



CLIMATE CHANGE ADAPTATION PROGRAM

A Roadmap for a Sustainable Agricultural Weather Network in BC

Project Report

Funding for this project has been provided by the Governments of Canada and British Columbia through the Canadian Agricultural Partnership, a federal-provincial-territorial initiative. The program is delivered by the Investment Agriculture Foundation of BC.

Opinions expressed in this document are those of the author and not necessarily those of the Governments of Canada and British Columbia or the Investment Agriculture Foundation of BC. The Governments of Canada and British Columbia, and the Investment Agriculture Foundation of BC, and their directors, agents, employees, or contractors will not be liable for any claims, damages, or losses of any kind whatsoever arising out of the use of, or reliance upon, this information.

DELIVERED BY

FUNDING PROVIDED BY



A ROADMAP FOR A SUSTAINABLE AGRICULTURAL WEATHER MONITORING NETWORK IN BC

2021



A Roadmap for a Sustainable Agricultural Weather Network in BC

Prepared by: *Peak HydroMet Solutions*

Published by: BC Agricultural Climate Adaptation Research Network and
Climate & Agriculture Initiative BC, 2021

Copyright

Copyright © 2021 BC Agricultural
Climate Adaptation Research Network
and Climate & Agriculture Initiative BC

Available to print and/or distribute under
a Creative Commons Attribution-
NonCommercial-NoDerivatives 4.0
International License.
[creativecommons.org/licenses/by-nc-
nd/4.0/](https://creativecommons.org/licenses/by-nc-nd/4.0/)

Citation Format

In-text: *Peak HydroMet* 2021

Reference List: *Peak HydroMet*. 2021. A
Roadmap for a Sustainable Agricultural
Weather Network in BC. BC Agricultural
Climate Adaptation Research Network and
Climate & Agriculture Initiative BC.
www.bcacarn.com
www.climateagriculturebc.ca

Disclaimer

Agriculture and Agri-Food Canada and the
BC Ministry of Agriculture, Food &
Fisheries are committed to working with
industry partners. Opinions expressed in this
document are those of the author and not
necessarily those of Agriculture and Agri-
Food Canada, or the BC Ministry of
Agriculture, Food & Fisheries. The
Government of Canada, the BC Ministry of
Agriculture, and their directors, agents,
employees, or contractors will not be liable
for any claims, damages, or losses of any
kind whatsoever arising out of the use of, or
reliance upon, this information.

ACKNOWLEDGEMENTS

This report was prepared by **Andrew Nadler** of Peak HydroMet Solutions, in partnership with the BC Agricultural Climate Adaptation Research Network (ACARN) and the Climate & Agriculture Initiative BC.

The project was initiated and guided by the BC ACARN Climate and Weather Data Working Group:

- **Faron Anslow**, Pacific Climate Impacts Consortium
- **Shabtai Bittman**, Agriculture and Agri-Food Canada, Agassiz
- **Andrew Black**, University of British Columbia
- **Serena Black**, University of Northern British Columbia
- **Rishi Burlakoti**, Agriculture and Agri-Food Canada, Agassiz
- **Kirsten Hannam**, Agriculture and Agri-Food Canada, Summerland
- **Jason Lussier**, BC Ministry of Agriculture, Food and Fisheries
- **Shauna MacKinnon**, BC Agricultural Climate Adaptation Research Network
- **Emily MacNair**, Climate & Agriculture Initiative BC
- **Ian McLachlan**, BC Ministry of Agriculture, Food and Fisheries
- **Nathaniel Newlands**, Agriculture and Agri-Food Canada, Summerland
- **Sean Smukler**, University of British Columbia
- **Anna Stemberger**, BC Ministry of Agriculture, Food and Fisheries
- **Stephanie Tam**, BC Ministry of Agriculture, Food and Fisheries

FUNDING

Funding for this project has been provided in part by the BC Agricultural Climate Adaptation Research Network and in part by the governments of Canada and British Columbia under the Canadian Agricultural Partnership, a federal-provincial-territorial initiative. Funding is administered by the Investment Agriculture Foundation of BC and the BC Agricultural Research & Development Corporation for the Climate Change Adaptation Program delivered by the Climate & Agriculture Initiative BC.



EXECUTIVE SUMMARY

Agriculture is facing unprecedented challenges due to climate change. Frequency of extreme events, abnormal weather patterns, and the potential introduction of new pests require strategic adaptation to manage risk. The sector also faces opportunities to adapt by implementing new and innovative production practices that can increase resilience and make BC more competitive. Such adaptation can only be accomplished by having quantitative data that will help us understand the changes that are occurring – and that will occur. Presently, this information is inconsistent and incomplete, lacking the necessary spatial representation to effectively be used to inform agricultural adaptation.

This report provides a roadmap, including actionable steps that can be taken to build a sustainable agricultural weather monitoring program in British Columbia. The report includes: (1) the status of meteorological monitoring within BC, (2) an assessment of agricultural areas that lack sufficient baseline coverage, and (3) recommendations for an operational structure that builds on work to date, along with tangible action items for improving weather monitoring and tools for agriculture in BC.

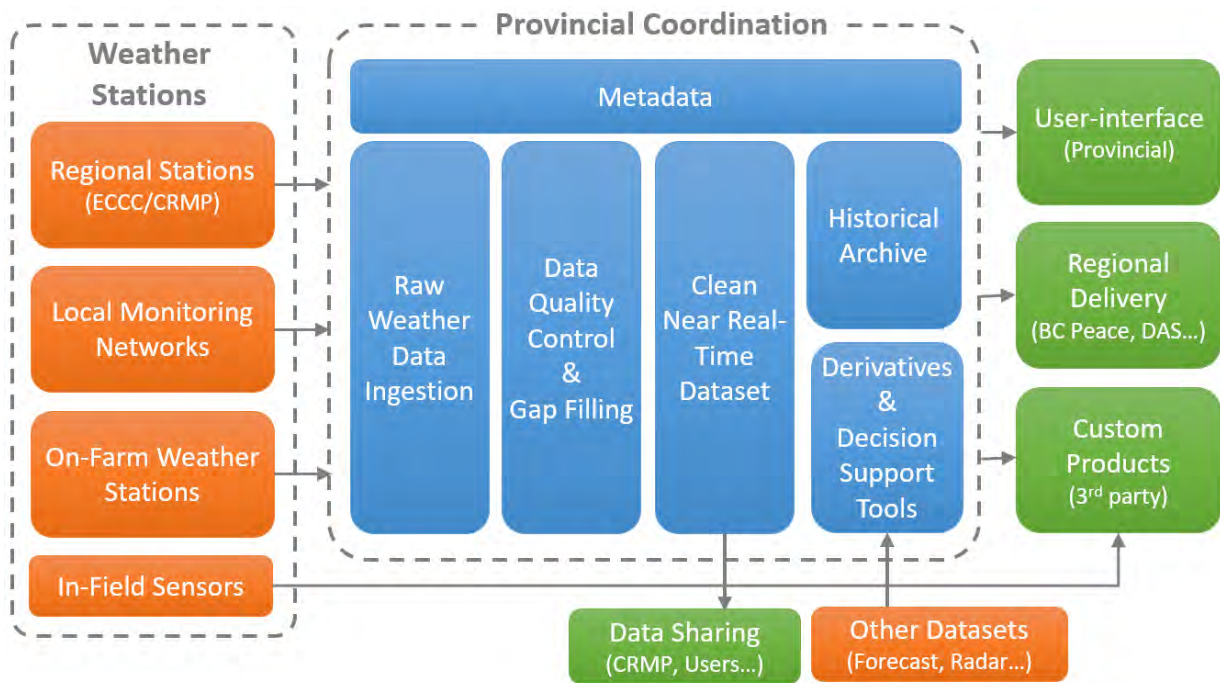
The gap analysis is focused on establishing a baseline level of weather data collection across the agricultural land base of the province. The analysis reveals agricultural areas that have inadequate regional weather monitoring for this baseline and that 90% of the total under-represented land are within the Omineca Skeena, Cariboo Chilcotin Coast, and Peace regions. These relatively remote and less populated areas also have the largest expanses of farmland used primarily as pasture for grazing. The baseline assessment suggests that adding a weather station to each of the top 25 ranked areas would cover 80% of the total least represented farmland. Adding 34 new stations would cover 90% of the least represented land. Broader baseline coverage would provide more robust information about climate and weather across BC's agricultural land base and would support more equitable regional-scale monitoring.

The more populated areas tend to have adequate baseline coverage but would benefit from additional stations to inform strategic and operational decisions, particularly for managing high value crops. A tiered methodology is proposed whereby the types of farm management decisions will influence whether monitoring is at a regional, local, farm, or field scale. Finding a balance between sufficient baseline coverage, while increasing the quality and consistency of monitoring in the higher intensity agricultural areas, will help to achieve a range of objectives with the agricultural weather network.

Several stakeholders are already collecting weather information to serve various needs within their regions or on their own farms. This has resulted in a fragmented distribution of observational equipment and collection methods. This report recommends an operational model that leverages and enhances these existing monitoring stations by providing provincial coordination and support. This community-based monitoring strategy would empower stakeholders by providing them with resources and expertise to manage their networks according to established guidelines, and ensuring that networks adhere to hardware, siting, maintenance, and metadata standards. This will result in measurements of known quality that can be used for multiple purposes. Centralized data management would benefit all agricultural stakeholders by providing quality control, derivatives, and dissemination of value-added information, including decision support tools. Central coordination would also help address the existing monitoring gaps so that these areas can also benefit from improved weather information.

Based on its findings, this report recommends actions for implementation, including resources that are required to achieve the stated objectives. This collaborative approach will require long-term resource commitments (budget and dedicated personnel) to build and maintain a successful program.

PROPOSED BC AGRICULTURAL NETWORK STRATEGY



Proposed agricultural weather network and data handling strategy that includes different network operators and a provincially coordinated data management platform. Important components include metadata, data quality control, and decision support tools.

RECOMMENDATIONS

COMMUNITY-BASED MONITORING

The most effective way to enhance weather monitoring is to promote a community-based model that involves participation in weather collection by different organizations and individuals. This decentralized approach improves efficiency and costs by engaging local resources.

To increase the inventory of available weather data, existing weather stations should be evaluated for their suitability for agricultural use based on monitoring standards and guidelines that need to be established. New stations would also need to adhere to these guidelines. The station owner could be eligible to receive assistance for hardware and data costs.

PROVINCIAL COORDINATION

Establish a formalized agricultural weather-specific entity that acts as a province-wide resource for existing and potential weather station and weather network operators. This entity coordinates closely with regional interests to provide support and resources. The entity would provide standards, guidelines, training, support, and a data handling infrastructure that would serve the needs of agriculture and provide methodological consistency between networks. A dedicated Network Coordinator should be appointed.

CENTRALIZED DATA PLATFORM

Develop and provide a central platform on which to process, manage, quality control (QC), model, and redistribute weather information in a user-friendly manner. An effective QC is imperative. This would be a combination of automated processes and human oversight. Every weather station and collected element must have sufficient metadata. All agricultural weather network operators in BC should be required to also follow this standard for documenting and reporting all monitoring details. A Data Technician is required to support this initiative.

DECISION SUPPORT TOOLS

Decision support tools (DSTs) help producers make informed decisions to improve efficiency, identify opportunities to optimize production, reduce inputs, and increase profit. The data platform must include decision support tools that serve different production types. Education and awareness are key components of any agricultural weather program. Uptake of decision support tools will require training and support. Regional and local farm advisors and industry groups can assist with this training.

HARDWARE

Some viable hardware options are identified. Stations that are less complex are ideal in that basic maintenance and repairs can be performed by local resources instead of centralized dedicated technicians. Davis Instruments and METER Group stations are well suited for such applications. All stations should collect a minimum of air temperature, relative humidity, and rainfall. Ideally, stations will also collect wind speed and direction and solar radiation. Stations that are used for disease prediction should have leaf wetness sensors. Information should be transmitted at least hourly.

FUNDING

To succeed, a formalized agricultural weather program requires long-term and secure funding. This funding will go towards establishing and maintaining the data platform, incorporating DSTs, and supporting network and station operators with hardware and operational costs. Adequate funding will enable the program to become established and to meet its short-term and long-term objectives.

ACRONYMS

AAFC	Agriculture and Agri-Food Canada
ACARN	British Columbia Agricultural Climate Adaptation Research Network
ACIS	Alberta Climate Information System
AEPI	Agriculture Environmental Partnership Initiative
AFF	BC Ministry of Agriculture, Food and Fisheries
API	Application programming interface
ARM	Application Risk Management
AWN	AgWeatherNet (Washington State University)
BC DAS	BC Decision Aid System
BCFC	BC Forage Council
BRM	Business Risk Management
BTM 1	Baseline Thematic Mapping – Present Land Use Mapping Version 1
CAI	Climate & Agriculture Initiative BC
CBM	Community Based Monitoring
CHU	Corn Heat Units / Crop Heat Units
CoCoRaHS	Community Collaborative Rain, Hail & Snow
CRMP	Climate Related Monitoring Program
CWOP	Citizen Weather Observing Program
DST	Decision Support Tool
EC	Environment Canada
ECCC	Environment and Climate Change Canada
EFP	Environmental Farm Plan
ENV	Ministry of Environment and Climate Change
ET	Evapotranspiration
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
GCOS	Global Climate Observing System
GDD	Growing Degree Days
GIS	Geographic information system
IoT	Internet of Things
IT	Information Technology
IPM	Integrated Pest Management
KDE	Kernel Density Estimation
LPWAN	Low-power wide-area networking
MoT	Ministry of Transportation and Infrastructure
NoN	Network of Networks
PCIC	Pacific Climate Impacts Consortium
PFCA	Pacific Field Corn Association
PCDS	Provincial Climate Data Set
RFQ	Request for Quotations

RH	Relative Humidity
SaaS	Software as a Service
SCIC	Saskatchewan Crop Insurance Corporation
SLA	Service-Level Agreement
SIR	Sterile Insect Release Program
UI	User Interface
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological organization
WSU	Washington State University

TABLE OF CONTENTS

- Executive Summary iv
- Proposed BC Agricultural Network Strategy and Recommendations v
- Acronyms vii
- List of Figures xi
- List of Tables xii
- Introduction and Rationale..... 1
- Weather Monitoring in BC2
 - Scales of Monitoring4
 - Agricultural Monitoring in BC.....5
 - Farmwest.....5
 - BC Peace Agri Weather Network6
 - Okanagan Valley Network.....8
 - Other Weather Stations8
 - Community Based Monitoring9
 - Agricultural Weather Networks Outside of BC..... 11
 - A Coordinated Approach..... 12
- Baseline Gap Analysis 13
 - Previous Work 13
 - Methods..... 14
 - Results 17
 - How to use this Gap Analysis 22
- Addressing the Gaps..... 23
 - Station Siting 23
 - Hardware 24
 - Dataloggers and Communication..... 24
 - Measurements 26
 - Weather Station Hardware..... 29
 - Weather Station Suitability 32
 - Station Maintenance and Upkeep 33
- Network Requirements 34
 - Quality Control 34
 - Metadata..... 36
 - Data Access and Discoverability 37
 - Data Preservation 38
 - Modelling and Derivatives 38

User Experience.....	39
Data Management Platform.....	39
Extension	41
Decision Support Tools	41
Types of Decision Support Tools.....	41
Strategic.....	42
Tactical	43
Operational.....	44
Available Tools	44
Decision Support Tool Portals	47
Stakeholder Feedback.....	48
Implementation.....	49
Steering Committee	50
Resourcing and Costs.....	51
Data Management.....	51
Weather Stations	52
Station Operation and Maintenance.....	52
Personnel Costs	53
Proposed Budget.....	53
Conclusion	55
Recommendations.....	56
Community-Based Monitoring	56
Provincial Coordination.....	56
Centralized Data Platform.....	56
Decision Support Tools	56
Hardware	56
Funding.....	56
References	57
Appendix A – Regional Maps of Sparse Coverage.....	59
Appendix B - Stakeholder Feedback.....	67

LIST OF FIGURES

Figure 1: Composition of weather network operators in BC from 1950 to 2019	3
Figure 2: Distribution and coverage of existing inter-agency weather networks across BC.....	4
Figure 3: Farmwest weather station (Grand Forks).....	5
Figure 4: Farmwest website showing daily temperature.....	6
Figure 5: BC Peace Agri Weather Network Station (Kelly Lake)	7
Figure 6: BC Peace Agri Weather Network Website showing historical station data	7
Figure 7: Davis WeatherLink stations in the Vanderhoof/Prince George areas and the Okanagan-Similkameen.....	9
Figure 8: Vineyard weather station in the Okanagan-Similkameen.....	9
Figure 9: School Based Weather Station Network plot of total rainfall	10
Figure 10: Community Collaborative Rain, Hail & Snow (CoCoRaHS) observations.	10
Figure 11: Washington State University's AgWeatherNet program.....	12
Figure 12: Heat maps showing areas of under-represented farmland	16
Figure 13: Percent of under-represented farmland broken down by region.....	17
Figure 14: Agricultural land beyond 15 km from a weather station.....	18
Figure 15: Areas identified as monitoring gaps, including their relative ranking	19
Figure 16: Farmland beyond 15 km and 30 km from an existing weather station.....	21
Figure 17: METER Group Atmos41/ZL6 (left) and Davis Instruments GroWeather (right).....	33
Figure 18: Pacific Climate Impacts Consortium Data Portal	38
Figure 19: Scales of Decision Support Tools (based on Rossi et al. 2019).....	42
Figure 20: BC Agriculture Water Calculator used to estimate crop and livestock water needs.....	43
Figure 21: Output from the BC Decision Aid System (BC DAS) Apple Scab model.....	44
Figure 22: Growing degree day summaries for grape growers	46
Figure 23: BC Application Risk Management (ARM) Tool.....	47
Figure 24: Wheat midge emergence calculator from BC Peace Agri Weather Network	47
Figure 25: Proposed agricultural weather network and data handling strategy	50
Figure 26: Gap Areas - Kootenay	59
Figure 27: Gap Areas - Okanagan.....	60
Figure 28: Gap Areas - Omenica Skeena North.....	61
Figure 29: Gap Areas - Omenica Skeena South.....	62
Figure 30: Gap Areas - Peace.....	63
Figure 31: Gap Areas - Thompson Nicola	64
Figure 32: Gap Areas - Vancouver Island/South Coast	65
Figure 33: Gap Areas - Cariboo Chilcotin Coast.....	66

LIST OF TABLES

Table 1: Active BC weather stations by operator and percent of stations with each measurement parameter	15
Table 2: Ranked list of underrepresented areas along with their region(s).....	20
Table 3: Common agricultural weather station measurement types	29
Table 4: Comparison of weather station options.....	31
Table 5: WMO Integrated Global Observing System.....	36
Table 6: Selected Decision Support Tools that are available in BC	45
Table 7: Estimated 3-year annual budget broken down by cost option	54

INTRODUCTION AND RATIONALE

This project responds to key findings from a series of industry consultations conducted by the Climate & Agriculture Initiative between 2013 and 2020 to identify priority climate impacts and strategies that support agricultural adaptation. The input was compiled in the [Regional Adaptation reports](#). In every region, a common theme emerges: The need for improved weather monitoring and access to decision support tools (DST).

In some regions such as the Peace and Kootenay & Boundary regions, producers highlighted baseline weather data gaps. Producers indicated that these gaps affect their ability to respond to and anticipate climate risks, including increasingly variable conditions and changing pest populations. Similar issues and concerns were raised by producers in the Cariboo, Bulkley-Nechako & Fraser Fort George, Okanagan, and Fraser Valley regions. In all cases, producers were interested in improving weather data coverage and quality, as well as accessing related tools and information to support precision management for irrigation, nutrients, and pests.

Reliable and accessible weather observations from the local to the regional scale are essential to address a wide range of agricultural stakeholder's needs. As governments, researchers, and extension services become increasingly focused on empowering a more resilient agriculture sector, a centrally supported weather data program will be essential to support and inform decisions at all levels. Governments require empirical data to support development and delivery of effective programs to assist producers with managing adverse conditions such as drought or excess moisture. As the climate changes, extreme events are becoming less predictable and more frequent which increases the value of local weather data. Programs like Agriculture and Agri-Food Canada's (AAFC) [Livestock Tax Deferral Provision](#) relies on Prescribed Drought and Flood Regions that are identified annually based on spring moisture and summer rainfall. While such information can be acquired from crop reports or local observers, this is time consuming and relies on inputs that can be highly subjective. Both producers and Business Risk Management (BRM) programs would benefit from accurate weather data that could reduce the amount of manual claim verification that is needed. Such data also creates opportunities for new and innovative parametric products.

Collecting accurate weather data over time (climate information) can help the agriculture industry improve its adaptive capacity to climate change. Adaptive capacity is having the necessary resources and ability to mobilize those resources to effectively respond to a range of potential impacts¹. Long-term weather monitoring and future climate projections can be used to assess the potential for new crops to be grown in areas that traditionally were not believed to be suitable and to ensure that crops and cropping practices are optimized and suited to their climate².

Better real-time and seasonal information about conditions on the farm can enable producers to predict the outcome of farming decisions more accurately. Accurate yield prediction can help farmers decide on appropriate investment in crop inputs, plan for storage capacity, and make marketing decisions. Eliminating spray treatments by following a risk-based spray program can save thousands of dollars (and reduce unnecessary/ineffective use of sprays). Detecting the presence of a pest can avert crop loss and treating it can reduce damage and result in a higher quality product.

Tools that help farmers to manage risk also benefit the public. Maintaining a strong agricultural sector contributes to BC's economy by providing employment and support for local businesses, often in rural areas. A strong and adaptive agricultural sector supports improved food security. There are also environmental gains attached to improved weather data and decision tools that increase precision management. Irrigation management tools can increase water conservation and reduce the risk of leaching or runoff that can cause nutrients to end up in surface water or groundwater. As noted, managing pest treatments based on accurate and timely weather derivatives can help to maximize efficacy and reduce unintended effects on nearby vegetation or habitat.

Over the past few decades, technological improvements in weather monitoring have made it increasingly more accessible for governments, organizations, business, and weather enthusiasts to operate their own weather observing systems. However, monitoring data is unusable if it is unreliable, of inconsistent or unknown quality, or is not readily accessible. Within BC, the quality and availability of agricultural weather data is variable amongst the disparate

networks. Central coordination and support could greatly enhance the current state of meteorological monitoring even without the addition of more weather stations. This can be accomplished by providing technical support, guidelines, and a data management system that can amalgamate datasets from the various operators. Increasing the broad accessibility of quality-controlled data in user-friendly formats would also substantially increase the value of existing stations.

To build on the regional efforts to date, this report proposes a community-based participatory approach to enhance agricultural weather monitoring and data retrieval. With central coordination and support, regional or local stakeholders are best suited to identify their specific needs and should allocate their resources accordingly. Regional organizations have the physical presence and the desire to provide value for their members or constituents. Provincial agencies have limited resources to address local needs and can most effectively play a coordinating and enabling role, rather than attempting to operate a large, distributed weather monitoring network.

Provincial agencies could support these organizations in establishing their own stations by offering a subsidy on the cost of hardware and data transmission, as well as by providing the network “backbone” of data handling, quality control, models, and data delivery. Centralized support should also include expertise, recommendations, and guidelines to ensure that regional networks meet the specified standards. Necessary standards include hardware specifications, siting guidelines, maintenance requirements, and management of metadata. Such a strategy ensures that the regional networks cater to their local agricultural needs while still adhering to provincial guidelines, enabling seamless interchange of data and derived information within agriculture and with other sectors.

At present there are many groups and individuals already involved in collecting weather data who would benefit from an enhanced provincial network. There has also been strong interest expressed by both producer groups and the research community in acquiring quality weather information to support existing or new derived tools to help manage risk or improve production. BC’s agricultural sector would receive immense value from an entity that can act as a meteorological resource and a hub for individual station or network operators. Formalized provincial coordination could greatly assist these groups in achieving their goals while also building a robust agricultural weather program across BC.

WEATHER MONITORING IN BC

Historically, the provision of weather and climate information has been the sole responsibility of governments. Within Canada, although supported by a legion of dedicated volunteer weather observers, the coordination, amalgamation, processing, interpretation, and dissemination of climate information has been handled exclusively by the federal Meteorological Service of Canada (MSC), part of Environment and Climate Change Canada (ECCC), previously Environment Canada (EC). These activities are to fulfill MSC’s mandate of helping Canadians protect themselves, their families, and their property from the hazards of severe weather. Weather information has traditionally been considered a public good, being supplied and funded through public dollars and made available free of charge.

Over time, the observing network has undergone major changes as automated weather stations gradually replaced most human observers and computers took over the processing of data. Another major shift has occurred in the composition of network operators. As specific weather information needs have emerged, and monitoring equipment has become more accessible, new networks have been established. For example, accurate forest fire risk assessment requires stations that adequately represent forested areas. Assessment of avalanche risk requires snow and weather measurements in avalanche-prone locations.

Figure 1 shows the evolution of network operators in BC since 1950. In 1950, all but five of BC’s 246 weather stations were operated by EC. By 1980, 38% of the weather stations in BC were operated by other agencies. In 2000, non-EC stations made up 56% of the overall total. Currently, ECCC stations make up only 27% of the network while 73% of stations are operated by other agencies. With over 200 weather stations, BC Wildfire was one of the first, and continues to be the most prominent network operator in BC. Figure 2 provides a map of weather stations that are operated by the various agencies. This map does not include privately-owned stations.

