifies where information about the observation or dataset can be obtained

The Canadian Metadata Standard further recommends that the metadata for any hydrometeorological station in Canada be published to a central repository, specifically Observing Systems Capability Analysis and Review Tool (OSCAR). OSCAR/Surface is the WMO's official repository of WIGOS metadata for all surface-based observing stations and platforms.

All equipment and siting factors should be documented according to the WIGOS metadata standard so that any issues, questions, or uncertainty can be investigated and possibly explained. Station maintenance, calibrations, and repairs must all be recorded. The information should be published to the OSCAR/Surface to provide users of the data with access to the relevant metadata.

DATA MANAGEMENT

As the proposed monitoring network gets established, it is important that some of the data management and some of the QC be performed internally. This would build some internal capacity and allow for some custom product development. This may involve working with a partner like Pacific Climate Impacts Consortium (PCIC). As a member of BC's Climate Related Monitoring Program (CRMP), PCIC collaborates with climate researchers and regional stakeholders to produce knowledge and tools that address the physical impacts of climate variability and change in the Pacific and Yukon Region. The group has extensive experience in working with climate datasets. Some of the region's educational institutions may also have the necessary resources.

This system does not need to be sophisticated. There are third-party cloud-based data-management tools and databases that can be leveraged for modest monthly subscription fees. A basic data handling system with some QC capabilities could be established and maintained internally. As the program evolves, this system could also be improved and expand in functionality to offer additional tools. Alternatively, there are companies that offer data management services.

INFORMATION DISSEMINATION

Having the information and tools readily available is key to promoting user-uptake. The data must be easy to access, clear, and concise. As users will have different preferences in how they access the information, it is important that there be options, both in platform and content. Many farmers will only use their smartphones while certain agrologists may manage several clients' agronomics from their desktop computer. Some users are primarily concerned with the final recommendation while others prefer to analyze the raw numbers.

Currently, users can access pest management information through BC DAS, which requires a free sign-up and sign-in. Or they can access some non-real-time agronomic tools through Farmwest. **Real-time weather conditions, such as winds and delta-T for spraying or temperatures for frost mitigation, should also be made available. To provide this data, ideally it could be integrated into either DAS or Farmwest. Alternatively, it could be hosted on a dedicated site or app, perhaps in collaboration with one of the project partners.**

In addition to having the data accessible, there should also be some information that gets 'pushed' to the user. This could be in the form of a regular conditions update, a weekly report, or even an SMS notification – something that will engage stakeholders and provide some useful insight when they may not have the time to seek out the information themselves.

Industry stakeholders should consider producing a regular in-season update that would provide all tree fruit growers with timely information about weather (growing degree days, rainfall accumulations, observed frost, forecast), pests (current concerns, estimated emergence dates, treatment options), and other relevant information (deadlines, field tours, announcements). This type of product could also be opened to sponsorship from various organizations or businesses. This would offer exposure to the industry while contributing some funds to the program.

RESOURCES

Establishing and operating a weather monitoring network is not a trivial undertaking. Many networks have been built but have failed to succeed due to lack of ongoing support. While long-term funding is always elusive, there will need to be a concerted effort to build a program whose value will ensure its longevity by justifying continued funding. This can be accomplished by providing vital information and engaging users.

SUPPORT & EXTENSION

For the program to gain traction, it requires that the data and products be used. This will only occur through a concerted effort of promotion and support. This should include demonstrations, field days, and regular communications, including alerts, advisories, and newsletters. Such efforts should be directed at decision makers, whether they be horticulturalists or orchard managers.

There are several organizations that are well-positioned to provide this support. In the Okanagan, SIR has, and should continue to, promote these tools. In Creston, KBFA would be a suitable collaborator. Also in Creston, the RDCK has committed to provide support for the monitoring network. Involvement of the RDCK will help to leverage resources and increase the user-base for the data.

Coordination and support from CAI have been instrumental in establishing BC DAS and promoting agricultural weather monitoring across the province. Their continued involvement will be critical to the success of the program.

Educational institutions, like College of the Rockies, University of British Columbia Okanagan, and Thompson Rivers University, can help develop resources and provide training. These institutions, along with AAFC are actively researching topics and developing solutions that are directly related to the industry. AFF is responsible for the production, marketing, and processing of agricultural products and brings a wide range of expertise. Regional districts, whose mandates include safeguarding water supplies, flood management, fire protection, and emergency services, can benefit greatly by having improved weather information.

There are also private consultants and horticulturalists who could use the information to better assist their clients. Engaging these professionals and ensuring their familiarity with DAS will further promote its uptake and continued use. Therefore, the station data and DAS should be made readily available to all stakeholders.

Growers Supply has played a critical role in operating the Okanagan weather stations but primarily as a service provider and data supplier. Going forward, Growers Supply has expressed interest in collaboration that could serve to benefit the entire tree fruit industry. This continued relationship could be in the form of data sharing, equipment operation, or in facilitating enhanced on-farm monitoring.

BUDGET

The proposed budget includes costs related to establishing and operating the monitoring network. These include hardware purchase, installation, configuration, communications, data management, and depreciation. Depreciation considers the lifecycle of the equipment and addresses replacement items like RH chips, damaged or lost components, and eventual upgrades to aging equipment. The budget does not include specific DAS-related costs such as setup, licensing, or extension. The amount that will be paid to WSU to host and support DAS remains under negation between SIR and WSU at the time of this report being published. Based on previous years and the additional work required to integrate new stations, this amount is expected to be between $60,000 and $80,000 per year.