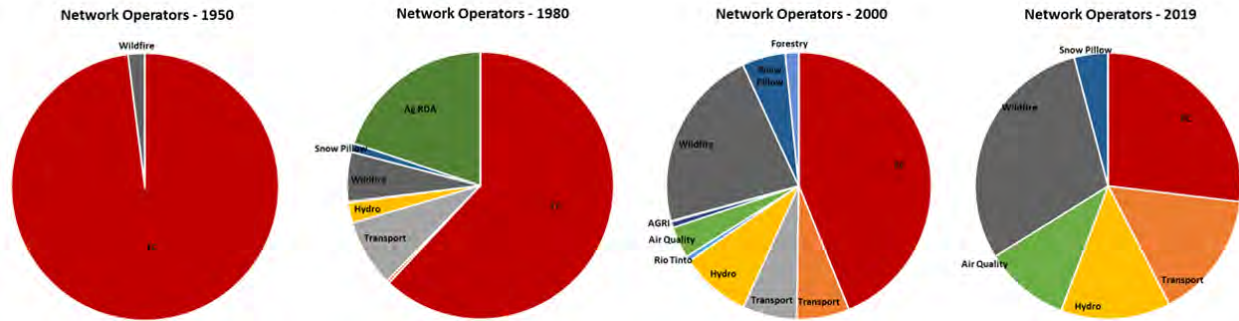


Figure 1: Composition of weather network operators in BC from 1950 to 2019

The cost of digital electronics has gone down and ease-of-use has improved greatly. Wireless communications have become ubiquitous and less expensive. These factors have eliminated many of the barriers that have traditionally prevented organizations or individuals from investing in weather monitoring. Networks are now being operated by a cross section of organizations, both public and private.

Within BC, due to its complex terrain, diverse climates, and prominent resource sector, there have been substantial investments in weather monitoring networks. When weather observations are collected in a consistent manner according to set guidelines, this information can be used beyond the specific purpose for which a station was established. For example, if it is sited suitably and includes the required sensors, a station that was established to monitor highway conditions can also be used to calculate the risk of forest fire. Likewise, there are many forestry stations in areas where agriculture and forests converge and some of these stations can be used for agricultural applications. Weather stations that can be used for multiple purposes introduce opportunities for efficiencies.

Network operators in BC have recognized the mutual benefits of sharing resources, expertise, and data, and have engaged in a formalized collaboration agreement called the Climate Related Monitoring Program (CRMP). This agreement, signed by ECCC, several provincial ministries, BC Hydro, Rio Tinto Alcan, two regional districts, and PCIC, provides a foundation for sharing of information and data. The goal is to integrate all federal, municipal, and private monitoring data into a single portal. This has been accomplished through guidelines and operational standards for monitoring and quality control (QC). Sharing has resulted in efficiencies in that the various organizations can take advantage of weather data that is already being collected and available through partner organizations. This can reduce the need to establish and maintain new stations that could be redundant due to existing partner stations that may already provide adequate coverage of an area.



Figure 2: Distribution and coverage of existing inter-agency weather networks across BC

SCALES OF MONITORING

Most populated areas of the country have adequate regional monitoring from the network of ECCC stations that are located throughout. These stations provide a snapshot of the weather conditions across the country and a reliable basis for detecting and analyzing regional long-term changes in climate. Accurate weather data at the regional scale normally does an adequate job of detecting large-scale weather features such as positions of storm tracks, prevailing wind direction, and widespread phenomena³. This information helps generate forecasts, timely severe weather alerts, and helps describe events like heat waves, cold snaps, or droughts. Regional weather information is adequate to guide most people's day-to-day activities. Many ECCC stations are located near populated centers. Further from these centers, the extent of weather monitoring decreases.

While regional measurements may provide approximations of field conditions and suffice for general farm decisions, many farming operations require a much higher degree of accuracy and detail. A single weather station can accurately measure and report conditions that occur at its specific location. For those located near a weather station, these measurements are representative of where they are. However, conditions change over distance as climate varies with elevation, slope, and terrain transition, proximity to water, vegetation/land cover, and wind conditions⁴ – all factors that are not accounted for by a single point measurement. Therefore, conditions experienced further from the station can be quite different from what the station is measuring.

Farm- or field-scale weather information and accurate forecasts can effectively be used to track and predict insect development, disease risk within the field, or evapotranspiration and soil moisture status of a specific crop. These parameters often require local or even micro-scale measurements. Knowing how the weather differs across a farm or field can help producers manage their crops more effectively. Regional weather data seldom addresses this need.

Both regional and sub-regional weather observations are needed to improve our understanding of a range of issues that are important to agriculture and the broader community. These include impacts from severe weather, such as drought, flood, storms, and extreme heat, availability of freshwater, and food safety and security. This can be accomplished through a better understanding of climates, how they are changing, and what that means for production risk. A combined network of regional and local weather monitoring stations can help provide the necessary data to inform a greater range of decisions. This information can further help to better identify risks and opportunities and serve as a basis for adaptation planning.

There have been advancements in agricultural weather monitoring in BC. Agricultural organizations have established monitoring initiatives to track conditions that are relevant to crop production. These networks are described below.

AGRICULTURAL MONITORING IN BC

FARMWEST

[Farmwest](#) was established in 2001 to provide weather and irrigation information and tools for BC farmers. The program is administered by the Pacific Field Corn Association (PFCA) with operational and financial support from the BC Ministry of Agriculture, Food and Fisheries (AFF), and Agriculture and Agri-Food Canada (AAFC). Despite 20 years in operation, funding for Farmwest has never been permanent nor guaranteed. The current federal and provincial support under the Canadian Agricultural Partnership (CAP) funding program expires in February 2023.

The network operates on a modest annual budget of \$50,000. This amount covers station maintenance and upkeep, data transmission costs, and website operation. Any remaining funds are allocated to network expansion, which normally involves adding one or two new stations per year. Farmwest has no dedicated personnel.

The Farmwest monitoring network consists of approximately 25 weather stations distributed across BC. Weather information from ECCC and the provincial monitoring networks are also incorporated into the dataset, encompassing over 150 stations in BC and over 300 across Canada. Minimal quality control (QC) is performed on the station data, making the information vulnerable to occasional data errors and gaps. This issue has been identified by



Figure 3: Farmwest weather station (Grand Forks)

users of the information. When a station goes offline and data are missing, measurements from a nearby station will be used as a temporary substitute while effort is made to retrieve the primary station's data from the source.

Farmwest stations have had some issues with continuity. For example, in spring of 2016, as part of an initiative to demonstrate innovative forage production practices and adaptation to climate change, the BC Forage Council (BCFC) had four new Farmwest weather stations installed in the Vanderhoof region. After the completion of the project, the ongoing data transmission costs were not funded, resulting in these stations being offline for the past three years. Despite this setback, forage growers recognize that more weather stations are needed in the Central Interior to reflect the different growing conditions from site to site and to help identify new and adaptive management practices.

The weather stations that are operated by Farmwest are Davis Instruments VantagePro2, mainly using cellular connections provided by ROM Communications (Figure 3). The stations record hourly measurements that get transmitted once per day. This update frequency, while adequate for most daily models, is not sufficient for operational applications that may require current temperatures, rainfall, or wind speeds. This limits the usefulness of the information for many on-farm decisions. Transmitting data at least hourly would increase the cost of the program but is a worthwhile improvement and a minimum standard for most monitoring networks.

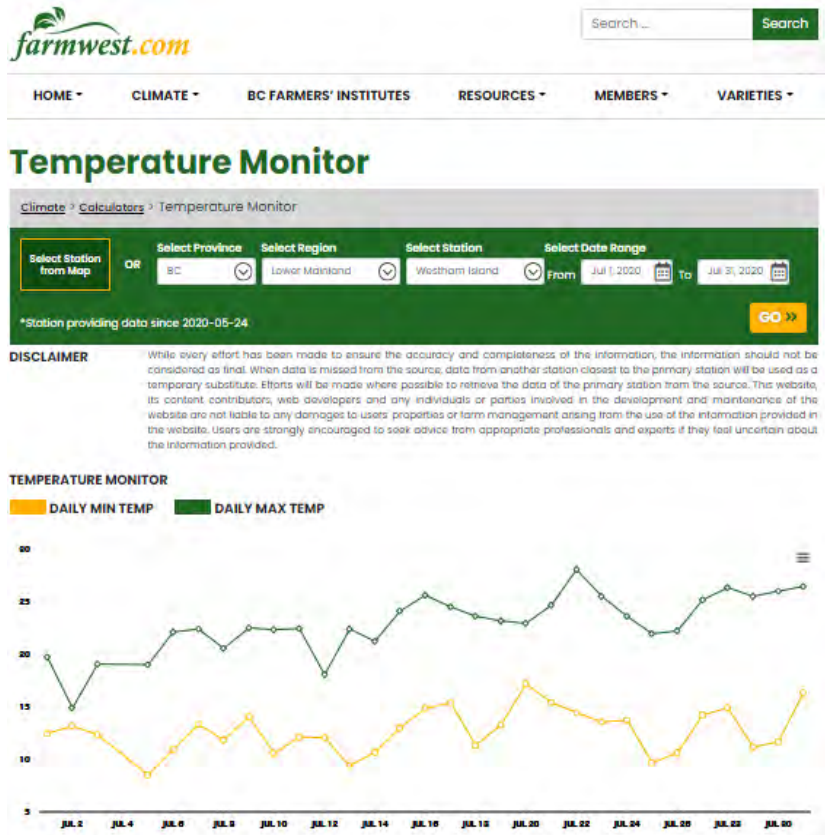


Figure 4: Farmwest website showing daily temperature

BC PEACE AGRI WEATHER NETWORK

The [BC Peace Agri Weather Network](#) was initiated in 2014 following the completion of adaptation planning with Peace producers, led by Climate & Agriculture Initiative BC CAI). Increasing producer access to weather data was identified as a priority. Baseline weather data was also identified as necessary for improving monitoring and forecasts for pests and diseases.

Since a 2014 assessment of weather data needs, the network has expanded to include 21 weather stations and a regional weather network platform for producers has been developed. The program has been consistently supported by producer organizations, as well as through CAI's Regional Adaptation Program. Funding contributions have been provided by the BC Grain Producers Association, the Canada Seed Growers Association, the Peace Region Forage Seed Association, and the Peace River Regional District.

The stations are all Davis Instruments Vantage Pro2 communicating through cellular or internet and reporting through the Davis WeatherLink portal. The raw data is retrieved via the application programming interface (API) to a database that is managed by a third-party website provider. Derivatives like heat units, fusarium head blight risk, and wheat midge emergence are calculated. All data and tools are freely available to users. The raw weather data undergoes only a basic level of quality control (QC).

Over the past year, the BC Peace Agri Weather Network has undergone improvements based on user input and priorities. Improvements include upgrades to the data retrieval and handling process, incorporation of climate normals, and enhancements to the website user-experience. Originally, the forecast that was provided was regional and based on large ECCC forecast regions. Producers were seeking more localized information, so the forecast is now grid-based where predicted conditions are specific to each weather station's actual location. Additional proposed improvements for 2021 include automated weather reports, crop staging models, and enhancements to the QC process.



Figure 5: BC Peace Agri Weather Network Station (Kelly Lake)

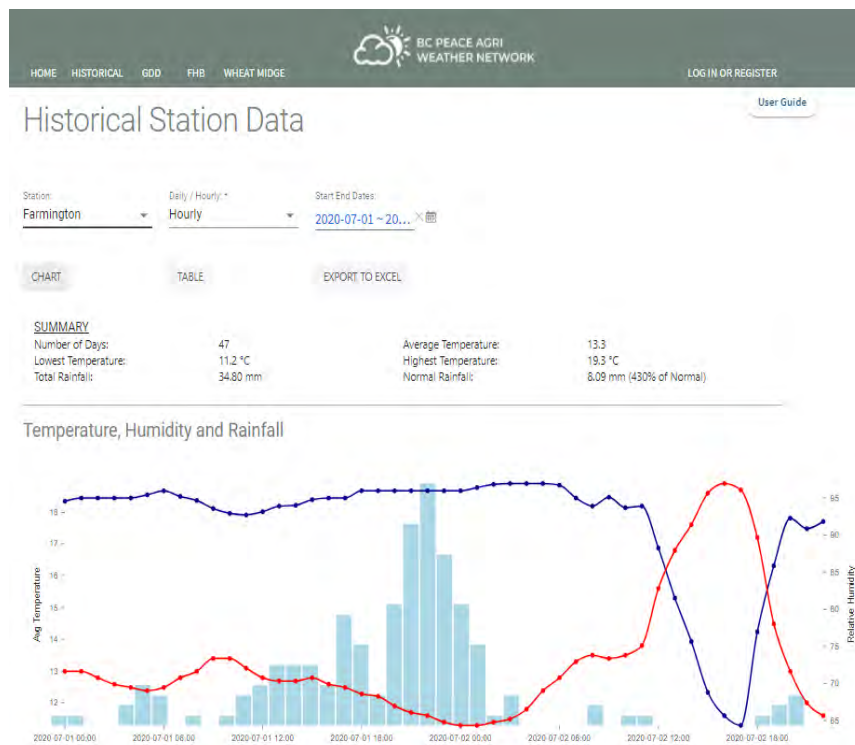


Figure 6: BC Peace Agri Weather Network Website showing historical station data

OKANAGAN VALLEY NETWORK

Between 2002 and 2004, the Okanagan weather network was established by Growers Supply, a local retailer. Funding was provided through the British Columbia Agriculture Council under the federal-provincial funding program Agriculture Environmental Partnership Initiative (AEPI). The network of 20 weather stations located throughout the Okanagan Valley were established to provide pest management support for the tree fruit industry.

During the development of the [Okanagan's Regional Adaptation plan](#) (2015-2016), improving decision support tools was identified as a priority. In 2016-2018, the Sterile Insect Release Program (SIR) partnered with researchers and industry groups to adapt Washington State University's (WSU) Decision Aid System (DAS) for the BC Okanagan tree fruit industry. DAS is an Integrated Pest Management (IPM) decision support platform that provides critical insect and disease models throughout the growing season. The tool's development for BC was co-funded by SIR and through CAI's Regional Adaptation Program. SIR continues to administer the BC DAS throughout the Okanagan-Similkameen.

The system relies heavily on the Okanagan weather stations. The stations themselves are manufactured by ADCON Telemetry. These stations are well suited to a network like the Okanagan's as they are quite robust and mainly communicate through UHF radio. Stations within the network send data wirelessly to a central gateway either directly or by linking through other stations that can act as relays. Cellular options are also available.

The Okanagan network faces challenges with its long-term operation and maintenance. Despite replacement of certain components over the years, the stations are old. This raises concerns about their reliability, data accuracy, cost to maintain, and the overall longevity of the network. The ADCON equipment also costs two to four times more than some of the viable alternatives that are now available. The renewal of this network needs to be addressed, including a strategy to modernize the network and ensure that it meets the needs of its stakeholders. Such an assessment will also need to address network operation and ownership, whether this remains with Growers Supply (part of BC Tree Fruits Cooperative) or otherwise. Any such strategy should align closely with the overall provincial goal of improving agricultural weather monitoring for producers.

OTHER WEATHER STATIONS

When it comes to improving agricultural weather monitoring, one of the most important untapped resources are the weather stations and networks that have been setup by universities, industry organizations, research groups, local governments, cooperatives, processors/distributors, and individual farms. These stations were acquired and established to meet specific requirements for improved weather monitoring - perhaps to cover areas with inadequate representation or to collect parameters that were not available from existing sources.

There are many producer-owned monitoring stations across BC's agricultural areas, including hundreds of Davis Instruments personal weather stations that report data to the Davis [WeatherLink](#) portal. According to the Current Weather Conditions maps within the portal, over 20 stations are reporting in the Vanderhoof and Prince George areas and over 30 stations are reporting within the Okanagan-Similkameen (Figure 7).

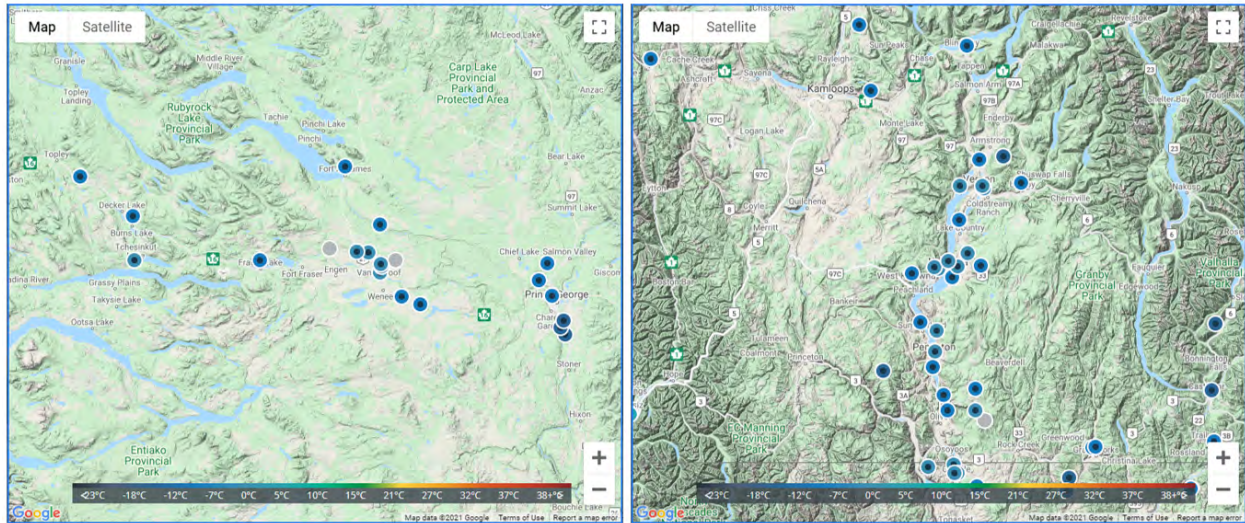


Figure 7: Davis WeatherLink stations in the Vanderhoof/Prince George areas (left) and the Okanagan-Similkameen (right)



In many cases, the information that is collected from local weather stations may be shared with certain organizations or researchers but is seldom accessible to the larger community. This may not be due to unwillingness on the part of the station owner, but because there is no clearly available option (formal platform) for sharing the station data. For example, at least 150 weather stations have been established on vineyards throughout the Okanagan-Similkameen. Information from these stations is mainly used by vineyard operators for site-specific management. Several AAFC researchers have operational weather stations in the Fraser Valley and the Okanagan to support their research activities. A group of key agricultural stakeholders in the Nechako Valley have been taking inventory of private and research-related weather stations in their region to work towards some coordination.

Figure 8: Vineyard weather station in the Okanagan-Similkameen

COMMUNITY BASED MONITORING

Community based monitoring (CBM) programs have grown in popularity as more citizens have taken a formative role in collecting and sharing various types of environmental observations. Commonly employed in the monitoring of water resources, this concept engages communities in filling information gaps from the diminished capacity of governments to monitor watersheds⁵. The collected information is used by agencies and researchers to inform better decisions while also encouraging environmental education and stewardship among citizens.

The CBM approach also occurs in the collection and distribution of weather information with countless enthusiasts monitoring and recording temperature, rainfall, and other parameters. For example, the previously noted Davis [WeatherLink](#) platform (Figure 7) allows the public to automatically upload data from their weather station so that the

information can be freely available to other users. They may also opt to share their data with other groups like the Citizen Weather Observing Program (CWOP).

Another example of CBM of weather is the University of Victoria's [School Based Weather Station Network](#). This project began in 2005 as an initiative to raise the profile of meteorology, physics, and science in the school curriculum. In cooperation with school divisions and individual schools, the group has installed and operates nearly 160 weather stations across Vancouver Island. The information is being incorporated into classroom projects and lessons and the aggregated network data can be used as a resource for local weather (Figure 9).

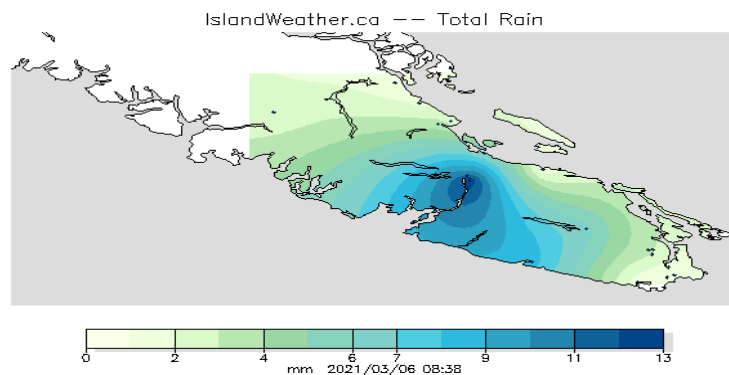


Figure 9: School Based Weather Station Network plot of total rainfall

The [Community Collaborative Rain, Hail & Snow](#) (CoCoRaHS) Network is a community-based volunteer network of weather observers that measure and submit precipitation information. The initiative originated with the Climate Center at Colorado State University in 1998 to gather better localized precipitation information for natural resource, education, and research applications. Program volunteers manually measure rain, hail, and snow and submit these records through an online portal. Measurement is done using basic instruments like a manual rain gauge and a ruler to measure snow depth. Today there are 20,000 active observers, with a large number throughout Canada and a few in BC.

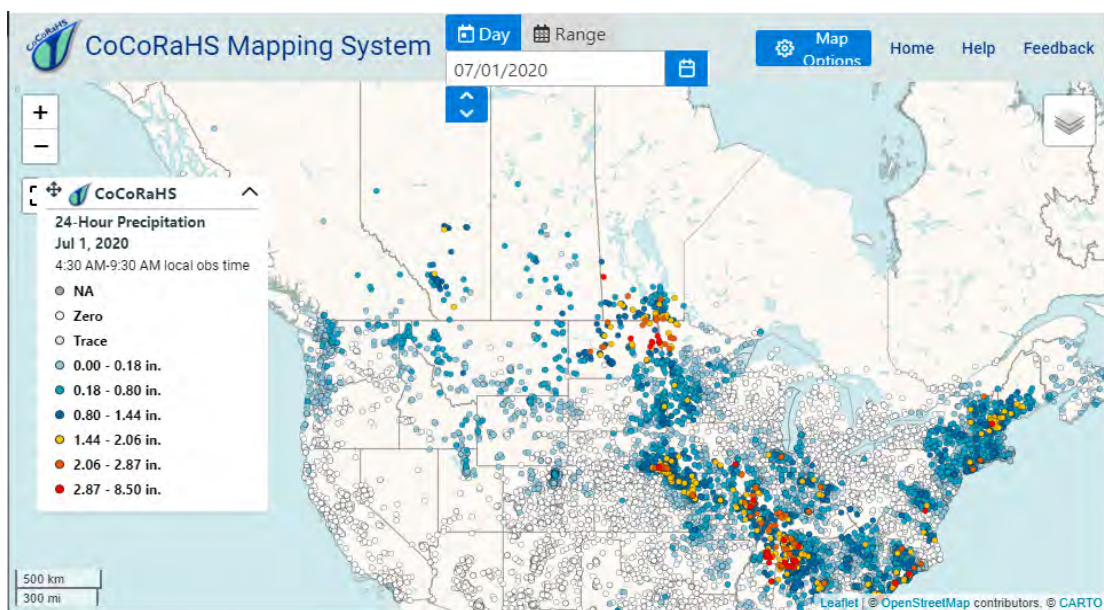


Figure 10: Community Collaborative Rain, Hail & Snow (CoCoRaHS) observations



Despite the tremendous efficiencies in monitoring that can result from CBM, a larger number of individual contributors introduces more variability in observing methods. This can be from station siting to how certain observations are interpreted. For this reason, education and training on monitoring protocols are essential. The School Based Weather Station Network provides training material and close guidance on how stations are installed and operated to standardize the measurements. Because CoCoRaHS relies heavily on human observations, the program stresses the importance of training and education for volunteers. Any network that is not operated and maintained by a single entity needs to ensure that rigorous protocols are in place and that participants are trained so that all measurements are acquired in as consistent a manner as possible.

The WeatherLink Network, the School Based Weather Station Network, and CoCoRaHS are presented as examples of collaborative CBM initiatives that encourage public participation in the collection of weather data. These networks demonstrate that with central coordination and engagement, groups and individuals are quite willing to participate. If the users can receive further benefits from their contributed data, such as maps, summaries, and value-added information, these types of initiatives can garner even greater use.

For agricultural weather, there are clear benefits to CBM, including better localized information that can fill some of the gaps in coverage. The CBM approach can leverage the numerous agricultural stakeholders who are eager to participate, support, and promote such an initiative. As CBM programs expand in other sectors, this concept can also play a key role in fulfilling the agricultural weather monitoring needs in BC.

AGRICULTURAL WEATHER NETWORKS OUTSIDE OF BC

Some of the other provinces have invested substantially in their agricultural weather monitoring networks. Alberta Agriculture and Forestry operates over 150 climate stations to address gaps in agricultural areas. Across Alberta, there are over 350 stations that report to the Alberta Climate Information System (ACIS). In Saskatchewan, the provincial crown corporation, Saskatchewan Crop Insurance Corporation (SCIC) contracts a private company to operate 150 weather stations specifically for their parametric insurance products. These data are not made publicly available. Manitoba Agriculture operates 109 agricultural weather stations that were established in the early 2000's through the federal-provincial Growing Forward agreement. This network continues to provide high-quality data to agricultural and non-agricultural users alike.

Washington State has an agricultural weather monitoring network with some features worthy of note in British Columbia. Operated out of WSU, the AgWeatherNet (AWN) program uses measurements from different types of equipment that are owned by AWN or by third parties. To manage these different data types, AWN employs a tiered system that indicates the type of station and station operator. A tier 0 station is one that is owned and operated by the federal government. These are considered the core climate stations for the region. A Tier 1 station is a core AWN-owned station with a full suite of professional-grade sensors. The cost of a Tier 1 station is approximately \$10,000 USD and an additional \$1,500 USD per year to maintain.

Tier 2 stations are also owned and operated by AWN, but the station consists of a more economical all-in-one sensor. A Tier 3 station uses the same hardware as a Tier 2 but has been purchased and is maintained by a third party. Tier 2 and Tier 3 stations start at \$2,500 USD and cost much less than Tier 1 stations to maintain. For example, a replacement temperature/relative humidity sensor on a Tier 1 station is approximately \$900 USD. A replacement humidity sensor for the Tier 2/3 all-in-one sensor is approximately \$40 USD. The coordinators of AWN have begun to realize the benefits of Tier 2/3 station hardware and have been moving towards the more affordable all-in-one sensors in favour of the more complex and costly Tier 1 stations.

Owners of Tier 3 stations must agree to operate and maintain their stations to a certain standard, including cleaning and replacement or calibration of sensors at set intervals. They must also agree that this data is accessible to all AWN users. In return, contributors can access their weather information and the associated tools that are available on the [AWN](#) and the [AWNfarm](#) websites and app. All AWN users have access to information about each station, including the Tier level and pictures of the actual station. Currently, AWN consists of 317 weather stations throughout Washington, Oregon, and Idaho. 87 of these stations are Tier 0, 128 are Tier 1, 57 are Tier 2, and 45 are Tier 3.

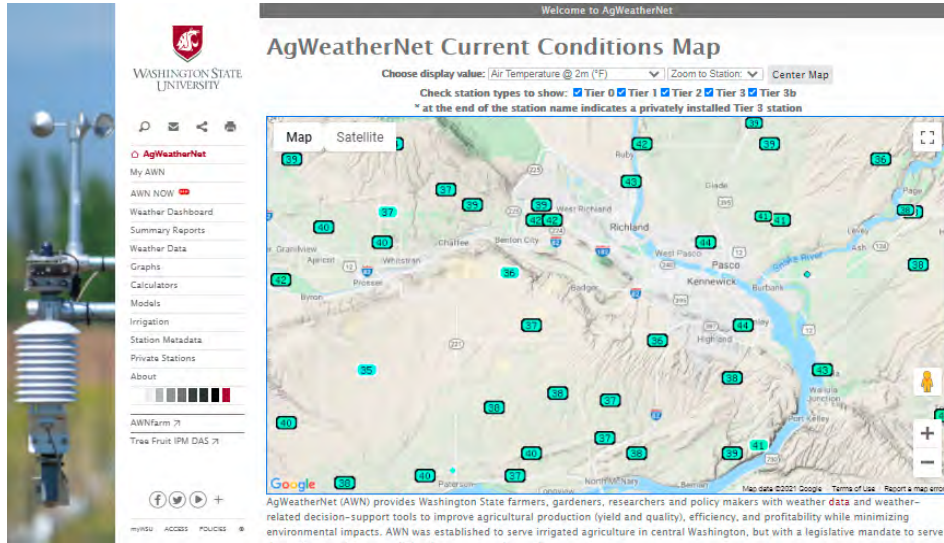


Figure 11: Washington State University's AgWeatherNet program. Users can specify the Tier of weather stations that they access

The tiered approach is a model that would suit agriculture in British Columbia as it would leverage the existing networks and empower local groups or individual farmers to establish their own monitoring stations without having to build or pay for their own data management platform.

A COORDINATED APPROACH

British Columbia has made great progress towards coordinating organizations that collect weather information through the formalized CRMP. A large gap to date has been province-wide coordination within the agricultural sector. For this reason, agricultural groups and producers have taken it upon themselves to independently establish and maintain their own weather stations. These groups have had to find resources, put in a great deal of effort, and build their programs from the ground up.

In the context of amalgamating disparate weather data sources, the term “network of networks” (NoN) is an appropriate concept. It describes the exchange of meteorological data between data providers, which can only be effectively done by using certain standards and protocols. At the national scale, ECCC has been actively promoting the NoN concept since 2010. ECCC recognizes that their station network cannot adequately meet all monitoring requirements and acknowledges the value of weather observations that are collected by the many other organizations. These networks provide supplementary data and fill gaps in the existing coverage. At present, ECCC has begun to incorporate various networks into their data stream. Many CRMP members both contribute and make use of climate data that is accessible through the MSC.

Within agriculture, a goal should be to integrate some of the disparate monitoring systems and to work with entities that require weather information. A coordinated approach that includes existing networks and encompasses CBM in a tiered approach would greatly improve coverage across agricultural areas while ensuring the data is available to stakeholders. Centralized coordination could provide resources to facilitate sharing of information and data amongst these groups and to the greater agricultural community. Data sharing would take place on a data management platform on which measurements get standardized and quality assured, complete with thorough metadata.

Linking BC's agriculturally relevant stations and networks would form a provincial-scale agricultural monitoring network of networks. This would be the most efficient use of resources. Support that is offered at a provincial level would benefit existing and newly established local networks and facilitate integration of data, improve the quality of data, and result in overall cost savings. This would provide enhanced coverage of agricultural land and help to leverage resources that can be shared between providers.

BASELINE GAP ANALYSIS

One of the key objectives of this report is to provide a gap analysis that identifies agricultural areas within the province that lack adequate baseline weather monitoring. What is deemed adequate weather monitoring is highly variable depending on how the information will be used. A certain density of monitoring stations will be adequate for some applications, but of little or no benefit for others. For example, calculating regional drought indices may require just one representative weather station for a production area that encompasses hundreds or even thousands of hectares of farmland. In contrast, frost protection for an orchard or vineyard requires data drawn from the specific crop location. Given the value of certain crops, the level of management required, the cost of inputs, and the cost of potential losses, certain production types would be ill-advised to use regional or even local stations that do not accurately represent their actual in-field conditions.

This analysis is based on the premise that a minimum standard of monitoring is needed across all agricultural areas of the province to provide a baseline indicator of regional conditions. Once this baseline is achieved, additional stations will bring incremental benefits at a sub-regional scale. The tiered community-based monitoring (CBM) approach as discussed above (A Coordinated Approach) could facilitate both baseline monitoring station and supplemental stations that can be used for more intensive/higher value cropping areas. All these stations would provide value to both individual producers and to the overall monitoring network.

PREVIOUS WORK

This initiative follows previous work, *Gap Analysis and Overview of Weather Station Data in British Columbia Agricultural Regions*⁶, a study authored by BC Ministry of Agriculture and Pacific Climate Impacts Consortium (PCIC), coordinated by the British Columbia Agricultural Climate Adaptation Research Network (ACARN). The objective of this work was to provide an analysis of weather station data usage and spatial distribution of existing weather stations across BC.

The methodology consisted of a quantitative analysis of the station locations and their recorded variables. Network sufficiency was assessed by investigating relationships of temperature and precipitation between locations using objective network analysis. The study presents distance statistics between monitoring stations by region, including median and maximum distances to the nearest and second nearest stations.

The distance statistics show the North region having the greatest maximum distance between weather stations. The median distances between weather stations were also quite high in the North, with similar values in the Central Coast. The densest networks in terms of distances between stations were found in the Lower Mainland, in the North Okanagan, and on Vancouver Island. The authors point out that areas with low median values should not be interpreted as having complete coverage as clustering of stations near populated areas tends to skew the results. All agricultural regions were found to have some areas with high concentrations of stations while other areas remain sparse.

The study also assessed the radius of representativeness for monthly and seasonal average precipitation and daily maximum and minimum temperatures of actively reporting stations. The radii were based on the distances within which the precipitation was within 30% and temperature correlation was within 0.5°C and 1.0°C of the nearby station's value. A larger radius indicates a greater area of adequate coverage from a single station – less spatial variability. A smaller value indicates a smaller area of coverage due to greater spatial variability.

The results show the corresponding radii to be extremely variable. For example, for daily maximum temperature, an accuracy threshold of 1.0°C ranges from as little as 20 km for some locations in January to over 2000 km at other locations, generally in October. At a threshold of 0.5°C, radii range from 0 km to slightly over 100 km. Overall, radii of representation were largest for spring and smallest for winter. During the winter months, the radii were smaller in the north compared to southern regions. Despite some larger gaps in the northern regions, the report concludes that for monthly temperature and precipitation, the observational coverage is sufficient in agricultural regions. However,

the authors point out that for observational periods of less than one month, such as daily or hourly, there are likely to be substantial gaps that should be addressed. A triage system to incrementally address such gaps is recommended.

In 2020, a project was undertaken through CAI's Regional Adaptation Program to address producer priorities identified in the [Kootenay & Boundary Regional Adaptation plan](#). This project included a gap analysis that produced a ranked list of agricultural areas without sufficient weather monitoring. The analysis revealed that 99% of the farmland in the entire region could be adequately covered with 13 new weather stations. Each proposed station location was ranked in order of additional farmland that would be represented by new stations. Localized monitoring was also recommended for the Creston Valley to address the on-farm needs of the tree fruit industry.

The current project leverages some of the results of the 2018 gap analysis and expands on the methods used in the Kootenay & Boundary study to provide a province-wide triage to enhance baseline agricultural weather monitoring.

METHODS

It would not be feasible to add enough weather stations to achieve the optimum station density to account for all the necessary measurement parameters, user requirements, times of year, and spatial variability in agricultural areas. Instead, a triaging system allows ranking of areas from most-in-need to less-in-need of improved monitoring. Adding stations to the areas that rank high on the priority list will provide the largest increase in landscape coverage. This strategy can be used to address the issue of resource scarcity. If resources are only available for a limited number of stations, those stations can be allocated to areas that will provide the most incremental benefit. As more resources become available, additional stations can be added, using the determined order of priority as a guide.

The first step to evaluate the extent of weather monitoring was to classify all agricultural land in the province by its distance from an operational, suitable, and representative weather station. A full inventory of official weather stations in BC was acquired from the [Provincial Climate Data Set](#) (PCDS), a database that is maintained by the CRMP and made available through the public data portal that is hosted by PCIC. This dataset does not include independently operated stations that are not a part of the CRMP.

Of the over 7,000 stations in BC, just over 1,200 were labelled as having an "active" designation – meaning that approximately 5,800 stations or 83% of the total inventory have been phased out, were non-permanent, or have at some point become non-operational for some reason. Of the operational stations, suitability was further determined based on the parameters measured at each weather station. The primary purpose of some stations is for specific applications such as hydrometric monitoring, avalanche assessment, or marine conditions from moored buoys. Stations included are terrestrial, monitor at least temperature and rainfall, are automated, and collect and archive measurements at least hourly. While manual stations are still extremely valuable to the climate record, they are not conducive to any sort of near-real-time applications. Stations not equipped to monitor temperature and rainfall and manual stations were filtered out.

Representativeness of each weather station was further evaluated based on station elevation as it relates to its surroundings. Where nearby farmland had elevation that was quite different from that of the nearest weather station - a difference greater than 100 metres, that parcel of land was considered to not be adequately represented by that station.

This process of elimination left 886 active weather stations. Though, not all these stations were necessarily located nearby to any agricultural land. Table 1 shows a breakdown of all active stations by network operator and parameter.

Table 1: Active BC weather stations by operator and percent of stations with each measurement parameter

Network Operator	Total Active Stations	Air Temperature	Relative Humidity	Liquid Precipitation	All-Weather Precipitation	wind Speed/Dir.	Solar Radiation	Barometric Pressure
ECCC	339	●	◐	●	●	◐	○	◐
Foresry	352	●	●	●	●	●	◐	○
Environment	117	●	◐	◐	●	◐	○	○
Agriculture	26	●	●	●	●	●	○	○
Peace River	21	●	●	●	○	●	○	○
Transportation	156	●	●	◐	●	◐	○	○
MVRD	44	●	◐	◐	●	◐	○	○
CRD	11	●	●	●	●	●	◐	○
BC HYDRO	132	●	◐	●	◐	○	○	○
Rio Tinto	6	●	○	◐	◐	○	○	○
Growers Supply	20	●	●	●	○	○	○	○
Total	1224	1179	821	1044	953	771	105	231

● ≥80%
◐ ≥ 60%
◑ ≥ 40%
◒ ≥ 20%
○ <20%

Agricultural land use was identified using the Baseline Thematic Mapping – Present Land Use Mapping Version 1 (BTM 1) spatial layer, published by the Ministry of Forests, Lands, Natural Resources Operations and Rural Development (FLNRORD). This dataset was originally derived mainly from Landsat 5 satellite images, considered accurate to approximately 250 m. This dataset was compiled in the late 1990’s and does not reflect certain land-use changes that have occurred since that time. The bulk of these changes would likely have taken place in the more populated areas that are generally well represented by weather stations. While this dataset would not be suitable for local small-scale analyses, the layer was deemed appropriate and well suited to a provincial scale analysis. For actual station placement, local surveys and feedback would be necessary.

From the BTM 1, the land use categories that were considered include “Agriculture”, described as “Land based agricultural activities undifferentiated as to crop”, “Rangelands” - “Unimproved pasture and grasslands based on cover rather than use.”, and “Residential Agriculture Mixtures” - “Areas where agriculture activities are intermixed with residential and other buildings with a density of between 2 to 0.2 hectare”. In general, “Agriculture” would refer to field crops while “Rangelands” would refer to pastures and grasslands that are mainly grazed by livestock.

For this analysis, the land use categories are treated equally. One production type is not weighted more heavily or considered more important than another, despite differences in required management, input costs, and the value of the crops that are produced. This analysis is intended to represent agriculture on a provincial scale, identifying gaps that exist throughout all production areas. Current land use may not reflect potential or future production capacity. As climate patterns shift or as new crops and varieties are introduced, types of production that may have never been feasible in certain areas may become feasible and profitable. The most effective way to determine such opportunities and the limitations of a location is to have good quality and representative climate data.

Using a geographic information system (GIS), all farmlands have been classified based on their distance from the nearest suitable weather station. The category thresholds include land that is greater than 30 km from a station, land between 25 to 30 km, 20 to 25 km, 15 to 20 km, and 10 to 15 km. Agricultural land that is within 10 km of a weather station is considered to have adequate representation. As noted previously, there are high-value crops that may require site-specific monitoring, but this approach satisfies regional baseline monitoring criteria. Within a spatial scale of 10 km, climate patterns tend to be most influenced by factors such as terrain and water bodies, primarily through the direct effects of elevation, cold air drainage, inversions, and coastal effects. Such factors were found to be less important at larger scales⁷.

To provide an overall weighting of areas with higher concentrations of less-represented agricultural land, a series of Kernel Density Estimations (KDE) were performed. The agricultural parcels that were classified within the various distances from weather stations were weighted based on the number of hectares. This method provides a computation

and a visual representation of the concentration of under-represented hectares across the province through a series of density or heat maps (Figure 12). Areas with higher concentrations of under-represented land were quantitatively filtered and then ranked.

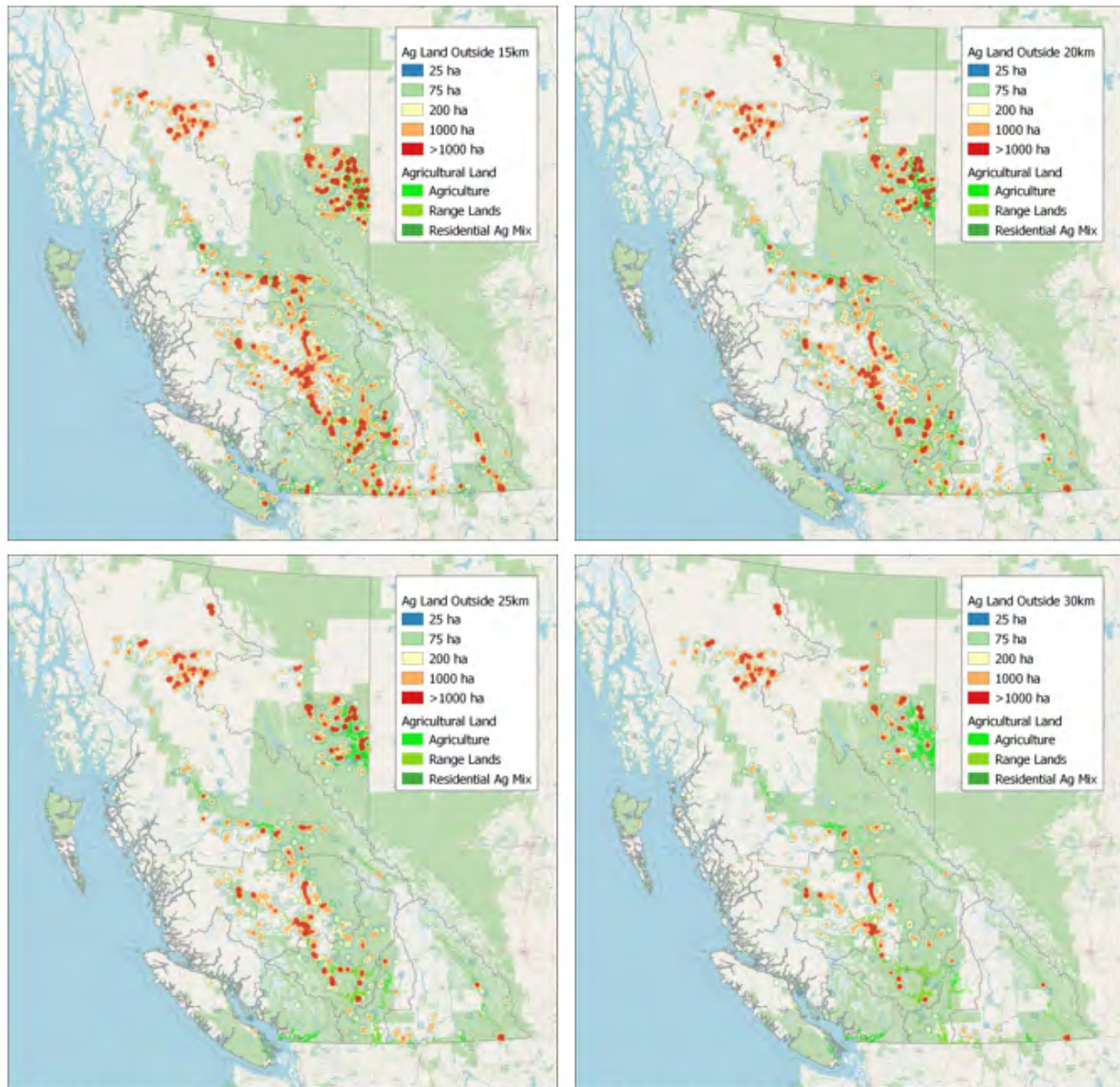


Figure 12: Heat maps showing areas of under-represented farmland

The regions identified as having the densest clusters of under-represented parcels were grouped into areas of somewhat continuous farmland. Each of these areas represent a candidate location for a new weather station. If a new station were placed somewhat centrally within an identified area, the associated increase in coverage of agricultural land can be calculated. This increase in coverage forms the basis for the ranking system. High concentrations of farmland that were the furthest from weather stations - particularly those beyond 30 km, ranked highest. Determining if a new weather station is worthwhile in an area can be based on how much new coverage could be achieved. At a certain point, the added coverage and associated benefits from additional weather stations will be minimal and perhaps not worth the investment.

RESULTS

Based on the distance of agricultural land from the nearest applicable weather station, a total of 1,200,000 ha of farmland were found to not have a weather station within 15 km. Of that amount, 826,000 ha did not have a weather station within 20 km. 350,000 ha did not have a station within 30 km.

Across the agricultural regions of the province, the quantity and type of under-represented farmland varies considerably. Areas with higher population and more concentrated agricultural production naturally tend to have more weather stations, thus better coverage. Areas that are sparsely populated with large expanses of farmland, particularly broadacre crops or rangeland, had the greatest amount of under-represented area. Omenica Skeena region has the highest percentage of land in the province that is further than 30 km from a weather station (40%) followed by Cariboo Chilcotin Coast and the Peace regions with 25% and 24%, respectively (Figure 13). These three regions make up 90% of the provincial total of farmland underrepresented by weather monitoring - over 300,000 ha.

Of the farmland further than 15 km from a weather station, the Peace region has the most, representing 31% or slightly more than 360,000 ha. This is somewhat expected as the agricultural weather monitoring network established in the Peace has effectively filled many of the larger gaps, while still leaving some local areas with less representation. The Thompson Nicola, Omenica Skeena, and Cariboo Chilcotin Coast make up the next largest areas with 20%, 20%, and 17% of the provincial total, respectively. Together, these four regions make up 88% or just over 1,000,000 ha.

More than 30 km from a station



More than 15 km from a station

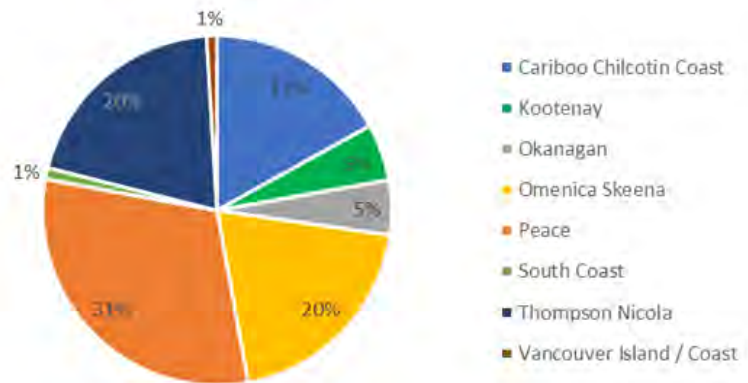


Figure 13: Percent of under-represented farmland broken down by region

Between the regions, the areas of under-represented farmland vary considerably by land-use (Figure 14). Within the Thompson Nicola, rangeland is the most dominant at 84% of the under-represented farmland. The Cariboo Chilcotin Coast, Kootenay, Okanagan, and Omenica Skeena are more evenly split between rangeland and other agricultural uses. Within the Peace, South Coast, and Vancouver Island/Coast, most of the land is designated as Agriculture. Vancouver Island/Coast has the greatest percentage of Residential Agriculture Mix with 23%, followed by South Coast and Kootenay with 9% and 8%, respectively. These values are somewhat reflective of the overall distribution of farmland within these regions.

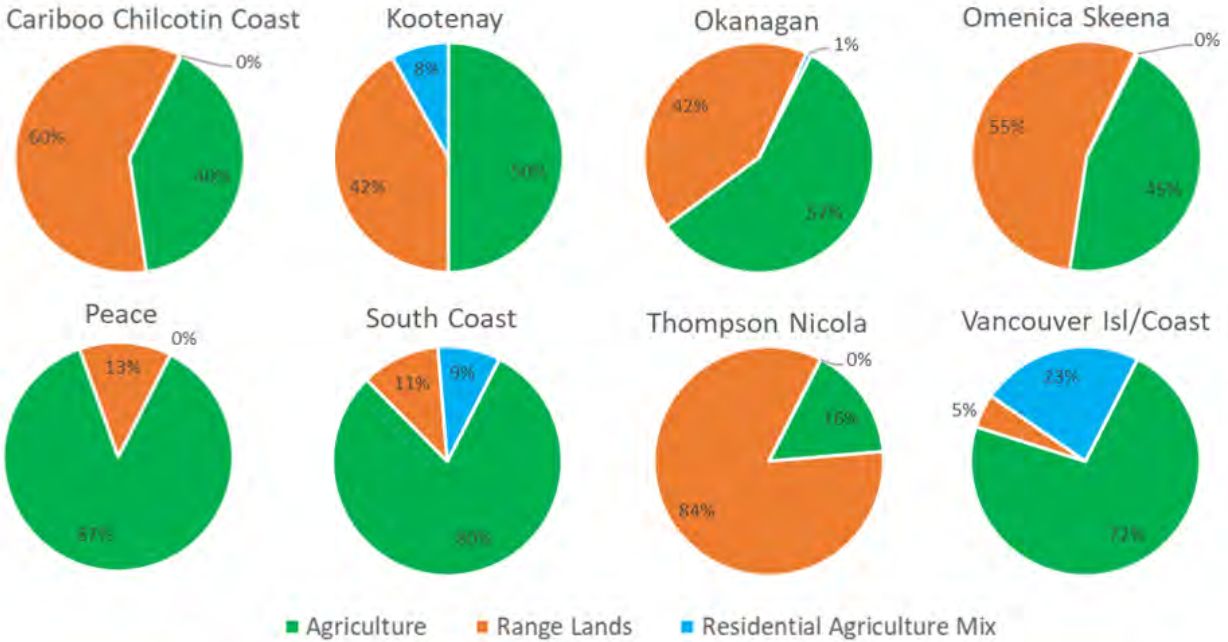


Figure 14: Agricultural land beyond 15 km from a weather station, broken down by agricultural region and by land-use classification

Based on the groupings of mainly continuous agricultural land, a total of 92 areas of farmland with inadequate or marginal coverage from weather stations were identified province wide. The hectares of agricultural land within each area, primarily those furthest from a weather station, serve as the basis for ranking. Locations with the largest areas of farmland that are furthest from existing weather stations are ranked highest. This provides an indication of the incremental increase in coverage that would be achieved by adding each new station. The ranking is based purely on the objective of reducing the amount of agricultural land that has little or no coverage. The provincial map in Figure 15 shows the locations and ranking of these areas. Maps of each region are shown in Appendix A – Regional Maps of Sparse Coverage. Table 2 lists the areas in ranked order along with their associated agricultural regions.