In the Okanagan, the budget includes the replacement of all 20 existing weather stations. This number will ultimately be influenced by how many suitable new stations that partners like Growers Supply may install and whether the data is freely shared. The objective will be to work collaboratively with industry partners by sharing data and avoiding duplicated efforts. There will be continued dialogue with Growers Supply to ensure that the overall tree fruit monitoring network gets revitalized in the most efficient manner possible.

In the Creston area, eight new stations are being proposed. In addition to specific tree fruit requirements, these stations are also intended to enhance regional monitoring that will benefit other sectors. Of the eight stations, five are expected to be incorporated into BC DAS.

Data flows and database setup will include programming automated processes to efficiently retrieve, display, and transfer the data to WSU and Farmwest. Some basic internal QC capabilities will also be implemented. These will include some automated data checks, visual checks, and alerts that will notify personnel of any errors, missing data, or delayed data.

Region-specific costs are divided between the Okanagan and Creston since funding will come from different sources. The detailed budget is provided in Table 6.

Table 6: Proposed program budget

OKANAGAN				
HARDWARE		**Qty**	**Each**	**Total**
	ATMOS 41 All-in-one weather sensor	20	$ 2,500	$ 50,000
	PHYTOS 31 Leaf wetness sensor	20	$ 180	$ 3,600
	Datalogger/modem - Cell or LPWAN	20	$ 1,000	$ 20,000
	Outdoor LoRaWAN gateways	3	$ 1,250	$ 3,750
	Station & gateway mounting hardware	23	$ 150	$ 3,450
	Total Hardware			**$ 80,800**
HARDWARE & SOFTWARE SETUP				
	Station installation	20	$ 250	$ 5,000
	Gateway installation	3	$ 500	$ 1,500
	Data flows and database setup			$ 5,000
	Total Setup			**$ 11,500**
NETWORK OPERATION (ONGOING ANNUAL COSTS)				
	Station maintenance	20	$ 500	$ 10,000
	Station data costs	20	$ 60	$ 1,200
	Gateway data costs	3	$ 180	$ 540
	Data management & QC	20	$ 500	$ 10,000
	Amortization/depreciation/replacement			$ 8,000
	Total annual operation			**$ 29,740**
SUMMARY FOR OKANAGAN				
	Total Year 1 (hardware, software, setup, operation)			**$ 122,040**
	Annual Costs - Year 2, 3… (Operation)			**$ 29,740**

CRESTON				
HARDWARE		**Qty**	**Each**	**Total**
	ATMOS 41 All-in-one weather sensor	8	$ 2,500	$ 20,000
	PHYTOS 31 Leaf wetness sensor	8	$ 180	$ 1,440
	Datalogger/modem - LPWAN	8	$ 1,000	$ 8,000
	Outdoor LoRaWAN gateways	3	$ 1,250	$ 3,750
	Station & gateway mounting hardware	11	$ 150	$ 1,650
	Total Hardware			**$ 34,840**
HARDWARE & SOFTWARE SETUP				
	Station installation	8	$ 250	$ 2,000
	Gateway installation	3	$ 500	$ 1,500
	Data flows and database setup			$ 5,000
	Total Setup			**$ 8,500**
NETWORK OPERATION (ONGOING ANNUAL COSTS)				
	Station maintenance	8	$ 500	$ 4,000
	Station data costs	8	$ 60	$ 480
	Gateway data costs	3	$ 180	$ 540
	Data management & QC	8	$ 500	$ 4,000
	Amortization/depreciation/replacement			$ 4,000
	Total annual operation			**$ 13,020**
SUMMARY FOR CRESTON				
	Total Year 1 (hardware, software, setup, operation)			**$ 56,360**
	Annual Costs - Year 2, 3… (Operation)			**$ 13,020**

IMPLEMENTATION

In the Okanagan, depending on available resources and budget, a phased deployment strategy is likely to occur. This would allow a gradual replacement of the existing in-orchard Growers Supply weather stations while still getting some useful life out of those that remain. As stations reach the end of their effective lifespans, they would be retired and get replaced by new stations. This process could take place over two to four years.

In the short-term, ideally prior to the 2022 growing season, the siting of the existing stations should be improved so that they meet the necessary siting protocols. This would involve moving stations or setting up new stations in proximity, but outside of the orchard. This will allow those stations to conform with the DAS standards and to those being adopted by tree fruit network.

In Creston, the necessary resources are anticipated to be available by early 2022, allowing the network to be fully built and operational before the 2022 growing season. This will require immediate sourcing of hardware and identification of specific station locations and landowners. The Creston area also needs to be integrated into BC DAS, a task to be undertaken by WSU. Negotiations with WSU will determine the budget and timelines of this requirement.

Project partners, including their contribution commitments, will need to be confirmed to assign tasks and commence work. This will include levels of government, educational institutions, industry groups, and other stakeholders.

CONCLUSION

The proposed network renewal strategy will contribute to the resiliency and sustainability of the BC tree fruit sector by providing accurate and timely orchard management information. BC DAS is proven to be an effective suite of decision support tools, and promotion across the industry should continue. And based on demand, the program should also be expanded in coverage to include Creston.

In addition to the necessary funding resources, the non-financial contributions from many of the supporting organizations will be vital. Groups like SIR have been instrumental in promoting and expanding BC DAS. They will continue to play an important role in coordinating and supporting the network. Additional collaborators will need to be engaged.

The strategy that has been laid out in this document provides many of the foundational pieces that will need to be established. As the network develops, new opportunities will present themselves. These may include additional collaborations, new risk-management tools, and innovative ways to monitor and quantify agricultural ecosystems. These weather stations will serve as a much-needed resource that will benefit many stakeholders within multiple sectors. This is an exciting and essential initiative.

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