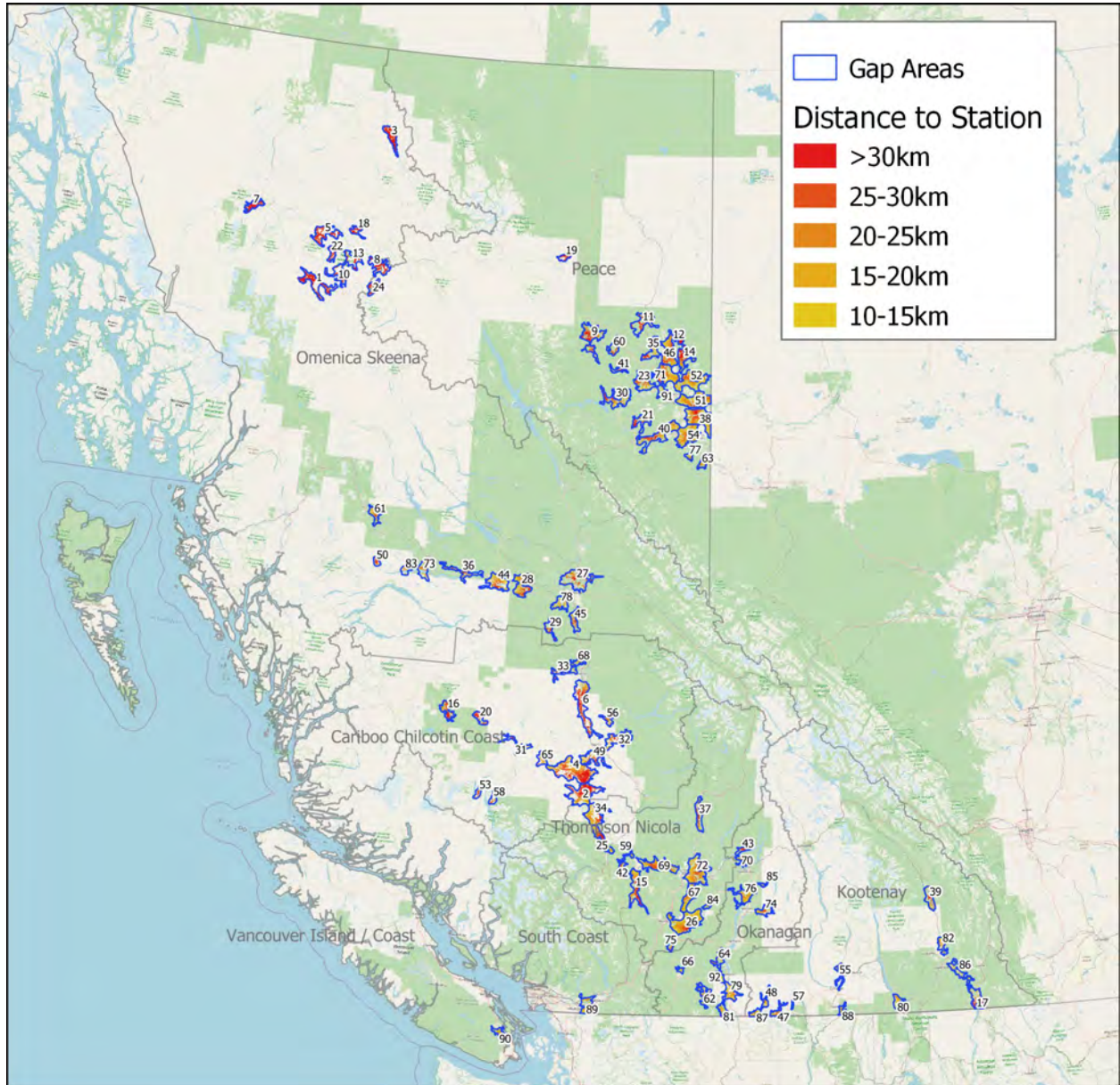


Figure 15: Areas identified as monitoring gaps, including their relative ranking

Table 2: Ranked list of underrepresented areas along with their region(s)

Rank	location	REGION	Rank	location	REGION
1	Spatsizi/Skeena Rivers	Omenica Skeena	47	Greenwood-Midway	Kootenay
2	Canoe Creek	Cariboo Chilcotin/Thompson Nicola	48	Kettle River	Kootenay
3	Kechika River	Omenica Skeena	49	Williams Lake South	Cariboo Chilcotin Coast
4	Junction Sheep Range Park	Cariboo Chilcotin Coast	50	Owen Lake	Omenica Skeena
5	Cold Fish Lake	Omenica Skeena	51	Fort St. John East	Peace
6	Alexandria/Soda Creek	Cariboo Chilcotin Coast	52	Cecil Lake North	Peace
7	Konthil Creek	Omenica Skeena	53	Potato Range	Cariboo Chilcotin Coast
8	Tuff Creek	Peace/Omenica Skeena	54	Dawson Creek West	Peace
9	Halfway River	Peace	55	Crescent Valley	Kootenay
10	Happy Creek	Omenica Skeena	56	Big Lake	Cariboo Chilcotin Coast
11	Nig	Peace	57	Granby River	Kootenay
12	Altona	Peace	58	Nemaiah Valley	Cariboo Chilcotin Coast
13	Cassiar Land District	Omenica Skeena	59	Pavilion-Clinton-Cariboo	Thompson Nicola
14	Milligan Creek Road	Peace	60	Gundy Creek	Peace
15	Trans-Canada/Thompson	Thompson Nicola	61	Bulkley River	Omenica Skeena
16	Lilie lake	Cariboo Chilcotin Coast	62	Hedley	Okanagan
17	Lake Koocanusa	Kootenay	63	Peavine Lake	Peace
18	Pitman River	Omenica Skeena	64	Trout Creek	Okanagan
19	Prophet River	Peace	65	Tl'Etinqox	Cariboo Chilcotin Coast
20	Alexis Creek	Cariboo Chilcotin Coast	66	Princeton-Summerland Hwy	Okanagan
21	Bond	Peace	67	Stump Lake	Thompson Nicola
22	Mount Skady	Omenica Skeena	68	Moose Heights	Cariboo Chilcotin Coast
23	North Cache Creek (Peace)	Peace	69	North Thompson River	Thompson Nicola
24	Brothers Lake	Peace/Omenica Skeena	70	Tappen	Okanagan
25	Edge Hills Park	Thompson Nicola	71	Montney-Murdale	Peace
26	Sugarloaf to Douglas Lake	Thompson Nicola	72	Kamloops East	Thompson Nicola
27	Salmon Valley	Omenica Skeena	73	Francois Lake Ferry	Omenica Skeena
28	Vanderhoof East	Omenica Skeena	74	Lumby	Okanagan
29	Punchaw	Omenica Skeena	75	Merritt-Princeton Hwy	Thompson Nicola
30	Beryl Prairie	Peace	76	Armstrong	Okanagan
31	Chilko/Chilcotin Rivers	Cariboo Chilcotin Coast	77	Upper Cutback	Peace
32	Ochiltree	Cariboo Chilcotin Coast	78	Mud River/Beaverley	Omenica Skeena
33	Baker Creek	Cariboo Chilcotin Coast	79	Okanagan Falls	Okanagan
34	Churn Creek	Thompson Nicola	80	Wynndel	Kootenay
35	Buick	Peace	81	Similkameen River South	Okanagan
36	Fraser Lake	Omenica Skeena	82	Wasa	Kootenay
37	Little Fort	Thompson Nicola	83	Francois Lake West	Omenica Skeena
38	Kiskatinaw River	Peace	84	Salmon Lake	Thompson Nicola
39	Fairmont Hot Springs	Kootenay	85	Shuswap River	Okanagan
40	Pine River	Peace	86	Wardner-Jaffray	Kootenay
41	Halfway Ranch	Peace	87	Bridesville	Kootenay
42	Harry Lake Aspen Park	Thompson Nicola	88	Montrose-Fruitvale	Kootenay
43	Celista	Okanagan	89	Barrowtown	South Coast
44	Vanderhoof West	Omenica Skeena	90	Cowichan	Vancouver Island / Coast
45	Cariboo Highway	Omenica Skeena	91	Charlie Lake	Peace
46	Rosette Creek	Peace	92	Green Moutain Road	Okanagan

Figure 16 shows hectares of farmland and land-use category in each area that are beyond 15 km and 30 km from an existing weather station. Of the top 10 locations, eight areas consist of mainly rangeland, making up between 85% and 90% of the under-represented farmland in those areas. This is not unexpected as the areas that are more sparsely populated and remote, generally in the central and northern regions, have the largest expanses of farmland that is mainly used for grazing.

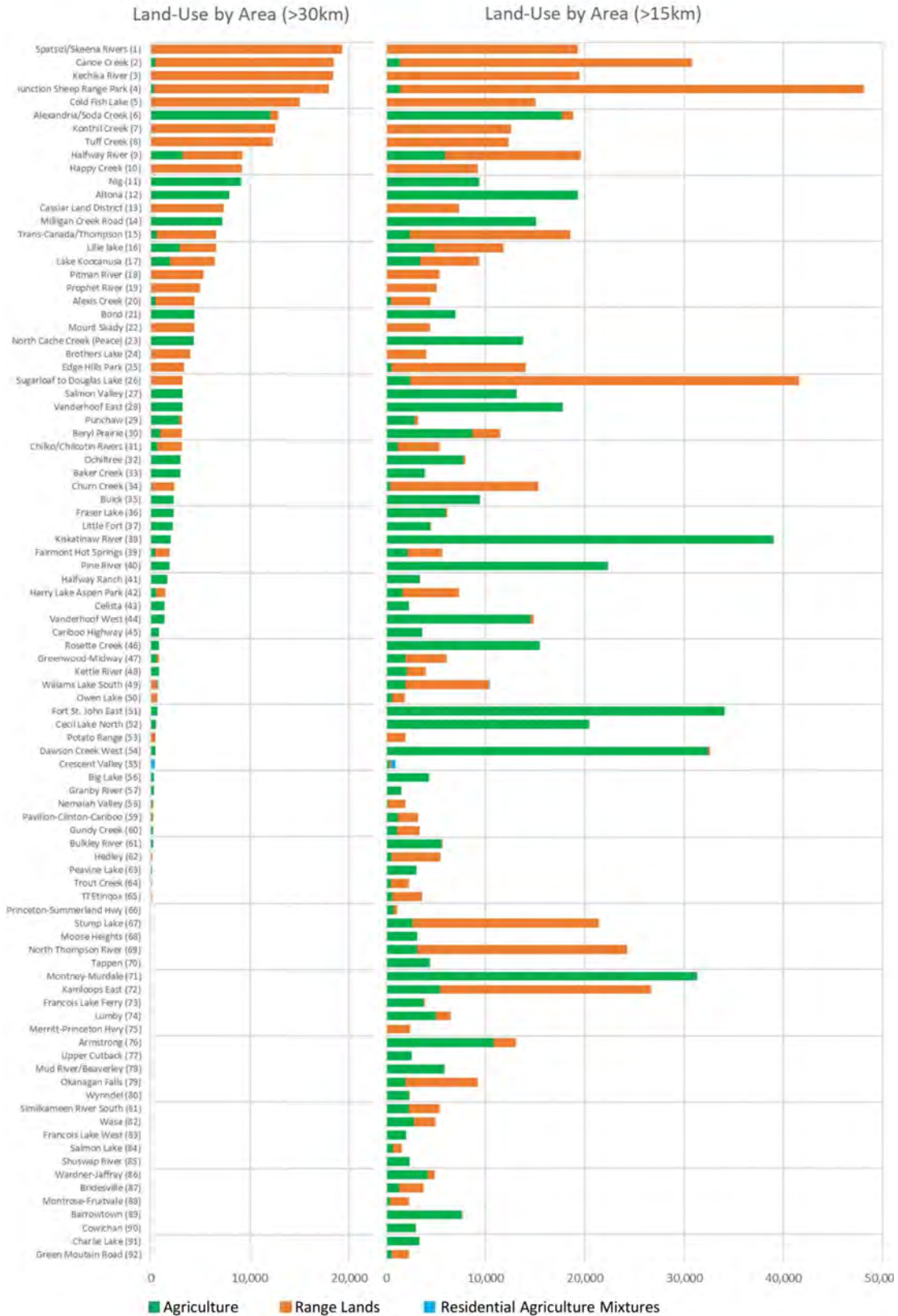


Figure 16: Hectares and types of farmland in each area that are beyond 15 km and 30 km from an existing weather station, representing the approximate area that would be covered by adding each additional weather station

To increase the absolute coverage of continuous production areas that are currently furthest from existing weather stations, the most effective strategy would be to address the highest-ranked locations first and then move down the list as resources permit. This strategy enables each new station to cover the largest possible under-represented area of farmland. For example, adding stations within the first 10 ranked areas would cover approximately 145,000 ha or just over 50% of the least represented areas. Adding stations to the top 25 ranked locations would cover approximately 80% of the least represented farmland (>230,000 ha). At 34 additional stations, 90% of the under-represented areas would be covered. The bottom 22 ranked areas have no agricultural land that is beyond 30 km.

HOW TO USE THIS GAP ANALYSIS

The preceding section provides an overview of the relationship between BC's farmland and locations of weather stations. Concentrations of farmland that are found to be further from any applicable weather monitoring are indicated and ranked based on land area and its distance from weather stations.

The overall ranking of areas is objective and based on continuous areas of farmland. The ranking does not distinguish between land-use type - nor the comparative benefits of increased weather monitoring for one land-use type versus another. This is based on the principle that all agricultural land in the province should have at least a minimum level of monitoring of regional conditions to provide basic information about conditions in those areas. Currently, weather events that occur in these more remote regions can go completely undetected, preventing any sort of response.

The ranking should be used as a general guideline for adding new stations that will provide a consistent level of baseline data at the provincial scale. Regional priorities and resources will vary considerably and should further guide the prioritization. Beyond basic geographical representation, the reality is that certain agricultural systems are likely to make greater use of weather-based decision support tools and will benefit more from increased monitoring. This is likely to encompass crops that typically require weather-sensitive inputs or management activities to sustain production or mitigate risk. These inputs could include water (irrigation), nutrients, pest and disease treatments, frost protection and/or timely field operations such as planting, scouting, or harvesting. With regards to land-use, much of this segment would be classified under either agriculture or residential agriculture mixtures. Thus, certain areas, those with a higher proportion of agricultural land-use, could realize greater operational benefits from improved weather monitoring. Specifically, this would include areas like (#6) Alexandria/Soda Creek with 94% agriculture, and (#11) Nig, (#12) Altona, (#14) Milligan Creek Road, (#21) Bond, (#23) North Cache Creek (Peace), (#27) Salmon Valley, and (#28) Vanderhoof East, all classified as 100% agriculture (Figure 16).

There are also certain areas that are not highly ranked from the perspective of being furthest from existing weather stations, but which have large areas of agricultural land that is between 15 km and 30 km from a weather station (Figure 16). Notably, (#38) Kiskatinaw River, (#44) Vanderhoof West, (#46) Rosette Creek, (#51) Fort St. John East, (#52) Cecil Lake North, (#54) Dawson Creek West, and (#71) Montney-Murdale.

ADDRESSING THE GAPS

Despite the known gaps, installation of new monitoring stations should not be rushed in advance of implementing a provincial strategy that will support the sustainable operation of an agricultural monitoring network. This includes establishing protocols and building the necessary infrastructure that is needed to effectively manage data and support regional networks. Data handling infrastructure will help to ensure that information gets to the intended audience and can be used with confidence, as well as be applied to a range of decision support tools.

Once the strategy and the supporting infrastructure are in place, the next step is to foster regional partnerships through which existing or new weather stations can be integrated. These regional partners would be best suited to identify their respective requirements and to establish and maintain local stations with the support of the coordinating provincial entity. Existing stations would need to be evaluated for suitability, including siting and hardware specifications. New stations would need to follow set standards and guidelines that are to be established. The requirements are described in the following sections.

STATION SITING

The physical placement of a weather station has tremendous influence on the data that gets collected. A weather station should represent its surroundings and should not be affected by obstructions in the immediate area - unless the intention is to monitor a distinct microclimate like inside a crop or tree canopy.

Stations that are sited according to established guidelines provide standardization between monitoring locations and between networks. This allows intercomparison of measurements and reinforces the “one system - many uses” model that is promoted by the Global Climate Observing System (GCOS) as fundamental to the efficient and effective operations of a climate observing system⁸. A well-sited station will result in the maximum possible utility for a monitoring system.

Suboptimal siting can cause subtle influences on the sensors, resulting in measurements that are not reflective of the local area. Weather stations should be located far enough from obstructions so that measurements are not affected by the obstruction. For example, a station too close to a building may report unrepresentative conditions due to the influence that the structure has on temperature, humidity, wind, rain, and possibly solar radiation. Such measurements would misrepresent the general area and lead to inaccurate conclusions.

Sensors should be installed at standard heights to prevent variability from being introduced. Stations should not be installed on rooftops. Roofing materials often emit heat that will affect the temperature and humidity readings, which will already be different than those nearer to the ground. Wind speed increases with height, therefore wind readings will be higher than those closer to crop height. And stronger winds will result in under-catch from the rain gauge, resulting in rainfall values that are lower than actual amounts.

A station that is in a depression versus a hilltop will result in quite different measurements, particularly during a freezing event that could more severely affect either the lowlands or the highlands, depending on the nature of the event. During a radiation frost, which is commonly associated with calm and clear conditions, the cold air can “drain” downslope, causing greater damage in low-lying areas. Alternatively, a typical advective frost event will likely result in greater damage to the higher and more exposed areas.

A station located near pavement or water bodies will also be affected and the influence will be reflected in the measurements. Changes in landscape, vegetation, and structures can influence temperature, relative humidity, wind, even rainfall. Vegetation can encroach on a station. When the station was first established, the siting may have been ideal. However, over time, trees may have grown nearby, resulting in rain or wind shadows.

Although different types of networks will have some variation in siting protocols, there are universal guidelines that should be followed for general monitoring stations. Existing weather stations need to be inspected, documented, and

evaluated for compliance to set standards. Stations that do not conform would need to either be moved or retrofitted to comply. Any proposed station must be appropriately sited to provide the most representative coverage of the surrounding region.

HARDWARE

Weather monitoring relies on sensors that collect measurements from their immediate surroundings. This information is gathered by an electronic datalogger and relayed to a remote location for further use. Monitoring hardware must withstand the harshest of conditions and continue to function reliably for several years. Selecting the appropriate hardware is important for ensuring that quality measurements are taken in a repeatable manner. In selecting hardware for a specific type of monitoring, the following factors should be considered.

- Hardware Cost - Upfront
- Costs - Ongoing
- Durability/Longevity
- Accuracy
- Ease of use

Weather stations vary in features, functionality, complexity, durability, and price. The price of a full weather station can range from a few hundred dollars to tens of thousands of dollars. The number of weather stations that can be established will be a function of the cost of a weather station in relation to the overall hardware budget of the program. Given that all budgets are finite, deciding to go with a more expensive higher-end weather station limits the number of sites that can be established. A professional-grade weather station will produce precise and accurate measurements that apply to the immediate vicinity of the station. Further from the station, there may be little added benefit. While higher cost normally improves accuracy, the more expensive options are not necessarily the better choice for a given purpose.

The same fixed hardware budget could alternatively be allocated towards a higher number of more affordable stations or sensors that can be distributed across areas of interest to provide a clearer picture of the inherent spatial variability. There are many good quality, reasonably priced weather stations that are well-suited for agricultural applications. While the sensors themselves may potentially be slightly less accurate, the improved coverage will provide superior information across the landscape. In addition, more monitoring points will provide redundancy and backup in case a station or sensor fails.

There are low-cost and low-quality hardware options on the market that are not appropriate for agricultural monitoring. In addition to having unacceptable accuracy, the reliability may also be questionable. Despite being initially cheaper to purchase, stations that are unreliable can end up costing more in the long term due to expensive site visits. Lost or inaccurate data has little value.

For specific applications like research or for tracking of long-term climate trends, highly accurate sensors are imperative. But often, the margin of error associated with distance from a station is much higher than the margin of error associated with any sensor. Conditions that are measured very accurately at a weather station can be quite different than those experienced just a few kilometers away. For agricultural applications, spatial representation is important. For hardware selection, there is an appropriate balance that must be struck between quality, accuracy, and cost.

DATALOGGERS AND COMMUNICATION

A datalogger is at the heart of every automated weather station. This component consists of a microprocessor, internal memory, and a power source. The type of weather station and the data logger that it uses will influence how raw measurements get processed. Frequency of sampling, the logging interval, and how the samples are converted into actual records will affect the final dataset.

Datalogger models range in their ability to be configured by the user. Basic weather stations that are somewhat plug-and-play are mostly hardcoded to collect and process sensor data in a certain way. For example, a METER Group ZL6 datalogger will take a sensor reading each minute. The averages, maximums, minimums, and accumulations are then calculated at a user-selected logging interval, which could be from 5-minutes to 12-hours. More complex dataloggers, such as the Campbell Scientific CR1000X are completely configurable where sampling interval can be as high as 1,000Hz (1,000 samples per second).

Except for in specialized applications, complete configurability is not necessary and can introduce a degree of complexity that requires specialized skills and expertise to set up. The default or hardcoded configuration of most weather station dataloggers is adequate for general purpose monitoring. It is important to have a suitable logging interval to meet user and decision support tool requirements. A general growing degree day calculation only requires daily maximum and minimum air temperature, while certain disease models require hourly data. Higher frequency logging intervals can easily be converted into a lower frequency interval. For example, daily summaries can be derived from 10-minute or hourly data, but the reverse is not possible. Therefore, an hourly logging interval is the absolute minimum for agricultural uses – 10- or 15-minute intervals are preferable.

The weather station datalogger must have some sort of communications module, either integrated or peripheral. This enables information to be transmitted on a regular basis and to be utilized for decision support. For example, for irrigation management, the previous day's weather data would be necessary to calculate evapotranspiration and perhaps soil moisture content. If the data were transmitted more frequently, the user could be alerted to rain or a wetted root zone so that the irrigation system could be turned off. In contrast, a station without communications that requires data to be manually downloaded, or a station with infrequent transmission intervals, may be adequate for retrospective analysis or research, but would not provide tactical or operational benefit.

Frequent data transmission also enables timely detection of station issues. If a station does not report at its scheduled time, the operator can investigate and respond accordingly. Or if certain values are anomalous, these issues can be detected and dealt with sooner rather than having to wait perhaps days or weeks for the data to be available. For general regional monitoring, hourly data transmission over the cellular network is a realistic and achievable minimum.

As communication network coverage and reliability have improved and data costs have gone down, cellular has generally become the most practical means of communications. For a few dollars per month, a weather station can transmit measurements by cellular network at least hourly, perhaps even more frequently depending on system capabilities. Cellular is an excellent option when stations are relatively dispersed and where there is coverage.

When stations or sensor networks are dense, having a cellular modem and a data plan on every station may not be practical or cost-effective. Many industries, including agriculture, are beginning to embrace the so-called Internet of Things (IoT), which consists of numerous connected devices and sensors that collect and exchange data with other devices and systems. This technology is often associated with “connected farms” or “smart farms” that leverage IoT to inform analytics to support farm management. On the farm, this could involve a network of temperature, humidity, and leaf wetness sensors to detect variations in pest infestation or risk of frost within different parts of an orchard or at different heights above the ground. For irrigation, this could be soil moisture sensors at various depths in the root zone within different parts of the field to monitor water status. Sensors and actuators can further interface with nozzles, pumps, pipelines, and reservoir/well levels to fully monitor, manage, and optimize a farm's irrigation system.

Communications for IoT devices are becoming increasingly reliant on low-power wide-area networking (LPWAN). These networks consist of wireless sensors that can send small amounts of data over long distances using extremely low power. In rural areas, operating range can exceed 10 km and a typical sensor node can operate for several years on a single battery. Using this technology, hundreds of communication nodes transmit through one or more central gateways that upload data to the cloud. The cost of these devices and communications are much more economical than other methods, making this approach well suited for denser monitoring networks across a single farm or a cluster of farms within a production area. This option should be considered for certain regions like the Okanagan, the Fraser Valley, and parts of Vancouver Island.

In areas that have no cellular reception, satellite communications may be the only option in that satellite coverage is everywhere. Weather stations with satellite communications capabilities are less widely available, hardware costs are higher, and there is normally more power draw than other methods. With the advent of microsattelites over the past few years, the cost of transmitting data through satellite has gone down. But currently, this option remains a last resort.

MEASUREMENTS

Standard agricultural indices require a basic suite of meteorological measurements. These include temperature, relative humidity, and rainfall. Wind speed and wind direction are also useful. These parameters meet most agricultural requirements allowing for calculation of many derivatives like dew point, heat units, apparent temperature, chilling units, insect models, certain disease models, and spray indices. For applications like irrigation or managing certain fungal diseases, additional sensors are recommended. Common measurement options are discussed below and summarized in Table 3: Common agricultural weather station measurement types.

Air Temperature: Air temperature is the most widely used climatological element and serves as a basic indicator of climatic trends and variability. In agriculture, air temperature can be correlated with many biological processes like crop development, weed emergence, and stages of insects. Temperature near or below freezing can have devastating effects on crop survival. Accurate temperature measurement is imperative on any weather station.

A temperature sensor is universally mounted at a height between 1.25 m and 2.0 m above the ground in a properly ventilated enclosure that is shielded from direct solar radiation⁹. This standard must be maintained to provide consistency from one location to another.

For applications that require more granularity, sensors may also be installed at different heights or within the crop to get a better indication of how the plants may be affected by certain temperatures. A short crop may benefit from sensors located closer to the ground where temperatures may be colder than those measured above. To detect inversions, where air temperature near to the ground is colder than aloft, two or more sensors can be installed at different heights on a tower. Temperature sensors that are installed close to the ground or within canopies – at non-standard heights – will have limited applicability beyond the specific farm.

Relative Humidity: Relative humidity (RH) is a measure of the amount of water vapour contained within air, representing the ratio of actual water vapour to the amount that would be present if the air were saturated at the same temperature and pressure. Dew point, which provides insight into water droplet formation, spray suitability, and frost formation can be derived from RH. Humidity is important for certain disease models as a humid environment is most conducive to the development of certain pathogens. For calculating evapotranspiration, humidity represents the gradient between the saturated leaf surface and the ambient air. Drier air results in a higher vapour pressure deficit and an increased rate of potential evaporation. The combination of temperature and humidity are also used to calculate indices like humidex or heat stress that can be applied to human or animal health and safety.

An RH sensor is standard on most weather stations and should be included on any agricultural station. The sensor is mounted alongside or integrated with a temperature sensor at the standard 1.25 m to 2.0 m height.

Rain: Knowing the amount of rain received is vital for non-irrigated crops and helpful for producers with irrigation to determine how much supplementary water is needed. Rainfall is important for drought assessment, flood prediction, and hydrological modelling. Given that rain can vary considerably over distance, the representativeness of rain gauges is rarely adequate, particularly across complex terrain and over short durations of time. Limited ability to monitor precipitation on a range of timescales reduces understanding of, and ability to predict droughts and severe floods¹⁰. While radars can help fill in these gaps, they are less effective in mountainous regions due to signal blocking propagation errors.

Most standard siting guidelines specify that the top of the rain gauge should be between 0.8 m and 1.0 m above the ground. This height is meant to minimize the effect of wind, which reduces the amount of rain that gets measured,

while also avoiding splash from the ground. Unfortunately, all-in-one type weather stations do not allow for the rain gauge to be placed closer to the ground as the sensor suite is integrated into a single unit. This will introduce some wind-induced errors¹¹. Lowering the rain gauge on an integrated unit would require that the temperature and RH sensors also be lowered, which would bring those sensors to non-standard heights and would not be ideal.

An important clarification is that rain gauges measure liquid precipitation but are less effective at measuring precipitation that falls as snow or ice. When temperatures remain below freezing, no precipitation gets recorded. For this reason, network operators that require snowfall amounts will monitor all-weather precipitation or snow accumulation. This can be done using standpipes, weighing gauges, distance sensors, or snow pillows. These sensors tend to be quite costly and require a high degree of maintenance. While critical for estimating snowpack and runoff - and despite the contribution of snowmelt to soil moisture recharge in crops – all-weather precipitation is seldom monitored for agricultural applications.

Wind: Wind speed and direction are important for knowing whether spray products will drift to non-target areas and cause damage. Wind speed is also important for calculating the rate of crop evapotranspiration as air turbulence is the main mechanism to remove moist air from the evaporative surface. A windier day will result in a higher rate of crop evapotranspiration.

Regular climatological stations measure wind speed and direction at a height of 10 m above the ground, which is the standard for meteorological monitoring. However, for agrometeorological applications, 2.0 m or 3.0 m is the standard¹². For practical purposes, the agrometeorological standard is preferable as the 10 m height requires a tower which is expensive to install and makes accessing the sensor difficult.

Conventional anemometers consist of a propeller or wind cups to measure wind velocity and a wind vane is used to measure direction. These sensors have moving parts that are prone to wear and require regular bearing replacement. While replacement bearings are not expensive, the cost of time and travel can be. Bearings that are starting to wear will cause errors in that measured wind will be less than actual wind speed. Such errors are difficult to detect as they can be subtle.

Ultrasonic wind sensors are highly accurate and have no moving parts, therefore are not subject to the same issues as mechanical sensors. Traditionally, ultrasonic wind sensors have been quite expensive and have had high power requirements, making them unaffordable and impractical for use in general monitoring. Over the past few years, more economical ultrasonic sensors have become widely available. To reduce maintenance costs and increase sensor longevity, ultrasonic wind monitoring technology should be considered for new monitoring stations.

Solar Radiation: Irrigation management is normally done in one of two ways - by calculating the amount of water being used by the crop, or by measuring the actual water in the soil. The former is most often done by calculating potential evapotranspiration, which is mainly a function of available energy. This energy comes from the sun. Having an actual measurement of solar radiation using a pyranometer will improve the accuracy of such calculations.

For stations that are to be used for irrigation management, having a pyranometer is recommended. Most weather stations can be retrofitted with this sensor for a nominal cost. There is also some additional maintenance as the sensor must remain clean to produce accurate measurements. Pyranometers should be replaced or recalibrated regularly as calibration can drift over time. Given that radiant exposure does not vary as much across distances, solar radiation measurements from a single station can be applied to a larger area.

Leaf Wetness: One of the key requirements for the propagation of many pathogens is the presence of “free water” that results from rain, irrigation, fog, dew, mist, or hoar frost. Temperatures during periods of free water can be used to predict the development or severity of certain diseases. A leaf wetness sensor is used to simulate that presence of moisture on an actual leaf surface. Alternatively, leaf wetness can be proxied using other parameters such as relative humidity and dew point. There tend to be mixed opinions on the appropriateness of this method. However, given that some models specifically require a leaf wetness measurement, stations that are to be used for disease risk prediction

should have a leaf wetness sensor. This would include stations located in tree fruit, wine grape, berry, and vegetable producing areas.

A leaf wetness sensor can be added to most weather stations. Ideally, the sensor should be located beside or within a field or orchard to provide the most accurate representation of actual leaf surfaces. Wetness values are influenced by local factors, including terrain, slope, air turbulence, and light. Therefore, while monitoring of leaf wetness is important for crop specific management, it is less useful for applications that are beyond the immediate proximity of the weather station. A leaf wetness sensor on any type of regional station would have little or no benefit.

Soil Moisture: Soil moisture sensors are most often used within a field to measure the amount of water in the root zone and to inform decisions about crop irrigation. By measuring the actual water content at certain points in the soil, operators can fine-tune application at key crop stages to prevent too little or too much water from being applied. Inadequate water can stress the crop, resulting in yield loss. Too much water can damage the crop or cause runoff or leaching of water and nutrients along with increasing the risk of certain diseases.

The measurements from in-field soil sensors are specific to that field as they are dictated by irrigation, drainage, soil properties, and by crop type, stage, and vigour. Soil moisture in one field will be different from that of neighboring fields that are not managed identically. While in-field soil moisture sensors are an excellent on-farm tool for optimally managing water, these measurements are as much affected by management practices as by local weather, having little to no value beyond the specific farm.

On a regional basis, strategically placed soil moisture sensors can be an effective means of quantifying and validating water balance and evapotranspiration models. Directly monitoring subsoil moisture can provide insight for drought assessment, flood forecasting, or yield prediction. Such sensors need to be in representative areas, preferably under permanent vegetation that is not irrigated. Alberta and Manitoba's agricultural weather networks both monitor soil moisture and soil temperature at their stations to provide such regional indicators. Caution must always be exercised when extrapolating soil moisture values from a point measurement to a region. Given the extreme variability across BC's agricultural landscapes, regional soil moisture monitoring may not offer a great deal of insight.

Soil Temperature: Most soil moisture sensors on the market can also measure soil temperature. Alternatively, dedicated soil temperature probes are inexpensive and can be added to most dataloggers. Soil temperature can provide valuable information for determining depth of freeze, which can be used to estimate runoff, early-season crop development, and suitable soil conditions for fall fertilizer application. Like soil moisture, soil temperature is influenced by management practices, including vegetation and ground cover, and is affected by factors like soil moisture and snow accumulation.

Table 3: Common agricultural weather station measurement types

Parameter	Common Uses	Placement	Station Type
Air Temperature	Climatological trends, heat units/chilling units, frost monitoring, disease models	1.25 to 2.0m above ground	All stations
Relative Humidity	Dew point, frost formation, disease models, evapotranspiration	1.25 to 2.0m above ground	All stations
Rainfall	Crop supply, irrigation, flood/drought monitoring, runoff...	Ideally at 0.8 to 1.0m above ground. Often gets mounted closer to 1.5m	All stations
Wind	Evapotranspiration, spray drift, wind damage	2.0 to 3.0m above ground	All stations (ideally)
Solar Radiation	Evapotranspiration	Open area without shading	Stations used for irrigation management
Leaf Wetness	Disease forecasting	Specific to crop type	Stations used for disease prediction
Soil Moisture	Irrigation, flood/drought monitoring, nutrient application, runoff	Under permanent vegetation for regional monitoring	In-field stations Regional stations
Soil Temperature	Depth of freeze, early-season crop development, fertilizer application	Under permanent vegetation for regional monitoring	In-field stations Regional stations

WEATHER STATION HARDWARE

Underlying network objectives regarding geographic representation and the elements that need to be measured will help to determine what type of weather station equipment is suitable. These objectives will influence the type of equipment that is used, the types of sensors, and how the data is collected.

The criticalness of the information should be reflected in the calibre of the equipment. For example, a weather station at a major airport must have the reliability and redundancy to never fail at risk of jeopardizing flight safety. In contrast, a backyard weather station could go offline and not be noticed for days or weeks. Weather stations should provide a good compromise between measurement accuracy and cost-effectiveness.

An important consideration for equipment is to allow some degree of flexibility to suit the needs of the various users, while ensuring a necessary degree of standardization. A provincial multi-stakeholder network should seek to enable a variety of use-cases and budgets. This allows local partners to deploy hardware that fits their monitoring requirements while still adhering to set guidelines. It also supports a more seamless inclusion of existing networks that are using hardware that suits their monitoring needs. In addition, new technologies are emerging that are making weather monitoring more cost effective and user-friendly while maintaining necessary quality. Any equipment specification must allow for new technologies to be evaluated and implemented.

There are many types of equipment, each with their own advantages and drawbacks. This report does not cover all types of monitoring equipment. Rather, it presents a few viable options that are suited to agricultural monitoring and that are already being used (see Table 4: Comparison of weather station options).

METER Group: METER Group was formed in 2016 as a merger between Decagon Devices and UMS Ag. The company went on to develop the ATMOS41 all-in-one device that measures 12 variables in a single unit. These variables include air temperature, relative humidity, vapour pressure, barometric pressure, wind speed, gust, and direction, solar radiation, rainfall, lightning strike distance, and tilt.

One of the main benefits of this sensor is that there are no moving parts. This reduces the amount of wear that normally occurs on a standard weather station, including wind bearings and the tipping bucket mechanism of the rain gauge. Elimination of moving parts is expected to increase the longevity of these sensors, thus extending the overall value from investment. While the Atmos41 is slightly more expensive than some other options, its long-term durability make it more cost effective in the long term.

While these sensors have only been around for a few years, feedback from network operators who have been using the Atmos41 for some time has been positive. These networks include Washington's AgWeatherNet (AWN) and the Montana Mesonet. This sensor is also used throughout Africa under the Trans-African Hydro-Meteorological Observatory (TAHMO). Currently with approximately 600 weather stations, the goal of this initiative is to install 20,000 stations across Africa. Campbell Scientific Canada uses this same sensor rebranded as the ClimaVUE50.

Another benefit of the Atmos41/ZL6 datalogger is its ease of use. Unlike many other types of stations, the system can be installed or replaced in minutes and does not require a great deal of technical expertise or training to operate. The benefit is that tasks like replacing a component could be done by personnel with limited technical knowledge. The compact size of the unit makes it simple and inexpensive to ship, which would allow for swapping of problem devices by the local station contact, thus saving the time and expense of sending a specialized service technician.

Campbell Scientific: Campbell Scientific is a leader in professional and research-grade monitoring equipment. All ECCC automated climate stations have Campbell Scientific dataloggers and components. A standard Campbell Scientific datalogger can be quite complex given its wide range of features and functionality. Complete stations can easily cost tens of thousands of dollars.

Recognizing that many station operators do not require extensive functionality or sophistication, Campbell Scientific has developed a more basic and affordable option, the ClimaVUE50 all-in-one device paired with the CR300 datalogger. This package, while still more costly than most alternatives that are presented, provides a slightly premium option with features and custom capabilities. This configuration benefits from the quality and reputation that goes with the Campbell Scientific brand.

Davis Instruments: Davis Instruments has sold over 500,000 weather stations since producing its first hand-held wind meter in 1984. The company continues to sell relatively low-priced weather stations with reasonable quality and durability. Davis weather stations are not professional grade but do an acceptable job of collecting reliable and accurate weather data for excellent value. Davis equipment is widely available; therefore, replacement parts are cheap and easily accessible directly through Davis Instruments or through resellers.

The Davis Instruments Vantage Pro2 has been the station of choice for some of the BC agricultural networks like Farmwest (paired with ROM Communications) and the BC Peace Agri Network (with Davis Vantage Connect or Davis WeatherLink). The base model measures air temperature, relative humidity, rain, wind speed, wind direction and barometric pressure. Solar radiation can be added for an additional \$235. Davis has also recently come out with a sonic anemometer that measures wind without any moving parts. This feature costs an additional \$620. The Vantage Pro2 works with various communication options, either those available directly through Davis Instruments or those that are offered by third-party providers.

In 2017, Davis released their EnviroMonitor system, which consists of a mesh network that has a gateway, a GroWeather weather station, and optional nodes. The gateway acts as the communication hub and up to four sensors can be connected to each node. The station and sensor measurements get transmitted to the gateway and the data is uploaded to the cloud via a cellular or internet connection. When using long-range antennas, the gateway, the station, and nodes can be as far as 3 km apart.

The EnviroMonitor system allows for additional Davis or third-party sensors for more site-specific monitoring. The GroWeather station is like the VantagePro2 but comes standard with a solar radiation sensor. The GroWeather system is specifically intended for agricultural applications.

A drawback of the EnviroMonitor system is that it uses a proprietary communication network that only allows the Davis Instruments nodes and weather stations to connect. While nodes can accommodate a vast number of third-party sensors, they themselves are somewhat costly (\$500 plus the cost of the sensors) in comparison to emerging IoT technologies. For example, LPWAN nodes normally range from \$50 to \$150.

All the Davis Instruments options are affordably priced and have reasonable monthly fees. The Davis options that have been presented in Table 4 rely on cellular or internet communications. For remote areas that have neither, ROM Communications offers a satellite option. This configuration comes at a \$300 price premium and a slightly higher subscription cost.

ADCON Telemetry: Many of the existing weather stations on vineyards within the Okanagan Valley and the Growers Supply network are manufactured by ADCON Telemetry. ADCON produces low power telemetry that is well-suited for agricultural applications, including viticulture. The telemetry units communicate either via an integrated UHF radio or cellular modem, depending on whether there is a telemetry gateway nearby. The stations and sensors are of good quality but are also more expensive than most competitors. A basic station that monitors temperature, relative humidity, rain, and leaf wetness is approximately \$5,500. A full “ET” station that also comes equipped with wind speed and direction and solar radiation would cost approximately \$11,000. These stations are distributed and supported by Growers Supply.

One of the main attractions of the ADCON equipment is the accompanying subscription-based addVANTAGE Pro software. This platform comes bundled with several weather-based models, including growing degree days, apple scab, apple powdery mildew, grape powdery mildew, downy mildew, bunch rot, and potato late blight that growers can configure to provide risk indices for their crops.

Table 4: Comparison of weather station options

Weather Station	Datalogger/ Communications	Comms Type	Sensors	Optional Sensors	Price Approx.	Annual Data Fee		
ADCON Telemetry	Series 6 RTU	4G/LTE	T, RH, R, WS, WD, RS, LW	SM, others	\$11,000	\$420		
	A753 addWAVE	UHF						
Campbell ClimaVue50	Campbell Scientific CR300/CELL205	4G	T, RH, R, WS, WD, RS, BP, LT	LW, SM, ST, others	\$6,300	\$360 [†]		
METER Atmos41	METER ZL6	3G/4G	T, RH, R, WS, WD, RS, BP, LT	LW, SM, ST, others	\$3,500*	\$225*		
Davis Instruments EnviroMonitor GroWeather	Wireless to gateway	Wireless/	R, RH, R, WS, WD, RS, BP	LW, SM, ST, others	\$1,600*	\$195* [†]		
	Radio (up to 3000m)	Internet						
Davis Instruments Vantage Pro2	Cellular	4G	R, RH, R, WS, WD, BP	RS	\$2,000*	\$275* [†]		
	ROM Communications	Cell					\$2,700*	\$335
	Davis Vantage Connect	2G/3G						
	Davis WeatherLink Radio (up to 300m)	Wireless/ Internet			\$1,340*	Free for basic [†]		

T=Air Temperature, RH=Relative Humidity, R=Rain, WS=Wind Speed, WD=Wind Direction, RS=Solar Radiation, BP=Barometric Pressure, LT=Lightning, LW=Leaf Wetness, SM=Soil Moisture, ST=Soil Temperature.

*Converted from USD based on 1.25% † Based on 15-minute data plan.

Weather Station Suitability

Of the hardware types listed in Table 4, METER Group and Davis Instruments stations offer an optimal combination of quality and value. Both manufactures produce economically priced stations that are relatively simple to install, operate, and maintain.

From the perspective of upfront costs, the Davis Instruments stations are the most economical. A base Davis station, either the VantagePro2 or the GroWeather using internet communications costs \$1,340 or \$1,600, respectively. Where solar radiation is desired, the VantagePro2 would require the \$235 upgrade, making the cost of that unit close to that of the GroWeather. Upgrading the Davis stations with a sonic anemometer would bring the costs of those stations to approximately \$2,200. For cellular models of the Davis stations, the upgraded costs would be around \$2,850. For this configuration, the price of the Davis Stations and the METER Atmos41/ZL6 are close.

For maintenance, neither the Davis nor the METER stations require a high degree of technical training. On a Davis station, simple diagnostics, replacement of components, and repairs can normally be performed by an individual that has basic technical skills. And because Davis station sensors are relatively inexpensive, a supply of parts can be kept on hand locally.

METER Group's Atmos41/ZL6 is the simplest station to install and maintain. Unlike conventional stations that require individual sensors to be connected and mounted, the all-in-one configuration requires only that the sensor suite and datalogger be mounted to a vertical post and that the single cable from the sensor gets plugged into the ZL6 datalogger. This requires no specialized tools or expertise. Installation of an Atmos41/ZL6 can literally be completed in minutes. Replacing one of the two main components can also be done quickly and easily. Such a setup is most ideal for a remote network. If one of the main components were to malfunction, a replacement unit could be couriered to the site contact who could swap out the old one themselves. Given the features, the simplicity, and the competitive price of the METER station, this option is well suited for agricultural monitoring and should be considered for widespread deployment.



Figure 17: METER Group Atmos41/ZL6 (left) and Davis Instruments GroWeather (right)

STATION MAINTENANCE AND UPKEEP

Every monitoring device that is exposed to the elements for a prolonged period will require inspection, cleaning, sensor checks, and tending to the surrounding vegetation. Weather stations must be maintained to ensure that they operate properly and that accurate measurements are being collected. Unmaintained stations risk malfunction, which can lead to missing or inaccurate data and often require costly unscheduled visits.

While different networks have different requirements, at a minimum, stations should receive an annual scheduled inspection and maintenance visit. For agricultural monitoring, this will ideally be at the start of the growing season to ensure that the station is in optimal condition for crop monitoring. For stations in areas affected by vegetation, a mid-season visit may also be necessary to ensure that grass or foliage are not influencing the measurements.

Networks should have specific and documented requirements. For example, Washington State University's Agricultural Weather Network (AWN) requires that the station batteries and RH sensor chip be replaced and that the pyranometer (solar radiation sensor) be calibrated or replaced annually. Other requirements include ensuring that the station and instruments are plumb and level, that the station is properly oriented, and that the various components are cleaned.

Rain gauges often require additional attention depending on their location and surroundings. Ideally, rain gauges should be checked for calibration once per year or more frequently if readings are suspect. Rain gauges are also prone to blockages from debris, insects, and birds. Regular inspections should be performed throughout the season.

Who performs station maintenance and repairs depends on the type of equipment and its degree of complexity. More complex stations require specialized tools and expertise that are less likely to be found locally. In such cases, trained technicians with the necessary equipment would need to be deployed to repair and maintain stations. This can

be expensive as much of a technician's time would be spent travelling between stations. For planned maintenance trips, efficient routing can reduce travel time and allow several station visits per day. However, if a station malfunctions and requires a special trip, addressing this one issue could cost hundreds or even thousands of dollars.

Having weather stations that are relatively simple to install and maintain eliminates the need for dedicated service technicians and/or expensive service trips. This can mitigate many of the high costs associated with maintaining a network. Basic maintenance and repairs can be accomplished by on-site personnel or by a local field person - perhaps a seasonal university student who is already tasked with other responsibilities within the area. These activities could be coordinated and supported centrally with training, telephone support, and supply of replacement parts.

NETWORK REQUIREMENTS

An effective weather program extends well beyond simply collecting measurements from weather stations and relaying this information to users. A data management platform is the entire system that is used to manage devices and to retrieve, process, analyze, and store the weather data. This system also enables users to access and visualize the value-added information that can be applied to managing their farms. This platform is the necessary pipeline that ensures a reliable flow of clean and standardized data that produces actionable and easy to understand insights for its users. A dashboard alone is not a platform and only fulfills some of the user's needs.

Some organizations have invested considerable resources into purchasing equipment and establishing and maintaining a network of weather stations. But without investing in data management, quality control (QC), and development of derivatives and end-products, there are likely to be major deficiencies for end-users. A weather program that lacks these important features is incomplete and will likely not succeed in serving its intended beneficiaries.

From the moment a measurement is taken at a weather station, there are certain functions that need to occur to provide this information to the stakeholder in a usable form. According to the WMO publication, *The Global Observing System for Climate: Implementation Needs*, "Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems".¹³ The document goes on to outline the elements that must be considered: Quality control, metadata, accessibility and discoverability, and preservation. These elements, along with modelling and derivatives, user-interface, and extension are discussed below.

QUALITY CONTROL

Missing or inaccurate weather data is one of the biggest challenges and one of the more overlooked issues associated with weather monitoring and applications. Even with the best equipment and the best quality assurance processes, without exception, weather measurements will have some errors. These errors could be due to communication delays, which may be attributed to power issues, network problems, or physical damage to equipment. For example, if a sensor malfunctions or is damaged, it may stop working. Stations can be damaged by wildlife, lightning, fires, or vandalism. In some cases, a station may be physically damaged but continue to collect data that may appear valid but is inaccurate.

The Global Earth Observation System of Systems (GEOSS) published a Quality Assurance Framework for Earth Observations stating that all data and derived products should have a documented and fully traceable indicator of their quality¹⁴. Further, that a consistent system be implemented throughout all earth observation communities. This enables users to evaluate the "fitness for purpose" of any data or products that they are using. Without knowledge of data quality, it is impossible to gauge the quality or reliability of any derived conclusion or recommendation. As the province's agricultural weather monitoring initiatives develop, effective quality control is imperative.

Most derivatives, such as models, require a complete dataset to function. As an example, heat units, which are based on daily temperature, are frequently used as a measure of useful heat for the development of plants and insects. If

the calculation of these heat units relies on a certain weather station and that station stops sending data for a few days, a simple model may just assume that there have been no heat units accumulating during that time. From the perspective of the model, the development of the plant or insect has ceased, potentially leading to misleading recommendations. For this reason, gap filling is necessary. This involves providing an estimate to replace an erroneous or missing measurement so that the calculations or derivatives have a valid value to use. Gap filling can be done in various ways, either by spatial or temporal interpolation or by using values from different datasets. Any time a value is estimated, it should be indicated as such.

Ideally, all data that gets presented to the user has been through a thorough process of quality control to ensure accuracy and reliability. However, there may be a tradeoff between timeliness and quality. If the quality control process causes a lag in receiving information, this delay may reduce the usefulness of the data. For example, if processing and QC causes a several-hour delay in presenting the data, this would be of little value for deciding whether to spray or to stop spraying due to wind. Therefore, some near-real-time data may go unchecked and be labelled as “raw” or “preliminary” data. Where ECCC presents recent weather conditions, the web page includes the following statement: “This is an automated product, generated using preliminary data”.

Data validation and QC procedures vary across monitoring networks. Within the CRMP, each member performs its own QC before sharing their data, which results in combined datasets that have varying levels of quality and completeness. This is mainly because each network has different systems, each with their own capabilities, features, sophistication, and quality requirements for their datasets. Certain groups may also use their data in real-time, which can limit the level of scrutiny to which these measurements are subject. After-the-fact, the BC weather data that has been submitted to PCIC and ECCC for archiving, do receive an additional level of QC. Therefore, weather information that is retrieved from PCIC's [Data Portal](#) or from ECCC's [Datamart](#) will have undergone additional QC. PCIC is in the process of enhancing its QC system.

A typical QC system consists of an automated multistep process that subjects the data to various filters and rules. Some of these include coarse filters, internal consistency checks, temporal checks, and spatial checks. Each successive level in a QC system becomes increasingly more stringent to be able to catch more subtle errors. Often, these rules get developed based on observed errors and determining whether they could have been caught using certain algorithms. Such rules must be configurable to reach an optimum balance of sensitivity and specificity. Sensitivity is the proportion of correctly identified errors - true positives. Specificity is the proportion of measurements that are correctly classified as error-free - true negatives. Rules that are overly sensitive will result in too many false positives where correct values get mistakenly labelled as erroneous. Alternatively, if the sensitivity is reduced, the specificity will increase, resulting in more bad values that are incorrectly labelled as accurate - false negatives.

Data science, using machine learning can also be used to identify outliers and anomalies in weather datasets. Estimation models such as decision trees, artificial neural networks, and support vector machines are being used to analyze time series data¹⁵. Tools like support vector regression have been used to detect and correct abnormal values in spatial datasets¹⁶. Using both spatial and temporal QC methods, combined with the interaction between different types of weather elements appears to have the best performance¹⁷. Such methods are being developed and hold great potential for improving the overall quality of weather information.

An effective and efficient QC must be automated so that large amounts of data can be evaluated in a timely manner. Software can perform such tasks much better than any human. However, when the QC system flags a measurement as being suspect or implausible, there needs to be some investigation to confirm whether the value is in fact an error or whether it is abnormal but correct. For example, if a rainfall value gets flagged as suspect because it exceeds a certain threshold, there should be some investigation to determine if this extreme value occurred. This could be done by checking the radar or consulting the station contact. In some cases, simple communication can determine whether a suspect reading can be explained or if it is in fact a correct value. Such investigations are necessary for validating or rejecting certain flags. An effective QC system must be a combination of automated processes and human oversight. For this reason, a dedicated Data Technician is required to oversee a QC program.

As BC advances its agricultural weather strategy, a robust QC system that includes gap filling is essential. This system should be provided centrally to ensure that all data are subject to the same scrutiny. This is particularly important given that the dataset will include measurements from numerous organizations that are operating networks and equipment that are not all uniform, being maintained by individuals with varying levels of training and expertise. Despite set standards, more operators can introduce variability. While procedures and training can help reduce this variability, a centralized and coordinated QC system will help standardize the data, making it more reliable and transparent for the end-user.

METADATA

Metadata provides a description of how certain parameters are observed, including siting and sensors, how the raw data was processed, and any other information that might be relevant to the end-user. This information helps them to decide if the observations are appropriate for their intended application. Proper metadata can also serve to assist users with data discovery, access, and retrieval.

According to the WMO, metadata should be documented and treated with the same care as the data themselves. Observations without proper metadata are of limited use¹⁸. The WMO Integrated Global Observing System (WIGOS) provides a Metadata Standard that is intended to ensure maximum usefulness of observations. The standard identifies 10 main categories that are deemed important for interpreting observations. These categories are listed and described in Table 5.

Table 5: WMO Integrated Global Observing System (WIGOS) metadata categories (from: https://library.wmo.int/doc_num.php?explnum_id=10109)

Metadata Category	Description
1. Observed variable	Specifies the basic characteristics of the observed variable and the resulting datasets. It includes an element describing the spatial representativeness of the observation as well as the biogeophysical compartment 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. It also provides an unstructured element for additional meta-information that is considered relevant for adequate use of the observations and that is not captured anywhere else in this standard.
5. Instruments and methods of observation	Specifies the method of observation and describes characteristics of the instrument(s) used to make the observation. If multiple instruments are used to generate the observation, then this category should be repeated.
6. Sampling	Specifies how sampling and/or analysis are used to derive the reported observation or how a specimen 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	Specifies who is responsible for the observation and owns it.
10. Contact	Specifies where information about the observation or dataset can be obtained.

Every weather station and collected element must have sufficient metadata. Canada and the CRMP are participating in the WIGOS initiative and working towards implementing the standard throughout its member networks. Once fully implemented, this will greatly improve the utility of all datasets, providing important information for all users. All agricultural weather network operators in BC should be required to also follow this standard for documenting and reporting all monitoring details. For all agricultural weather datasets, centralized provincial coordination and curation of this metadata would be a great asset.

DATA ACCESS AND DISCOVERABILITY

Free access to all weather monitoring data and the associated metadata is integral for promoting its widespread use. This includes all measurements that pertain to general atmospheric conditions and that would be of interest to local and regional users - measured parameters like temperature, humidity, rain, wind, and solar radiation. Data sharing agreements between network operators and the coordinating body should require free distribution of contributed data.

Open sharing should not apply to parameters that are specific to certain users or that reflect that user's unique situation. For example, measurements like in-field soil moisture, in-canopy temperature, humidity, or leaf wetness are as much a function of management as they are environmental conditions. Such information, while of limited use beyond the specific farm, are proprietary and should not be distributed beyond that farm.

Data access naturally extends to discoverability, meaning that users must be able to easily locate and access the information, including derivatives and decision support tools (DSTs). Currently, there are several DSTs available to farmers in BC, but these tools are scattered across different websites that are managed by various groups. This can make it challenging for producers to locate a specific tool or to know what resources are available.

For baseline climate data, PCIC has done an excellent job at making historical and recent climatological data available for users. On the PCIC [Data Portal](#) (Figure 18), any user can search for stations by location, date range, variable, observing frequency, or network. The selected measurements and basic metadata can then be extracted in a format of the user's choosing. However, as PCIC serves multiple sectors, this portal does not include any agriculture-specific indicators.



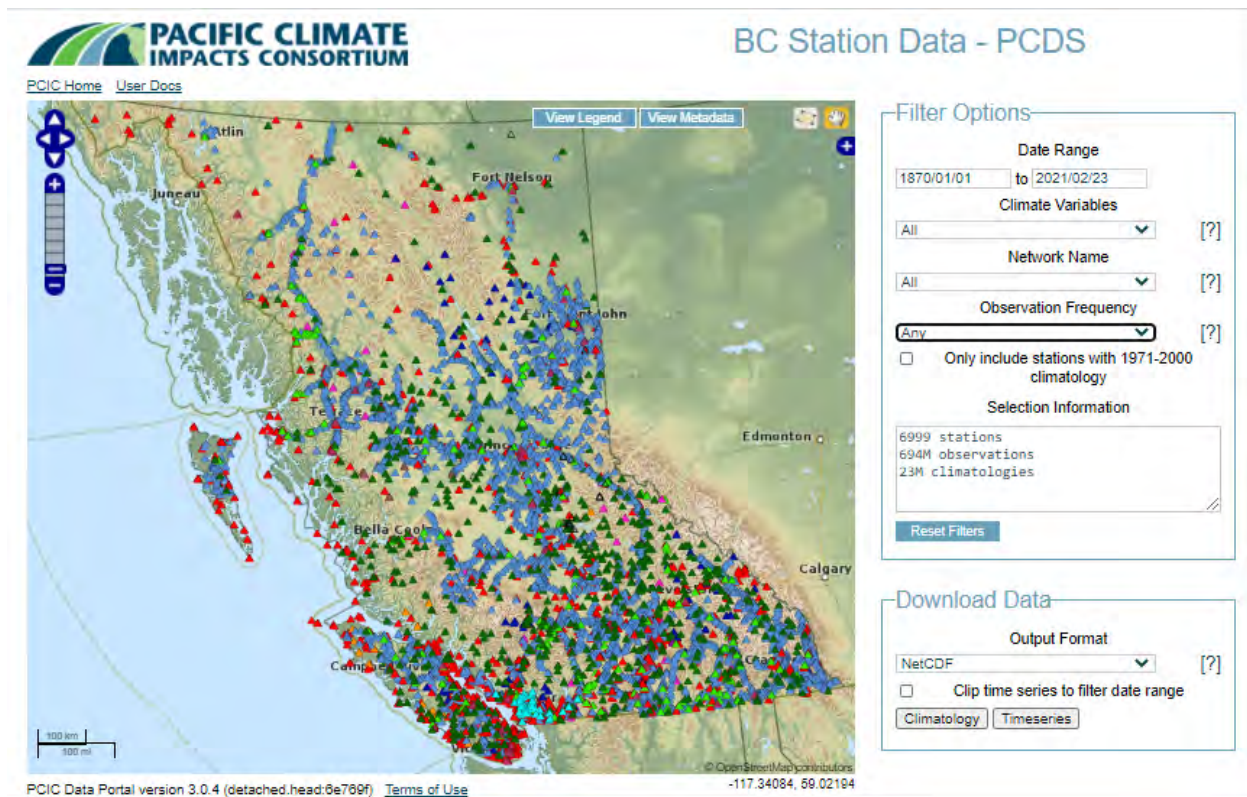


Figure 18: Pacific Climate Impacts Consortium Data Portal

Access and accessibility of basic observations is reasonably advanced within BC. However, the Data Portal would be accessed primarily by individuals who are comfortable with managing and manipulating datasets that can be used to generate agriculturally relevant information. These baseline observations serve as the building blocks for insightful tools, derivatives, and recommendations that are intended to inform management decisions. The value-added components are discussed in more detail in later sections.

DATA PRESERVATION

Data preservation is of utmost importance as climate change remains one of the greatest challenges facing agricultural production. Access to long-term datasets enables us to detect and quantify climatic changes that have taken place and be able to adapt accordingly. Ensuring that observations remain accessible will assist with future studies. Fortunately, through data sharing among CRMP partners and the archiving work done by PCIC, baseline climatological data is being curated and preserved.

MODELLING AND DERIVATIVES

Meteorological observations without analysis, prediction, interpretation, or recommendations may support certain curiosities but provide little basis for decision making and are of limited value to users. Derivatives are calculated values that add agronomic insight. These insights are intended to improve and/or protect the primary agricultural production factors such as yield, quality, and income while at the same time protecting the agricultural resource base from degradation¹⁹. The broader benefits (agricultural, environmental, and societal) of the observational system will be substantially increased with appropriate planning for observational analyses and model development. Such insights are generally in the form of decision support tools to help producers make informed decisions that will improve efficiency, identify opportunities to optimize production, reduce inputs, and increase profit.

Computational capabilities, including computing power and machine learning have improved our ability to model and predict agricultural outcomes. However, the average user does not have the time or expertise to build their own sets of decision support tools - nor should they. Such tools require subject matter experts, vast amounts of observational data, interpretation of the results, and building of the actual models - then ongoing validation and calibration. Researchers spend careers developing and improving these models and have a desire to see them implemented. The area of data science has greatly expanded in recent years, promising the ability to gain even more insight from ever increasing volumes of data. Farmers and agronomists are not likely to become data scientists. Having a platform on which to offer these tools would benefit the researchers and their institutions and the producers that use them.

USER EXPERIENCE

Data visualization is a particularly important aspect of a publicly facing weather program. Effective visualization should be able to summarize volumes of data and analyses in a concise form that does not require the user to pore through multiple data sources. The user interface must be intuitive and clear, enabling the user to leverage the information to make evidence-based decisions.

There are several guidelines and best practices that should be considered when implementing an agricultural weather and decision support user interface. Just showing the data is not enough. Rather, it must be presented in a way that contains the necessary information that enables the user to grasp what is important for their operation. Even the best quality data and derivatives, if presented in an awkward or difficult to interpret manner, will have little uptake. In fact, a user interface with a poor design or one that appears dated or slow can imply to the user a substandard system that is not adequately maintained and perhaps is not even accurate.

Mobile devices have increasingly become the default method of accessing information for many farmers. The ability to view real-time weather conditions, forecasts, and various model outputs on their phones or tablets enables them to make decisions in the field. Therefore, any data delivery system needs to be optimized for mobile devices.

DATA MANAGEMENT PLATFORM

All the components listed above – quality control, metadata, data access and discoverability, data preservation, modelling and derivatives, and user interface – make up the overall data management platform. This is the system that brings in weather data from various monitoring networks and individual weather stations, houses the metadata, manages and quality controls the observational data, and ensures that it is accurate and available to stakeholders in a useable format. Such a system and its components are necessary for a successful weather program.

Building such a platform can be difficult and expensive. Local industry groups or cooperatives should not be expected - nor are they likely to have the resources to build and maintain a fully functional data management platform. Furthermore, multiple groups building their own platforms that are designed to perform similar tasks is redundant. For this reason, a centrally administered data management platform should be developed to handle all agrometeorological data and metadata that is contributed by the various agricultural and other network operators. This would provide tremendous value to agricultural groups that operate weather stations and deliver a better service for all agricultural users. This is a critical role that a provincial agency could fill to support and strengthen agricultural weather monitoring in BC.

Establishing a data management platform can be accomplished in different ways. One way is to design, build, and maintain the system internally. This requires a team of dedicated Information Technology (IT) specialists, programmers, servers, and software. These resources do not appear to be readily available within AAF or any of its partners. Therefore, the internal costs to build these capabilities and establish this expertise could be prohibitive.

The second option is to outsource, either using an existing off-the-shelf-type product or by having one custom integrated by a provider that specializes in such systems. Some known providers include [KISTERS](#), [AQUARIUS Informatics](#), and [Lightship](#), all capable of managing time-series datasets. Another variation to outsourcing is to have

the weather information run through a third-party's ready-made cloud-based system. This option is becoming most common as there are more companies that offer this Software as a Service (SaaS) approach. In such scenarios, the software providers would host the application and manage the data using their own servers, databases, and computing resources. This enables the system to be highly scalable for greater flexibility.

There are commercial providers that operate such systems. Campbell Scientific is soon to launch [Campbell Cloud](#), a platform specifically designed for managing environmental data, including collection, quality control, notification, visualization, and insight. There are also open-source products that could be leveraged to fulfill the required tasks. [CKAN](#) is an open-source data portal and data management system that has tools for storing, sharing, and visualizing information, including metadata. Alternatively, there may be opportunities to leverage systems through partnerships with non-commercial providers. The Okanagan's BC DAS has employed such a strategy in working with WSU's DAS. Rather than building and maintaining an entirely new platform, the Okanagan tree fruit growers opted to leverage a system that was already fully functional and being used extensively in Washington State. With some validation and calibration to ensure that models were suited to the Okanagan, the BC DAS program has been able to take advantage of major investment on the part of WSU and its funders. BC DAS continues to benefit as WSU improves this platform. To determine whether such strategies are feasible at a provincial scale will require further investigation.

Outsourcing has certain advantages. Most notably that these systems already exist in some form or another. This can reduce the start-up time and ideally the overall cost, both upfront and ongoing. System maintenance and upkeep are done by the third-party provider, as are any improvements and the addition of new features. Under the SaaS model, the customer simply pays a subscription fee to access the system. For products such as these, the fee is normally based on the number of active weather stations and the number of users.

There are certain drawbacks to the SaaS model. One is that the customer has less control over the product itself. Changes or improvements can be difficult to implement if they do not align with the roadmap of the provider. If the customer is not satisfied with how the system is performing, they are somewhat at the mercy of the provider and the service-level agreement (SLA) that is in place. And if the relationship is not working, it can be difficult to switch providers as there would have been investment in learning and configuring the system and there would be large amounts of data stored within it. For this reason, at the outset of a SaaS agreement, clear expectations, a solid SLA, and agreeable termination of service language need to be included.

In selecting an outside provider, a competitive tendering process would be the most effective way to identify prospective proponents and to ensure optimal terms and pricing. The request for quotations (RFQ) would specify the required elements. Some of these would include the following:

1. Automated ingestion of meteorological data from various types of weather stations (Davis, METER, ADCON, Campbell Scientific) and feeds from other network operators (e.g.: ECCC, ENV, MoT, FLNRORD...).
2. Thorough QC process, complete with flagging of missing, erroneous, and suspect data. Ability to replace missing or bad values automatically or manually with estimated values. Alerts to notify staff and station operators of QC issues or offline stations. All QC activity must be logged, reported, and made available to users. All original and amended data must be retained.
3. Metadata handling system that enables station operators to enter information about each station, including siting details, sensor specifications, measurement details, maintenance activities, contact information, and pictures. Format must align with WIGOS Metadata Standard. Metadata records must be fully accessible to administrators and partially accessible to general data users (must be able to withhold private information).
4. Ability to integrate additional data sources, including georeferenced imagery (satellite, land-use, radar), forecasts, and long-term climate data).
5. Rest API's and exports to securely access station information and measurements within specified date ranges, at specified intervals through various documented endpoints.
6. Ability to integrate simple and complex weather-based models with various inputs.

7. Interactive web-based map tool to display locations of weather stations and to view station data and create charts.
8. Dashboard-type web display for users to view their station data and derived information.

EXTENSION

Education and awareness are key components of any agricultural weather program. One of the major factors that will influence the level of uptake of decision support tools is the delivery of training and assistance. Awareness that tools are available is the first step in attracting users. Understanding how to access the information, how to use the tools, and how to interpret the results can be greatly accelerated by effective extension. Even if the tools are well-designed and straightforward, users who are less comfortable with technology will require some level of support, at least initially, to overcome apprehensions they may have. As the tools gain uptake, there must also be support with interpreting recommendations.

These activities are best suited to local and regional agrologists and advisors who know the growers and who are most familiar with the production practices of the region. In consultations that took place in preparation of this report, several industry groups expressed interest in decision support tools should they become more widely available for their commodities or in their areas.

Consultants and technical advisors can also benefit from improved decision support tools. Features that enable an agrologist to remotely monitor conditions and crops can greatly increase their efficiency by informing them of key stages of plants or pests and providing risk of disease. More directed scouting allows them to allocate their time in the most efficient manner, thus increasing capacity and productivity.

DECISION SUPPORT TOOLS

Farming decisions have traditionally been based on experience and judgement - on actions that may have worked or not worked previously – and any other evidence that may be readily available. With a changing climate, new production practices, and technological innovation, this strategy has limitations. Current agricultural systems can collect massive amounts of complex data, be it from sensors in the field, from equipment, from satellites, or from other sources like weather forecasts. As the amount of data accumulates, analyzing and making sense of it becomes an onerous task. Decision support tools (DSTs) are meant to assist a user with evaluating certain options by providing quantitative analyses that are based on actual data. DSTs are intended to reduce the amount of guesswork involved in determining which management strategies will provide optimal outcomes in increasingly unpredictable and changing conditions.

TYPES OF DECISION SUPPORT TOOLS

DSTs can take on different forms and be used in countless ways. On the farm, there are some broad categories of DSTs that address various types of decisions that occur at different spatial and temporal scales²⁰ (Figure 19). The weather information that informs these decisions is also scale-dependent and should be considered when designing both monitoring networks and the DSTs.



Figure 19: Scales of Decision Support Tools (based on Rossi et al. 2019).

STRATEGIC

The first category of DSTs is Strategic. These decisions relate to the longer-term strategies that can have multi-year implications. For example, decisions like crop rotations, varieties, irrigation capacity, drainage design, and investment in equipment. Investigating expansion of crops into areas that were previously not feasible is becoming increasingly important as climate permits. Factors like normal heat unit accumulations, frost-free periods, average annual and seasonal distribution of precipitation, and expected crop water demand should be considered. In terms of weather inputs, longer-term climate records and future climate projections are critical. Such climate information is most often available at a regional scale, collected by public agencies like ECCC. Depending on the location that is being evaluated, this regional information should be assessed for its applicability and used with caution. Given BC’s tremendously diverse landscapes, having climate data that accurately represents local climates can be particularly challenging.

An example of a Strategic DST that is available for planning purposes is the BC Agriculture Water Calculator (Figure 20). This tool is used to estimate irrigation or livestock water demand for a farm based on the regional climate. Irrigation water demand estimates are calculated from the area of the field, crop type, soil texture, and irrigation system. Livestock water demand estimates are based on the type and number of animals.



Figure 20: BC Agriculture Water Calculator used to estimate crop and livestock water needs.

TACTICAL

The second category of DSTs include decisions that apply to shorter timespans, such as hours to days and that are based on somewhat local weather conditions. These Tactical decisions rely on factors like the stage of the crop, the local risk of pests and disease, the amount of rain received, and nutrients in the soil. These factors will inform management activities like scouting, crop protection, irrigation, and nutrient applications. Figure 21 displays output from the BC DAS Apple Scab model, an example of a Tactical tool available to apple growers.

Weather based Tactical decisions can only be effective when there is access to reasonably accurate and representative weather information for a farm. This is where local or on-farm weather stations are of benefit. Many of BC's existing monitoring stations may be well suited for use in Tactical decisions but this can vary by farm and by field as the representativeness of any weather station is a function of the variability of conditions across the landscape. In some cases, even a nearby weather station can yield measurements that are quite different than the surrounding area.

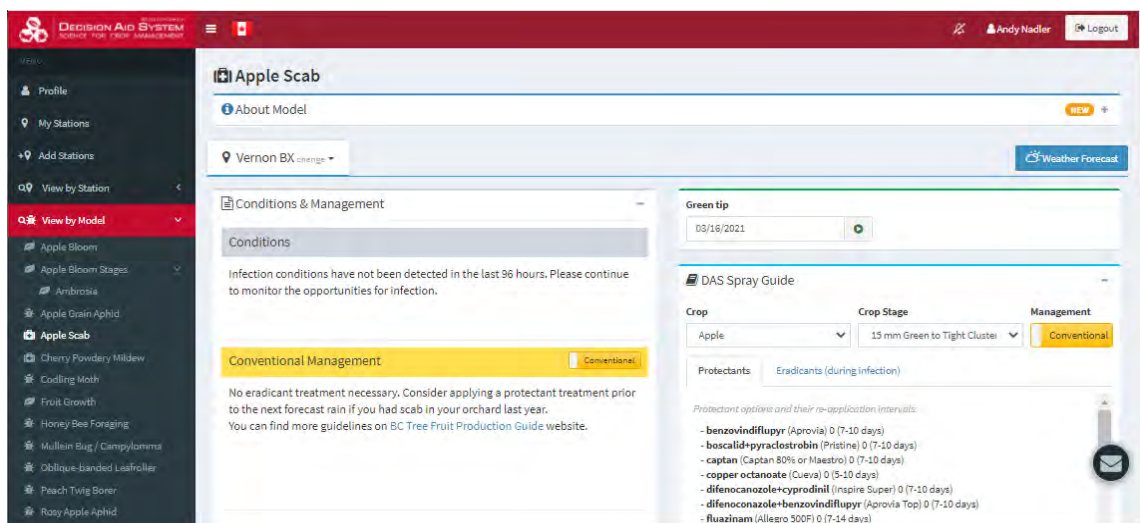


Figure 21: Output from the BC Decision Aid System (BC DAS) Apple Scab model

OPERATIONAL

The third category of DSTs support Operational decisions. These involve factors that can change within seconds or minutes and can be on a spatial scale that can vary within the field. Examples of Operational decisions include whether wind and temperature conditions are suitable for spraying or if frost mitigation is needed to protect a crop from damage.

Operational decisions are mainly based on weather stations and sensors that are located on the farm, perhaps within the field itself to best represent the environment that is being managed. Some of these sensors include in-field soil moisture probes and in-canopy temperature, relative humidity, and leaf wetness sensors. In most cases, producers will either operate these systems themselves or contract a third party to provide these monitoring services. Ideally, the measurements from these in-field sensors can inform a wide range of DSTs to provide the most accurate representation of field conditions as possible.

A provincial agricultural weather strategy must have a clear distinction of what scales of management the program aims to support. This will have implications for the type of monitoring that takes place and the tools that are deployed. While regional weather stations that primarily support Strategic decisions can in some cases be applied to Tactical and Operational decisions, the reverse is less likely to be possible. In-field stations that are used for Operational decisions are of little use for Strategic decisions as they are only intended to represent a specific field (or perhaps a zone within that field). For this reason, it is advisable that the provincial strategy focus on the Strategic and Tactical levels, both in monitoring and in DSTs. Monitoring and DSTs that are at the Operational scale should be supported and managed by individual farms or farming groups.

AVAILABLE TOOLS

Currently in BC, there are several publicly available weather-based agricultural DSTs that are accessible through various portals. Farmwest is the main source of tools, many of which are intended for all areas of the province. The BC Peace Agri Weather Network offers tools that are primarily for grains and oilseeds produced in that region. These tools include growing degree day calculators, a fusarium head blight risk for wheat, and a wheat midge emergence calculator. Additional tools are available through BC DAS and through AFF directly. Below is a summary of the existing online tools that are available to BC growers (Table 6).

Table 6: Selected Decision Support Tools that are available in BC

Tool	Provider	Crop	Description
BC Agriculture Water Calculator	BC Water Calculator	Multiple	Used to estimate irrigation or livestock water demand for a farm based on the type of production, the location of the farm, and the regional climate. https://bcwatercalculator.ca/
Ammonia emission calculator	Farmwest	Multiple	Estimates the amount of ammonia volatilization from cattle or pig slurries applied to fields. The user enters parameters, including soil moisture, air temperature, wind speed, slurry type, percent dry matter, ammonia content, application technique and rate, and cultivation. Defaults are provided so that the user can view some output before having to enter their information. Soil moisture, air temperature, and wind speed must be entered manually by the user.
Application Risk Management (ARM)	AFF	Multiple	Allows producers to quickly determine the risk of nutrient loss due to runoff following an application. The risk is based on the precipitation forecast, the desired day of nutrient application, and a user-entered assessment of field conditions. Once completed, the risk rating can be saved, printed, or emailed. https://agri-nmp-msa.pathfinder.gov.bc.ca/
Corn Heat Units (CHU)	Farmwest, BC Peace Agri Weather	Mainly corn	A measure of useful heat for the growth and development of warmer season crops like corn and soybeans. The CHU formula is based on daily minimum and maximum air temperature.
BC Decision Aid System (BC DAS)	Sterile Insect Release Program	Tree Fruit	An Integrated Pest Management (IPM) decision support system for Okanagan tree fruit growers, providing time-sensitive information on pest development and management options. BC DAS contains a suite of approximately 18 insect, disease, and horticultural models that are freely available to producers. https://www.oksir.org/bcdas/
Evapotranspiration (ET)	Farmwest	Multiple	A calculation of ET can be used to manage irrigation. Knowing how much water is being expelled into the atmosphere and measuring the amount of rainfall provides a good indication of how much supplemental water is needed to supply crop requirements.
Forage U-Pick	Forage U-Pick	Forage	A multi-agency, four-province (MB, SK, AB, BC) collaboration that offers a forage suitability selector and a seeding rate calculator that are based on biogeoclimatic zones and user-entered field and management information. There are also links to weed information and to the provincial Guides to Crop Protection. https://upick.beefresearch.ca/
Fusarium Head Blight Risk	BC Peace Agri Weather	Wheat	Provides a risk of fusarium head blight based on local weather conditions. If the risk is high, crops are at a higher risk of infection and fungicide treatment should be considered.
Growing Degree Days (GDD)	Farmwest, BC Peace Agri Weather	Multiple	A simple means of measuring useful heat for the growth and development of many types of organisms. Based on the mean daily air temperature, GDD operates on the premise that each organism has a physiological base temperature, below which no development takes place. Typical base temperatures are 0°C, 5°C (general plants), and 10°C (corn, soybean, grapes), though some plants have specific thresholds.

Pest Degree Days	Farmwest, BC Peace Agri Weather, BC DAS	Multiple	Calculated in the same manner as GDD. Like plants, the life stages of insects can also be predicted based on temperatures that exceed the base threshold. For example, the development of codling moth, a major pest in apples, is closely related to the accumulation of degree days above 10°C.
T-Sum	Farmwest	Multiple	T-Sum (or T=Sum 200) is used to determine timing of first application of nitrogen fertilizer in spring. The calculation of T-Sum is a simple GDD base 0°C whereby an accumulation of between 200 and 300 units is considered optimal.
Wheat Midge	BC Peace Agri Weather	Wheat	Calculates the emergence of wheat midge based on degree days. This tool assists with scouting and pest management.

In addition to the tools that are offered on the main agricultural portals, there are other derivatives that are sent out directly to growers. These may come from agronomists or horticulturalists, commodity organizations, processors/packers, or from researchers. For example, BC Grape Growers' Association posts charts produced by AAFC that show accumulations of growing degree days (Figure 22). Similar reports are produced by Wine Islands Growers Association. This information provides a tool to assess how the current growing season compares to previous years.

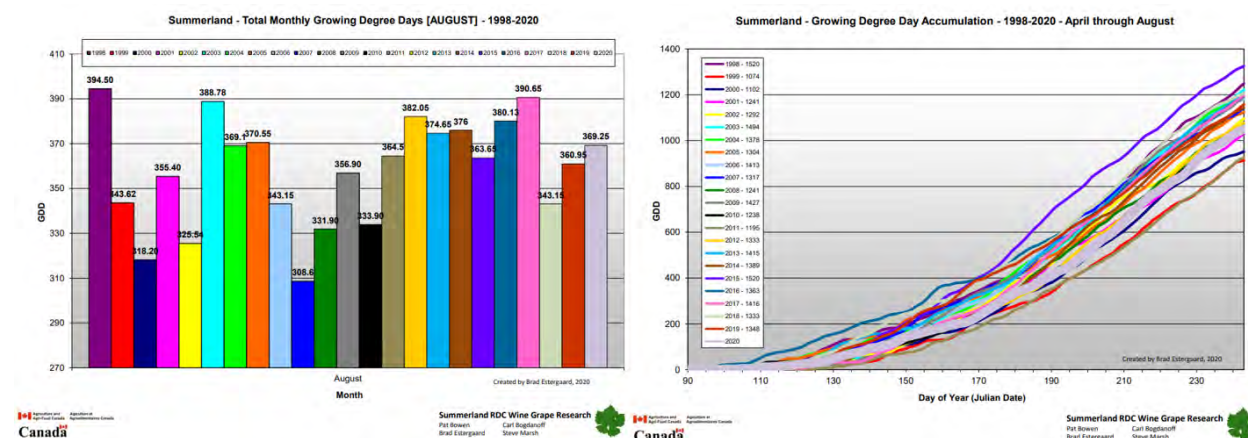


Figure 22: Growing degree day summaries for grape growers

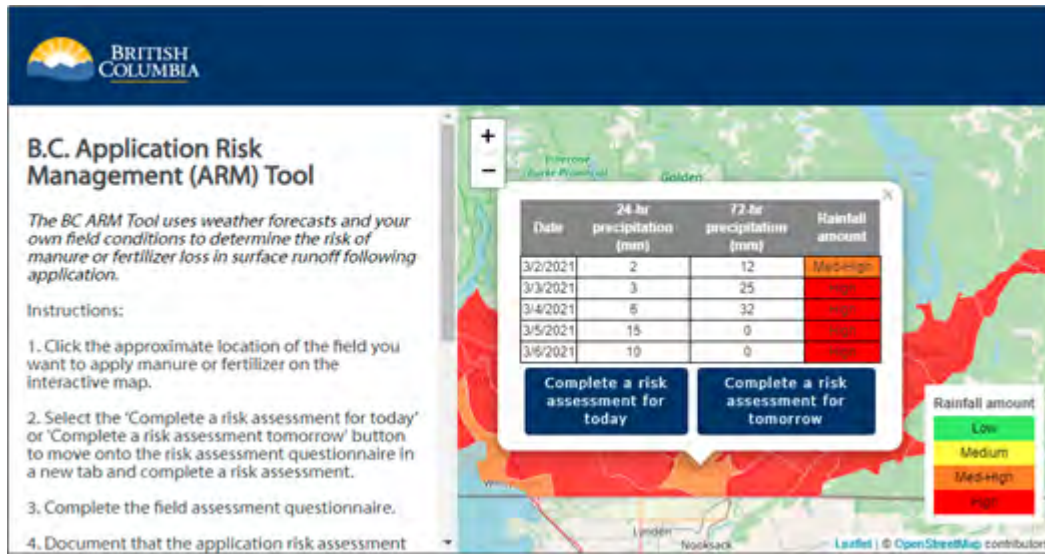


Figure 23: BC Application Risk Management (ARM) Tool

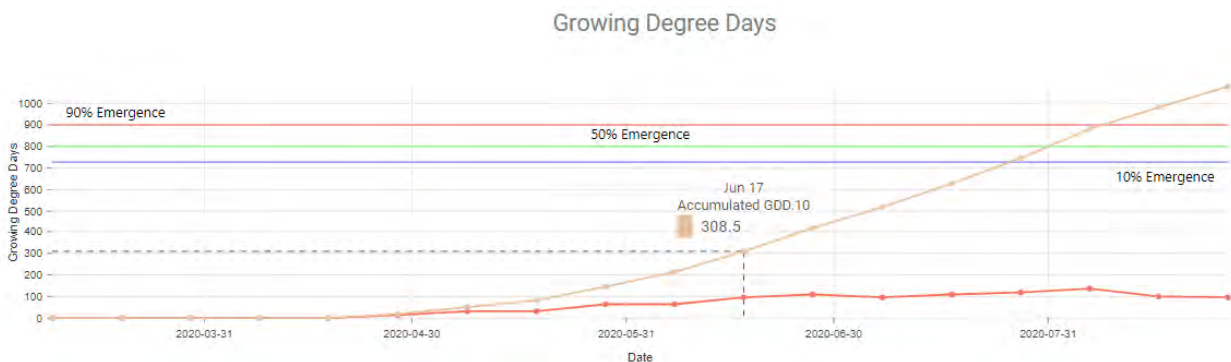


Figure 24: Wheat midge emergence calculator from BC Peace Agri Weather Network

DECISION SUPPORT TOOL PORTALS

The three main DST portals that are available for BC growers, Farmwest, BC Peace Agri Weather Network, and BC DAS, were all developed separately based on certain sector- or region-specific needs. Each program fulfills an important role in addressing these needs. Though having to access these tools in different places is not ideal in that growers who use more than one tool would need to visit and become familiar with multiple websites or applications. For example, a tree fruit grower in the Okanagan may use BC DAS for advice on pest control and then use Farmwest to calculate evapotranspiration for managing their irrigation. Likewise, a producer in the Peace may consult the Peace Agri Weather Network for current weather conditions, Farmwest for an estimate of ammonia loss, and then the ARM tool to estimate nutrient loss from runoff. Multiple portals can make accessing these DSTs cumbersome. Also, with no single brand to promote, exposure and awareness is challenging.

While these multiple platforms are often using information from the same sets of weather stations, the data is not always identical. In the Okanagan, BC DAS, which is operated out of WSU receives data from the Growers Supply stations. Prior to getting ingested into the DAS models, WSU subjects this weather data to an extensive QC that flags and replaces any erroneous or missing data. Measurements from the same stations also get sent to Farmwest but do not undergo this QC process. This results in two slightly different datasets that produce derivatives that are also different from each other. These discrepancies have been observed and have caused confusion and frustration

among users. A centralized and coordinated QC system, as described in the Quality Control section would alleviate some of these issues.

Ideally, there would be a single portal that contains all agricultural DSTs and weather-related content. Such a portal could also provide relevant climate change information, including observed climate trends and projections that can be used to inform strategic adaptation. A single portal would minimize the redundancies that currently exist, it would eliminate the data discrepancies that are occurring between DST providers, and it would provide a more streamlined experience for the user, presumably resulting in a higher rate of uptake.

In practice moving to a single DST platform may not be entirely feasible given that the various platforms are already established. Another complicating factor is that BC DAS is operated by an external agency that has invested in building a sophisticated yet user-friendly system that would be difficult and expensive to reproduce. Therefore, while a full amalgamation of DSTs is not likely to occur, these platforms should be somewhat more cohesive. Measures could include all DSTs being linked from a single landing page, adding some consistency in look-and-feel, providing the ability for single-sign-on, and most importantly, utilizing consistent datasets.

Both Farmwest and BC Peace Agri Weather Network are administered by industry organizations and have had their platforms built and be managed by local third-party web development companies. BC DAS is different in that the system was adapted from Washington State's DAS and continues to be operated under contract with WSU. This route was chosen because WSU's system was already fully built and functional with the tools that tree fruit growers needed. Adopting this system was quicker and much more cost effective than trying to build something new.

Going into its fourth year, BC DAS continues to gain traction among tree fruit growers in the Okanagan. Much of this is attributed to the system's ease-of-use and the promotion and support provided by SIR. There have been requests to extend the DAS coverage to additional tree fruit growing areas like Creston. WSU has expressed willingness to expand the coverage of DAS, though costs and funding will be the main factors that determine the direction of BC DAS. According to surveys in Washington, the DAS program saves growers an average of \$75 per acre (\$185 per hectare)²¹. With widespread uptake and given the area of tree fruit grown in BC, the overall savings could amount to many times the program cost.

Currently within WSU, there are discussions taking place about the future of DAS. In Washington, DAS relies on weather data from Ag Weather Network (AWN), also part of Washington State University (WSU). AWN recently released a new app called [AWNfarm](#) that offers some agricultural DSTs, including blueberry cold hardiness, cherry cold hardiness, and some wine grape management tools, such as grape cold hardiness, powdery mildew, and root-knot nematode. The intent is to eventually offer key DAS models on the AWNfarm platform.

If BC DAS were also able to offer tools for additional crops, this would be an asset to the program. Wine grape tools would introduce opportunities to combine resources with the wine grape industry, including sharing of weather station data and program costs. DAS is working on a new Potato Decision Aid System and is hoping to have it validated and released for 2022. The developments within AWN and DAS over the coming year will influence how the BC DAS evolves within the Okanagan and in other growing areas.

STAKEHOLDER FEEDBACK

Throughout the development of this report, many stakeholders were consulted for input and feedback related to weather monitoring and weather-based DSTs. These consultations occurred through one-on-one interviews, during a breakout session as part of the [2020 BC ACARN Virtual Workshop](#), and through two focused workshops. The intent of these consultations was to seek feedback from growers, industry representatives, processors, researchers, and administrators. The main objectives of these discussions were to determine which tools would be of most value to the respective sectors, to identify the current barriers to uptake, and to define what role the various stakeholders should play in developing, supporting, and maintaining these tools.

The two focused stakeholder workshops were divided by specific commodity areas – one was tree fruit and wine grapes and the other was berries and vegetables. Invitations were sent to industry group representatives, agronomists and horticulturalists, researchers, and producers. Within the workshops, examples of some successful decisions support tools were presented. For the berry and vegetable session, the Michigan Late Blight Forecast and the Strawberry and Blueberry Advisory Systems in Florida were presented. For the tree fruit and wine grape session, BC DAS was demonstrated. The ensuing discussions raised important issues and provided valuable insight that will be applied to the development of this program. While a great deal of the input has been incorporated into parts of this report, there remained many valuable comments that deserve mention. Selected feedback is provided in Appendix B - Stakeholder Feedback.

IMPLEMENTATION

There is a need for improved weather monitoring to support agricultural decision making and to provide vital climate information to guide adaptation. These requirements have been identified by farmers, agricultural organizations, researchers, and professionals that support the sector. The need has also been demonstrated by the efforts of groups that have established their own monitoring networks to fill some of these gaps. Unfortunately, many of these groups do not possess the necessary resources to effectively manage an operational weather program. Specifically, technical support, data handling, and development of tools. The provincial mandate should be to provide the resources that would support and encourage these regional groups to succeed.

It would be difficult and expensive for a central agency to be tasked with installing and maintaining monitoring stations that are distributed across the province. Rather, industry groups, cooperatives, and farmers themselves should be able to establish monitoring stations that meet their specific needs while still adhering to set standards and guidelines. This would be enabled through financial support, technical guidance, and central data handling infrastructure that is provided and maintained by a provincial agency. An outline of the proposed network and data handling strategy is presented in Figure 25.

A multi-tiered/hierarchical approach that leverages community-based monitoring (CBM) should be the goal. An adequate network of regional stations offers information that can assist with strategic farm management decisions and provide continuous monitoring of regional conditions. Local weather stations can provide farmers with tactical management tools. On-farm or in-field monitoring would be adopted by growers seeking the most accurate and representative information for critical operational decisions like pest treatment, frost mitigation, irrigation, or other activities that require granular, accurate, and timely data. Producers opting for the latter option are most likely willing to pay for this service as they will receive direct economic benefit through cost savings or higher yields. Ideally, these producers will benefit from all levels of monitoring – regional, local, and on-farm - to support the various types of decisions.

To increase the inventory of available weather data, initial efforts should go towards identifying existing weather stations, determining if they address any identified monitoring gaps, then evaluating their suitability for agricultural use. These would include stations that are operated by local government, industry groups, researchers, and farms, as well as many of the established CRMP member stations. To be considered, each station must be assessed to determine its operational status - both current and future, its hardware suitability, and its representativeness of the nearby farmland. Stations that are suitable and that have an operator willing to participate would be incorporated into the provincial network. In cases where a station does not meet the required guidelines, slight modifications in communications, siting, or sensors may be needed. The station owner could be eligible to receive assistance for necessary retrofits and with data costs.

Province-wide agricultural monitoring standards and guidelines will need to be established to evaluate the suitability of existing stations and to provide direction to stakeholders who are establishing new weather stations. Detailed and

specific metadata would guide end-users as to the standard and quality of data that they are accessing - whether a fully WMO compliant ECCC climate station or a basic weather station located on a farm.

One of the major differences between the agricultural sector and most other entities that operate weather networks is that agriculture has a high number of individual stakeholders, each operating independently and each with their own requirements. BC has roughly 17,500 farms²² and countless advisors, processors, packagers, suppliers, and other supports that are each a potential partner as well as a consumer of weather-based information.

The most valuable contribution that a provincial entity can offer is the support and the infrastructure to enable groups to participate in a monitoring program that is cohesive across the province. This central agency must be the champion that encourages engagement and coordinates and supports local and regional initiatives. This would greatly reduce the barriers to entry for these groups and democratize access to the latest innovations and technology-based tools that are necessary for a competitive agricultural sector.

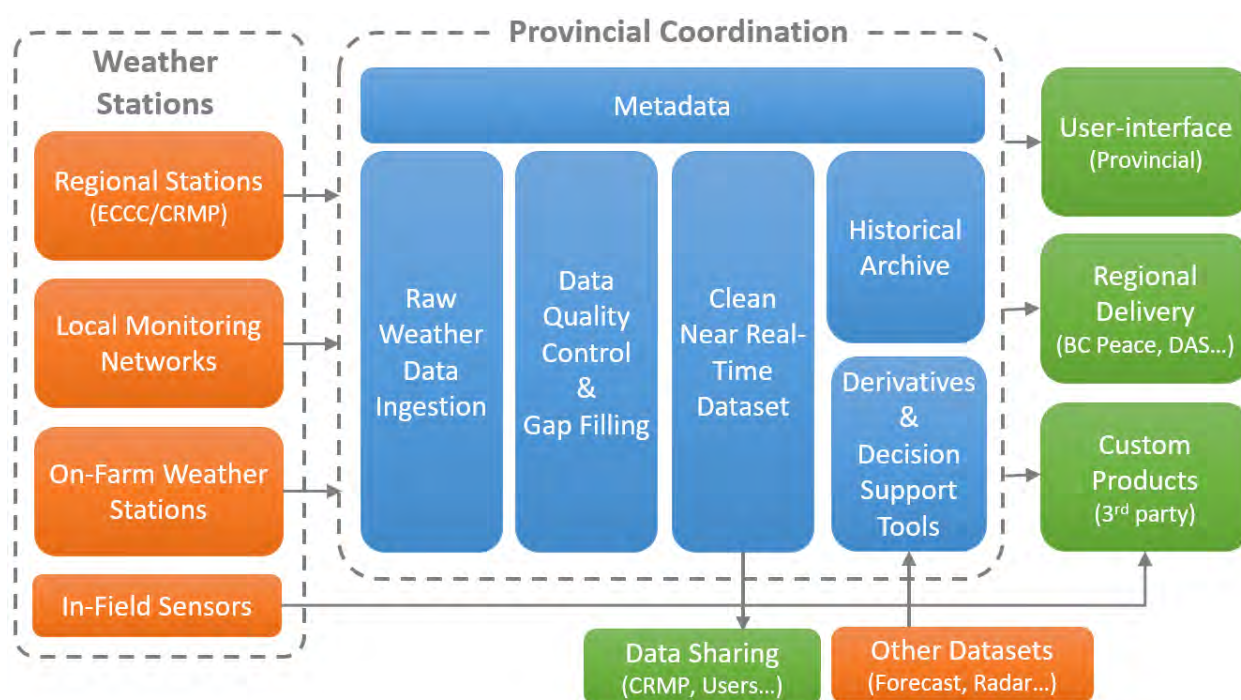


Figure 25: Proposed agricultural weather network and data handling strategy

STEERING COMMITTEE

There are many key decisions that will need to be addressed as this initiative moves forward. While its overall governance is yet to be determined, a project steering committee should be established to help guide and direct how the strategy is executed. This committee would consist of key stakeholders that represent agricultural interests across the province and build on the work that has already been done. Some of this groundwork includes previous reports, consultations, and activities that have been undertaken by the existing weather monitoring working group within BC Agricultural Climate Adaptation Research Network (ACARN). Some of the components that will need further refinement include the following:

Network Design: This component requires that suitable monitoring equipment, installation guidelines, maintenance protocols, and reporting standards, including specifications for metadata be defined. Such guidelines would reflect those recommended in this report, many of which are based on universally recognized standards. These standards

and guidelines will need to be compiled and made available as reference material for station operators. This could be in the form of manuals, tutorials, and training videos.

There would also need to be recommendations on potential cost-sharing programs for groups and individuals to establish and maintain weather stations that would contribute data to the provincial dataset. Such programs would be combined with appropriate data sharing agreements that specify the obligations of both parties, including the responsibilities of the station-holder.

Data Management: A coordinated provincial agricultural weather program will need to identify the most suitable data management platform that ingests measurements from various sources, provides quality control (QC), enables dissemination of the data and derivatives, and manages metadata. If the platform is to be sourced through a third-party, this component would entail issuing a request for quotes (RFQ), accepting and evaluating submitted proposals, selecting the most appropriate proponent, and working closely with the contractor to implement the chosen system.

Decision Support Tools: This area of activity would focus on working with industry organizations, agrologists, and researchers to develop, implement, support, and maintain DSTs that provide value to users. An important component would be to establish a product roadmap that would prioritize which models should be implemented and when. AAFC and university researchers would be instrumental in providing expertise related to agronomy, entomology, pathology, meteorology, and climatology. Provincial industry specialists would be great assets for their knowledge of their respective sectors. Industry group representatives would provide valuable input on behalf of their members.

User Experience: The user interface is one of the most important components in that it can attract or deter users based on its degree of user friendliness. This component encompasses several important pieces such as website design, development, and improvement that should be based on best practices and user feedback. Further work is necessary to define the specifications and scope of a user-interface, including evaluating whether some of the existing tools could be amalgamated into a single portal. This would also include developing strategies for outreach to regional groups and individual users.

RESOURCING AND COSTS

To establish and maintain a sustainable and cohesive provincial agricultural weather program, a dedicated long-term budget must be established. According to the World Bank, for every dollar invested in surface-based weather observations, at least twenty-six dollars in socio-economic return could be realized²³. Failure to invest in a province-wide strategy will result in more local stations and networks being established without central coordination. This creates redundancy and wastes resources. There is an opportunity for centralized leadership that supports agriculture in many regions and across many production systems. The following section outlines some of the estimated costs that would be associated with the individual components.

Data Management

One of the more significant investments will be to maintain the data management platform. As discussed in this report, there are some options for implementation, including in-house development or outsourcing. Outsourcing to a provider that already offers similar products and services would likely result in lower up-front costs as much of the functionality would already have been built. At a minimum, a full-featured platform would range in price from \$75,000 to \$150,000 per year, depending on the capabilities and features of the system. More stations and features would increase the overall costs.

Integration of DSTs needs to be considered. There are many models and derivatives available and still more being developed by researchers at AAFC and at BC's universities. As models get tested and validated, there needs to be a mechanism and the available resources to program these algorithms so that they can be integrated into the user platform. An estimated budget for this component is \$30,000 per year, which would enable a certain number of new models to be added.

BC DAS is a separate data management and decision support platform that serves the tree-fruit producers. Unless a suitable substitute can be developed internally, this system should be maintained and ideally expanded in terms of the crops that it supports and the geography that it covers. These two factors will depend on how WSU evolves the system and what resources are available in BC to support this system. As the provincial-scale weather initiatives proceed, close collaboration with the BC tree fruit industry should continue to ensure that both strategies align and are complimentary.

Weather Stations

From the individual weather station operator's perspective, there should be a motivation to connect into the network (beyond pure altruism). New station installations could be facilitated through incentive programs. By completing an Environmental Farm Plan (EFP), farmers can currently qualify to receive cost-share incentives towards eligible investments, including on-farm weather stations. Stipulations are that stations must be connected to Farmwest.com or similar networks as approved by AFF and that the station is installed in a suitable location. Similar initiatives should be continued and actively promoted to encourage participation. Cost-sharing is a key component of such an initiative as it requires the producer or the organization to provide at least a modest investment. This buy-in helps to ensure genuine interest.

Cost-sharing incentives to establish new weather stations and ongoing support for station maintenance and data transmission from new and existing stations could be offered on a priority basis. Areas that currently lack baseline coverage could be eligible to receive a higher rate of subsidy than areas with adequate coverage. This would provide additional incentive for groups or individuals in regions with sparse coverage to participate. The overall cost of this incentive could be capped based on the ratio of cost-share and the number of subsidized stations. Most suitable weather stations range in price from \$1,500 to \$3,500. A 50% subsidy would provide between \$750 and \$1,750 per station. This amount would be higher in some of the more data-sparse areas.

Station Operation and Maintenance

In addition to up-front support for hardware purchase, ongoing assistance with data costs would help ensure continued participation and flow of data. Data transmission could be cost-shared between the station-operator and the provincial network on the condition that the station is maintained and kept in good working order. Most annual subscription fees range from \$195 to \$335. This amount could potentially be covered fully by AFF to encourage continued participation and to minimize administrative burden - the communication network providers could be paid directly.

Field work, including installing, maintaining, and repairing weather stations would be the responsibility of the local or regional station operators with provincial coordination and support. While this distributed approach is much more cost-effective than centralized deployment, there are still associated costs. If done using existing resources, there are costs for time and travel. If contracted to a local service provider, there are those costs. There should be some budget allocation to assist regional organizations with some of the costs associated with station installation and upkeep.

Another important program cost is lifecycle management. This is to ensure that old or worn equipment gets recalibrated, reconditioned, or replaced regularly. Older equipment becomes less reliable and is more prone to failure, causing inaccurate or lost measurements and additional time spent addressing these issues. A suitable budget should be set aside for network renewal, particularly in the initial stages to account for existing stations that may require immediate attention. This includes providing replacement parts for privately owned equipment either free of charge or subsidized to ensure adequate upkeep. Assuming the average station/sensor lifespan is five to six years, approximately 15% to 20% of the network replacement value should be allocated to lifecycle management.

Personnel Costs

A coordinated provincial agricultural weather network cannot function without dedicated personnel. This program would need individuals focused on establishing, coordinating, and promoting a successful weather program. Likely a single person - a Network Coordinator - could serve as the main point of contact for local station owners and network operators. This person would also provide training and technical support for local service personnel. Direction and input would come from the program steering committee.

Initially it may be possible for the Network Coordinator to also manage the weather data. However, as the network expands, it will be important to have an individual whose primary role is to oversee the data management platform. This Data Technician would manage the weather data and station metadata, oversee the QC, and ensure that the systems are operating as they should. This individual would work closely with the Network Coordinator who would communicate with station owners and network operators about station or data quality issues.

Given that this strategy leverages local resources to do the field work, including installation and maintenance of the actual monitoring stations, centralized field service crews would not be required. This saves a great deal of personnel and travel costs.

Proposed Budget

The provincial agricultural weather network being proposed will provide resources, expertise, support, data handling, quality assurance, and tools that would benefit contributors. As a station owner, by committing to share data and maintaining their station, they would benefit from having access to tools that are specific to their local area. A collaborative agricultural network takes advantage of the tremendous local resources across the province, whether they be agricultural groups, cooperatives, processors, or individual farmers.

A breakdown of estimated annual expenditures is presented in Table 7. To provide a range of cost options, the budget is broken out into lower, mid, and upper annual ranges for each item indicated. Personnel costs are listed separately and indicated by the number of full-time equivalent positions.

Table 7: Estimated 3-year annual budget broken down by cost option

Budget Year	Year 1			Year 2			Year 3		
Hardware	Lower	Mid	Upper	Lower	Mid	Upper	Lower	Mid	Upper
Cost sharing of weather stations. 25 new stns per year (\$750 to \$1,750)	18,750	31,250	43,750	18,750	31,250	43,750	18,750	31,250	43,750
Lifecycle Management 15-20% value of all stations	25,000	30,000	35,000	30,000	37,500	45,000	40,000	50,000	60,000
Data Transmission	Lower	Mid	Upper	Lower	Mid	Upper	Lower	Mid	Upper
Cellular fees, data handling Year 1: 75 stns, Year 2, 100 stns, Yr 3: 125 Stns. Up to \$250/year	11,250	15,000	18,750	15,000	20,000	25,000	18,750	25,000	31,250
Network Upkeep	Lower	Mid	Upper	Lower	Mid	Upper	Lower	Mid	Upper
Cost Sharing of installation and maintenance \$250/station (subset)	12,500	15,500	18,750	18,750	23,500	28,000	25,000	31,250	37,500
Data Management	Lower	Mid	Upper	Lower	Mid	Upper	Lower	Mid	Upper
Ingestion, QC, modelling, dissemination (UI) ~ 250 stations total	75,000	100,000	125,000	75,000	100,000	125,000	75,000	100,000	125,000
Incorporating models into system	20,000	30,000	40,000	20,000	30,000	40,000	20,000	30,000	40,000
Ongoing use/expansion of BC DAS	50,000	60,000	80,000	50,000	60,000	80,000	50,000	60,000	80,000
Total annual Cost	212,500	281,750	361,250	227,500	302,250	386,750	247,500	327,500	417,500
Staffing Resources									
Full Time Equivalents	Lower	Mid	Upper	Lower	Mid	Upper	Lower	Mid	Upper
Network Coordinator	0.5	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Data Technician	0.5	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Additional Support			0.5		0.5	1.0	1.0	2.0	3.0
Total Staff Positions	1.0	1.5	2.5	2.0	2.5	3.0	3.0	4.0	5.0

CONCLUSION

The agriculture industry faces numerous challenges. Pressure from global markets lower commodity prices, while the prices of inputs, land scarcity, and labour shortages continue to drive up costs. Producers are also stewards of the land and must preserve this resource for future productivity. This involves judicious use of water, nutrients, and pest control products. Consumers are demanding increased accountability, transparency, and traceability across the entire supply chain. Consumers demand to know where their food came from and how it was produced, processed, and transported. Much of this accountability falls on farmers.

The industry must identify new and innovative strategies to increase efficiency and remain competitive. Such strategies exist, but uptake has been sluggish, perhaps due to lack of local expertise, understanding, perceived value, or urgency. Management that is based on suboptimal technology and techniques will fall short of its potential and will affect the competitiveness and sustainability of BC farms.

In a well-adapted production system, what to plant, when to plant, how it will grow, whether to apply supplemental water or other inputs, and when to harvest are greatly governed by the area's climate. Climate describes approximately when freezing is likely to occur, how much heat will be received, when and how much rain will come, the duration of the growing period, and countless other factors that influence how a crop behaves.

As climatic variability increases, so does the risk to production. While short-term forecasts can help with day-to-day activities, longer-term climatic changes may require a reconsideration and overhaul to how production is done. These adaptations are difficult without means to quantify the changes that are taking place. More accurate climate predictions, validated by improved observations, can then provide the basis for more cost-effective and lower risk climate policies²⁴.

Above all, these initiatives must be locally driven - working with communities and individuals who are passionate and interested in adopting new technologies that will help them manage their farms. BC has a high number of small independent farms. Improving access to the latest innovations and technological resources will make these farms more competitive. This benefits all of BC.



RECOMMENDATIONS

COMMUNITY-BASED MONITORING

The most effective way to enhance weather monitoring is to promote a community-based model that involves participation in weather collection by different organizations and individuals. This decentralized approach improves efficiency and costs by engaging local resources.

To increase the inventory of available weather data, existing weather stations should be evaluated for their suitability for agricultural use based on monitoring standards and guidelines that need to be established. New stations would also need to adhere to these guidelines. The station owner could be eligible to receive assistance for hardware and data costs.

PROVINCIAL COORDINATION

Establish a formalized agricultural weather-specific entity that acts as a province-wide resource for existing and potential weather station and weather network operators. This entity coordinates closely with regional interests to provide support and resources. The entity would provide standards, guidelines, training, support, and a data handling infrastructure that would serve the needs of agriculture and provide methodological consistency between networks. A dedicated Network Coordinator should be appointed.

CENTRALIZED DATA PLATFORM

Develop and provide a central platform on which to process, manage, quality control (QC), model, and redistribute weather information in a user-friendly manner. An effective QC is imperative. This would be a combination of automated processes and human oversight. Every weather station and collected element must have sufficient metadata. All agricultural weather network operators in BC should be required to also follow this standard for documenting and reporting all monitoring details. A Data Technician is required to support this initiative.

DECISION SUPPORT TOOLS

Decision support tools (DSTs) help producers make informed decisions to improve efficiency, identify opportunities to optimize production, reduce inputs, and increase profit. The data platform must include decision support tools that serve different production types. Education and awareness are key components of any agricultural weather program. Uptake of decision support tools will require training and support. Regional and local farm advisors and industry groups can assist with this training.

HARDWARE

Some viable hardware options are identified. Stations that are less complex are ideal in that basic maintenance and repairs can be performed by local resources instead of centralized dedicated technicians. Davis Instruments and METER Group stations are well suited for such applications. All stations should collect a minimum of air temperature, relative humidity, and rainfall. Ideally, stations will also collect wind speed and direction and solar radiation. Stations that are used for disease prediction should have leaf wetness sensors. Information should be transmitted at least hourly.

FUNDING

To succeed, a formalized agricultural weather program requires long-term and secure funding. This funding will go towards establishing and maintaining the data platform, incorporating DSTs, and supporting network and station operators with hardware and operational costs. Adequate funding will enable the program to become established and to meet its short-term and long-term objectives.

REFERENCES

- ¹ Crawford, E. and MacNair, E. 2012. BC Agriculture Climate Change Adaptation Risk + Opportunity Assessment, Provincial Report. BC Agriculture & Food Climate Action Initiative, https://pics.uvic.ca/sites/default/files/uploads/publications/BC%20Agriculture%20Report_0.pdf
- ² Nadler, A.J. 2007. An Agroclimatic Risk Assessment of Crop Production on the Canadian Prairies. MSc Thesis. Department of Soil Science, University of Manitoba.
- ³ Daly C. 2006. Guidelines for assessing the suitability of spatial climate data sets. *International Journal of Climatology* 26(6): 707–721.
- ⁴ Newlands, N.K., Davidson, A., Howard, A., and Hill, H. 2010. Validation and inter-comparison of three methodologies for interpolating daily precipitation and temperature across Canada. *Environmetrics*. DOI: 10.1002/env.1044, https://gracilis.carleton.ca/davidson/publications/2010/Newlands_Environ_2010.pdf
- ⁵ Carlson, T., Cohen, A., and Hartwig, K. 2017. A Snapshot of Community Based Water Monitoring in Canada.
- ⁶ Tam, S. and Anslow, F. 2018. Gap Analysis and Overview of Weather Station Data in British Columbia Agricultural Regions. https://bcfoodweb.ca/sites/default/files/res_files/Gap%20Analysis%20and%20Overview%20of%20Weather%20Station%20Data%20in%20BC%20Ag%20Regions%20-%20FINAL%20-%20Sep%202018.pdf
- ⁷ Daly C. 2006. Guidelines for assessing the suitability of spatial climate data sets. *International Journal of Climatology* 26(6): 707–721.
- ⁸ WMO. 2016. The Global Observing System for Climate: Implementation Needs, https://library.wmo.int/doc_num.php?explnum_id=3417
- ⁹ Environment Canada. 1992. AES Guidelines for Cooperative Climatological Autostations. Version 2.0. Canadian Climate Program Board.
- ¹⁰ Hou, A. Y., Kakar, R. K., Neeck, S., Azarbarzin, A. A., Kummerow, C. D., Kojima, M., Oki, R., Nakamura, K., and Iguchi, T. 2014. The global precipitation measurement mission. *Bulletin of the American Meteorological Society*, 95(5), 701–722. <https://doi.org/10.1175/BAMS-D-13-00164.1>
- ¹¹ Dombrowski, O., Hendricks Franssen, H.J., Brogi, C., and Bogena, H.R. 2021. Performance of the ATMOS41 All-in-One Weather Station for Weather Monitoring. *Sensors* 2021, 21, 741. <https://doi.org/10.3390/s21030741>
- ¹² FAO. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56.
- ¹³ WMO. 2016. The Global Observing System for Climate: Implementation Needs. https://library.wmo.int/doc_num.php?explnum_id=3417
- ¹⁴ QA4EO Task Team. 2010. A Quality Assurance Framework for Earth Observation: Principles. Group on Earth Observation. http://qa4eo.org/docs/QA4EO_Principles_v4.0.pdf
- ¹⁵ Lee M. K., Moon S. H., Kim Y. H., and Moon B. R. 2014. Correcting abnormalities in meteorological data by machine learning. *Proceedings of the 2014 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*; October 2014; San Diego, CA, USA. pp. 888–893.

-
- ¹⁶ Lee M. K., Moon S. H., Yoon Y., Kim Y. H., and Moon B. R. 2018. Detecting anomalies in meteorological data using support vector regression. *Advances in Meteorology*. 2018:14. doi: 10.1155/2018/5439256.54392565439256
- ¹⁷ Kim, H. J., Park, S. M., Choi, B. J., Moon, S. H., and Kim, Y. H. 2020. Spatiotemporal Approaches for Quality Control and Error Correction of Atmospheric Data through Machine Learning. *Computational intelligence and neuroscience*, 2020, 7980434. <https://doi.org/10.1155/2020/7980434>
- ¹⁸ WMO. 2019. WIGOS Metadata Standard. WMO-No. 1192. https://library.wmo.int/doc_num.php?explnum_id=10109
- ¹⁹ Stigter, C.J. 2007. From basic agrometeorological science to agrometeorological services and information for agricultural decision makers: A simple conceptual and diagnostic framework. *Agricultural and Forest Meteorology* 142 (2007) 2-4. 142. 10.1016/j.agrformet.2006.10.002.
- ²⁰ Rossi, V., Sperandio, G., Caffi, T., Simonetto, A., and Gianni Gilioli, G. 2019. Critical Success Factors for the Adoption of Decision Tools in IPM. *Agronomy* 9 (11).
- ²¹ Crowder, D. W. 2021. Interim Director for WSU Decision Aid System. Personal Communication.
- ²² Statistics Canada. 2016. Census of Agriculture. <https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/statistics/census-of-agriculture>
- ²³ SOFF. 2020. Establishing the Systematic Observations Financing Facility: A new way of financing basic observations. Systematic Observations Financing Facility. https://library.wmo.int/doc_num.php?explnum_id=10483
- ²⁴ Cooke, R., Wielicki, B.A., and Young, D.F. 2014. Value of information for climate observing systems. *Environ. Syst. Decis.* 34, 98–109. <https://doi.org/10.1007/s10669-013-9451-8>



APPENDIX A – REGIONAL MAPS OF SPARSE COVERAGE

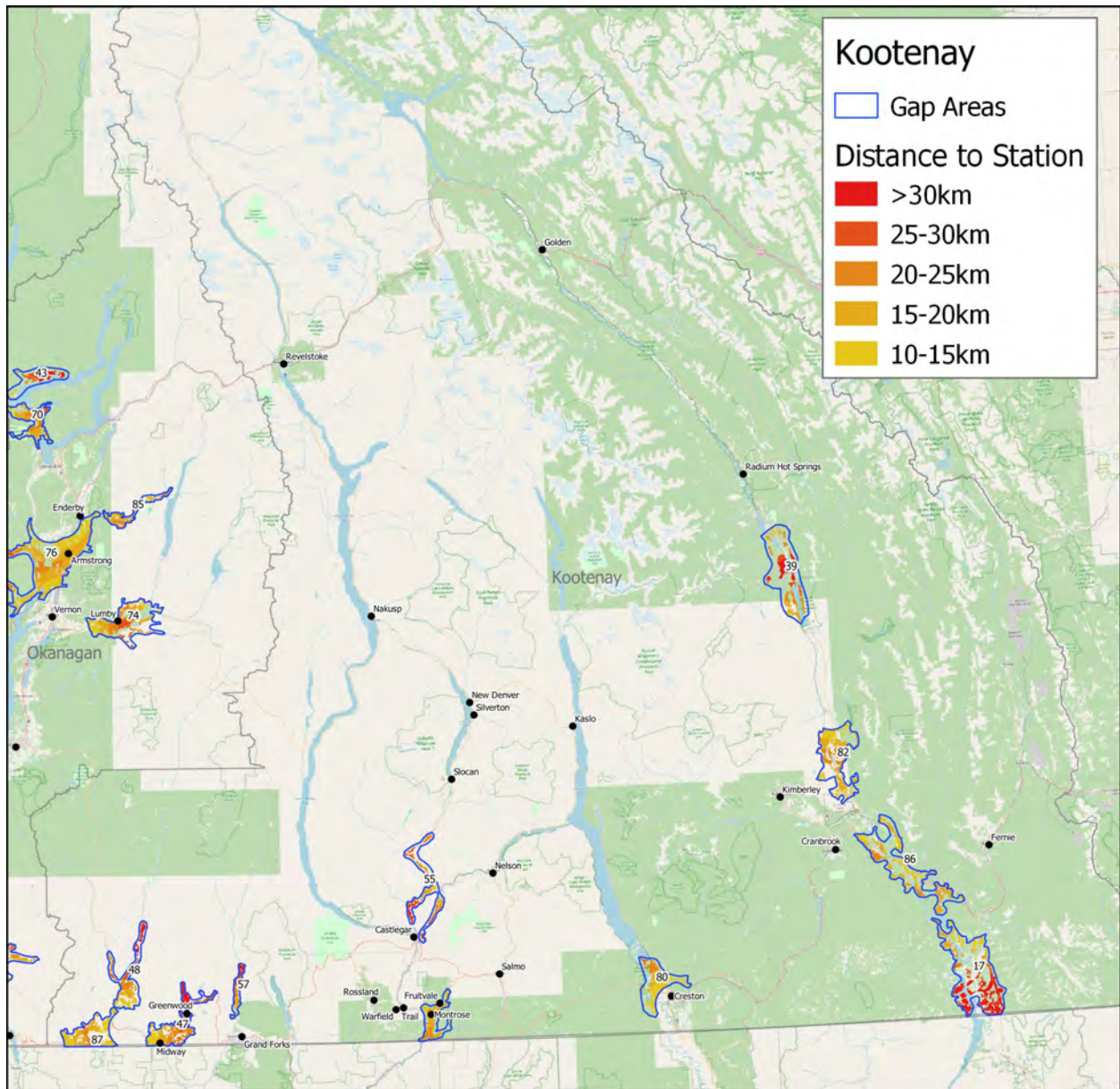


Figure 26: Gap Areas - Kootenay

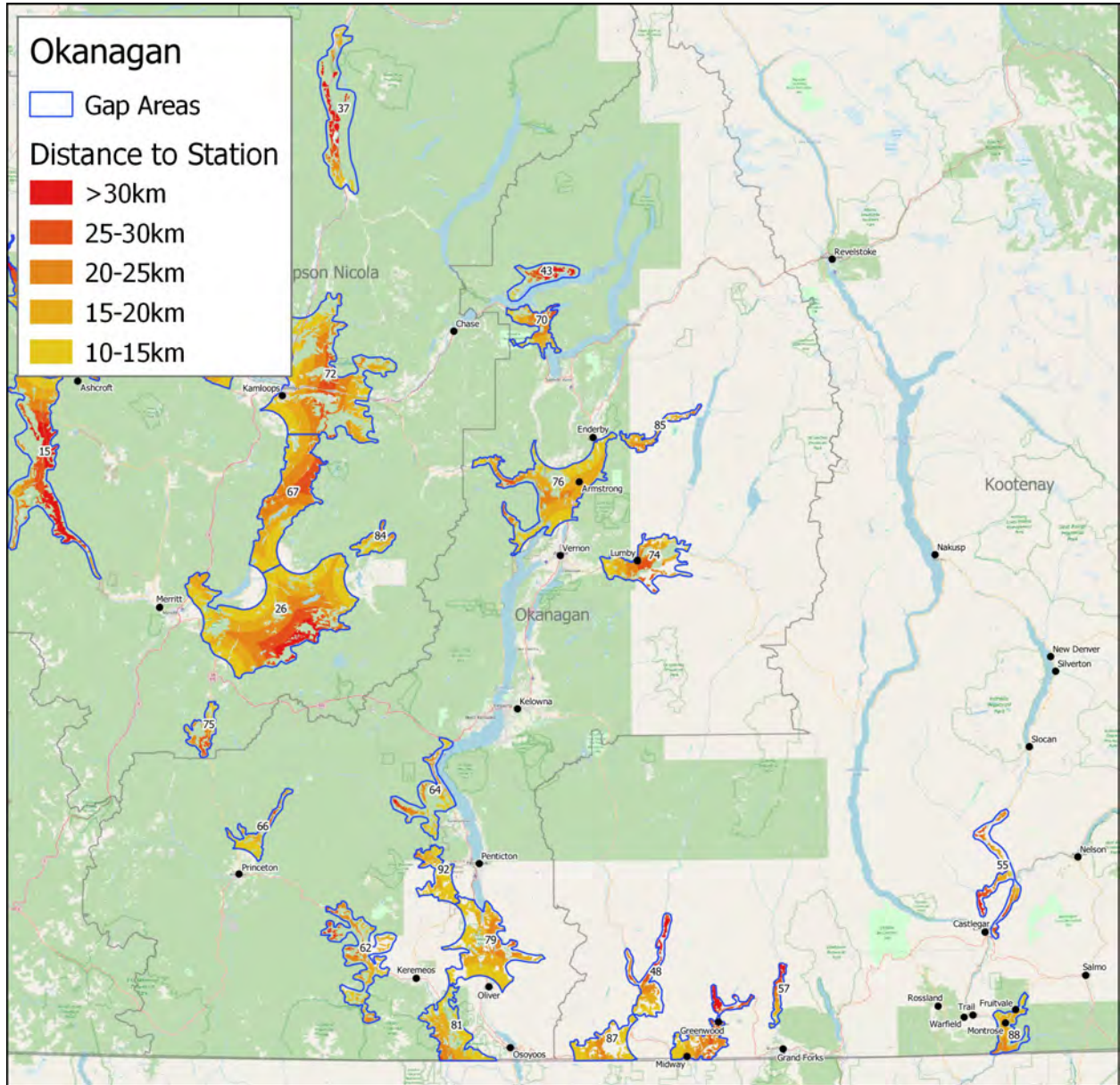


Figure 27: Gap Areas - Okanagan

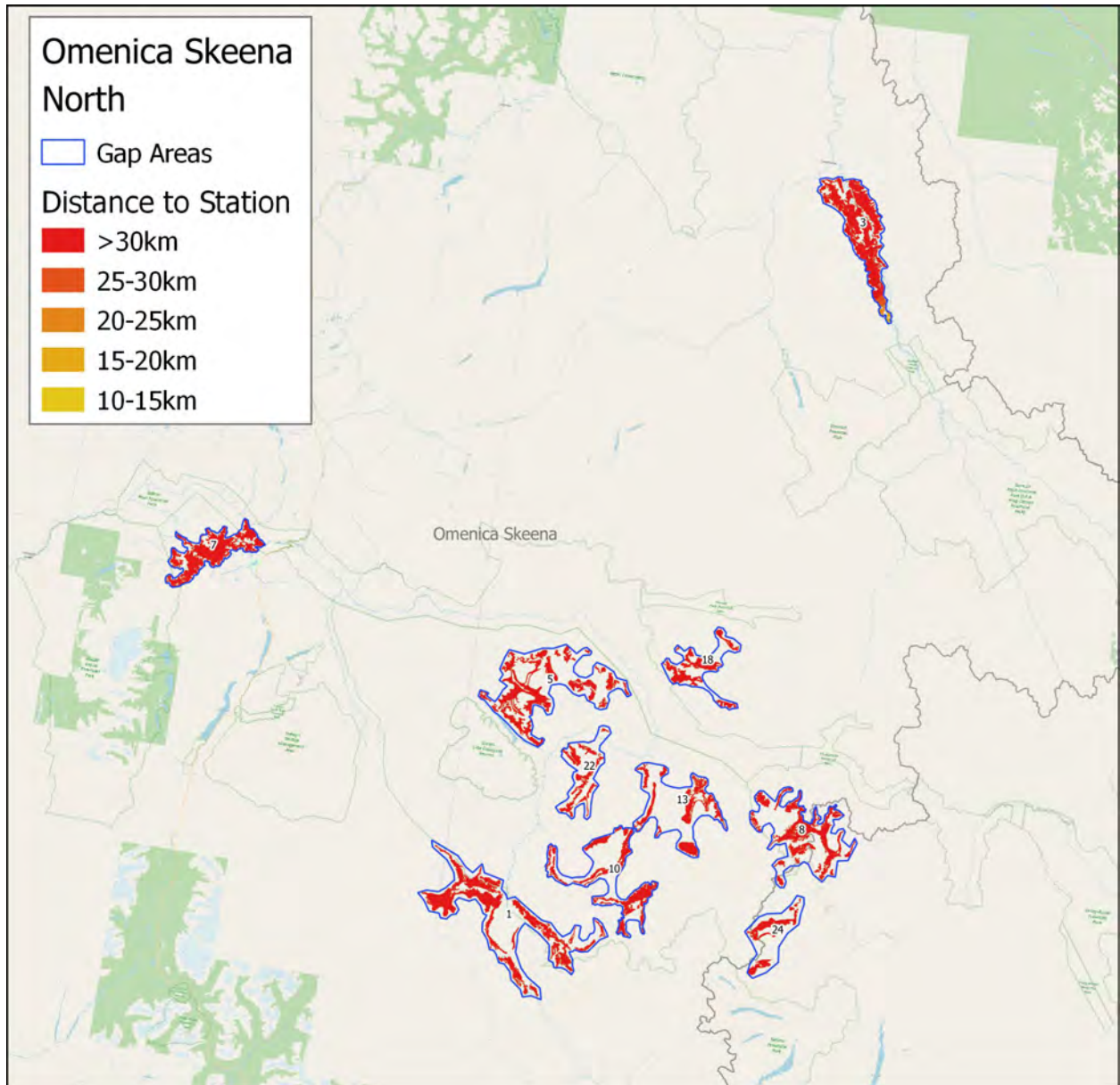


Figure 28: Gap Areas - Omenica Skeena North

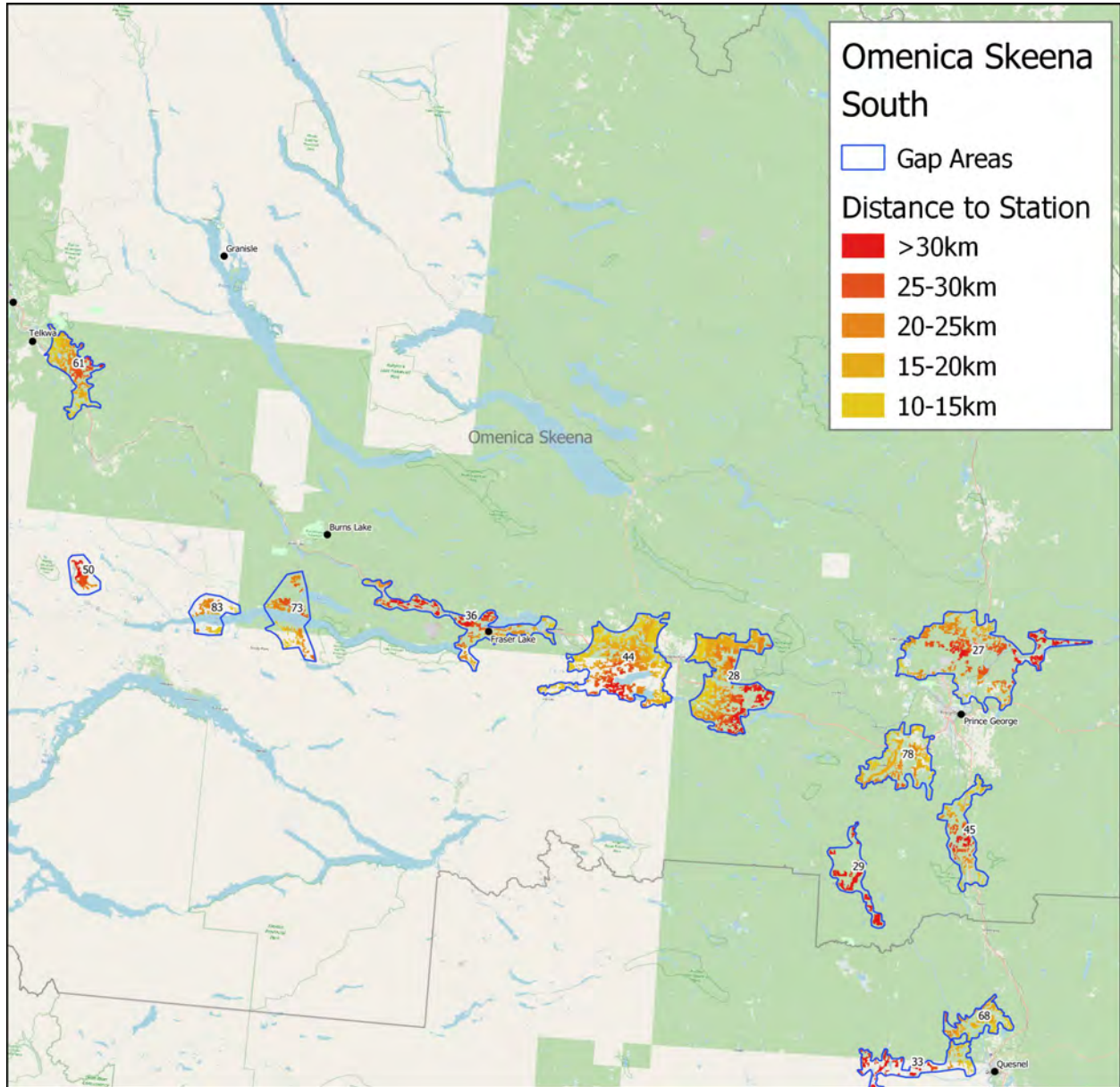


Figure 29: Gap Areas - Omenica Skeena South

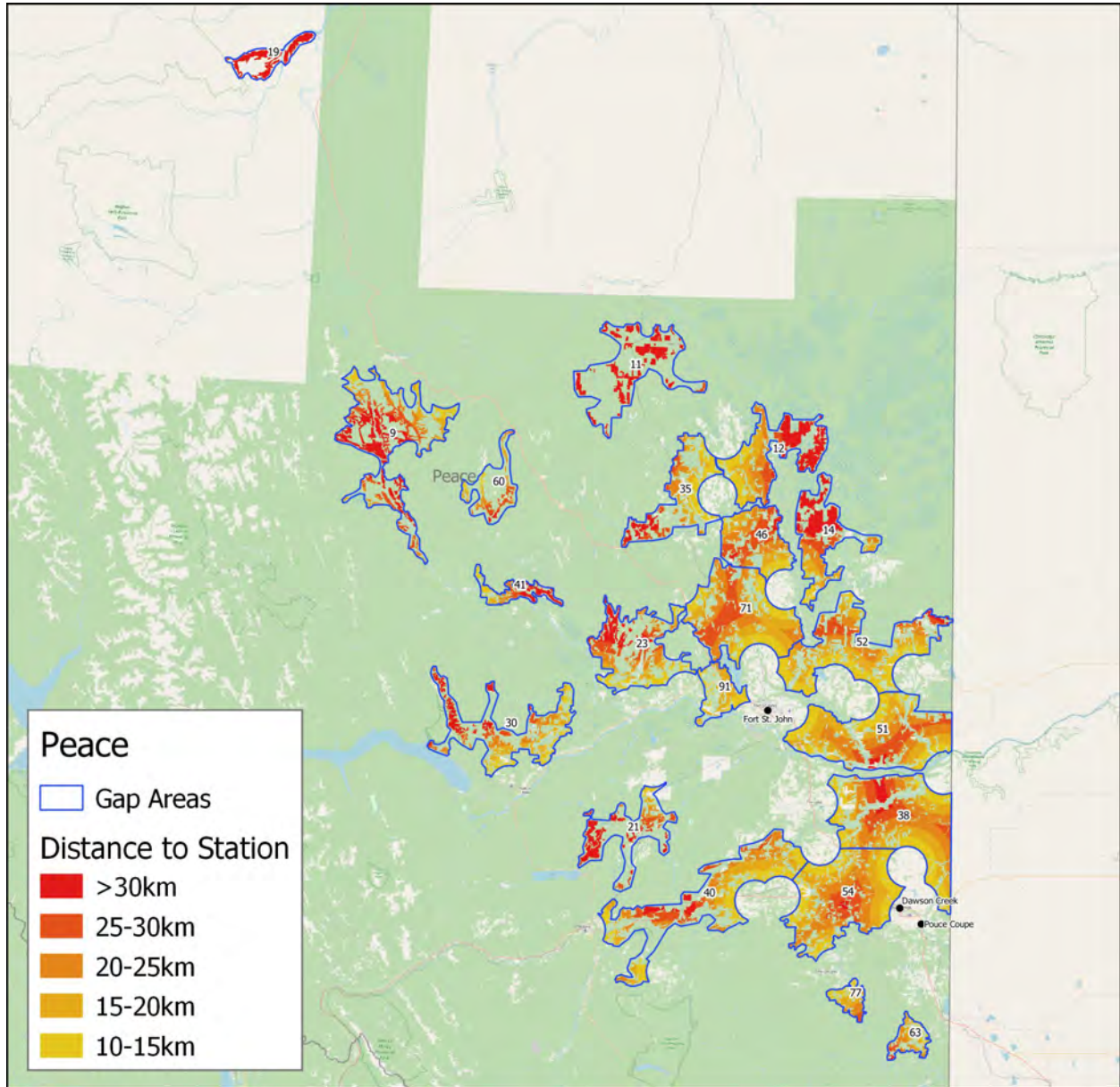


Figure 30: Gap Areas - Peace

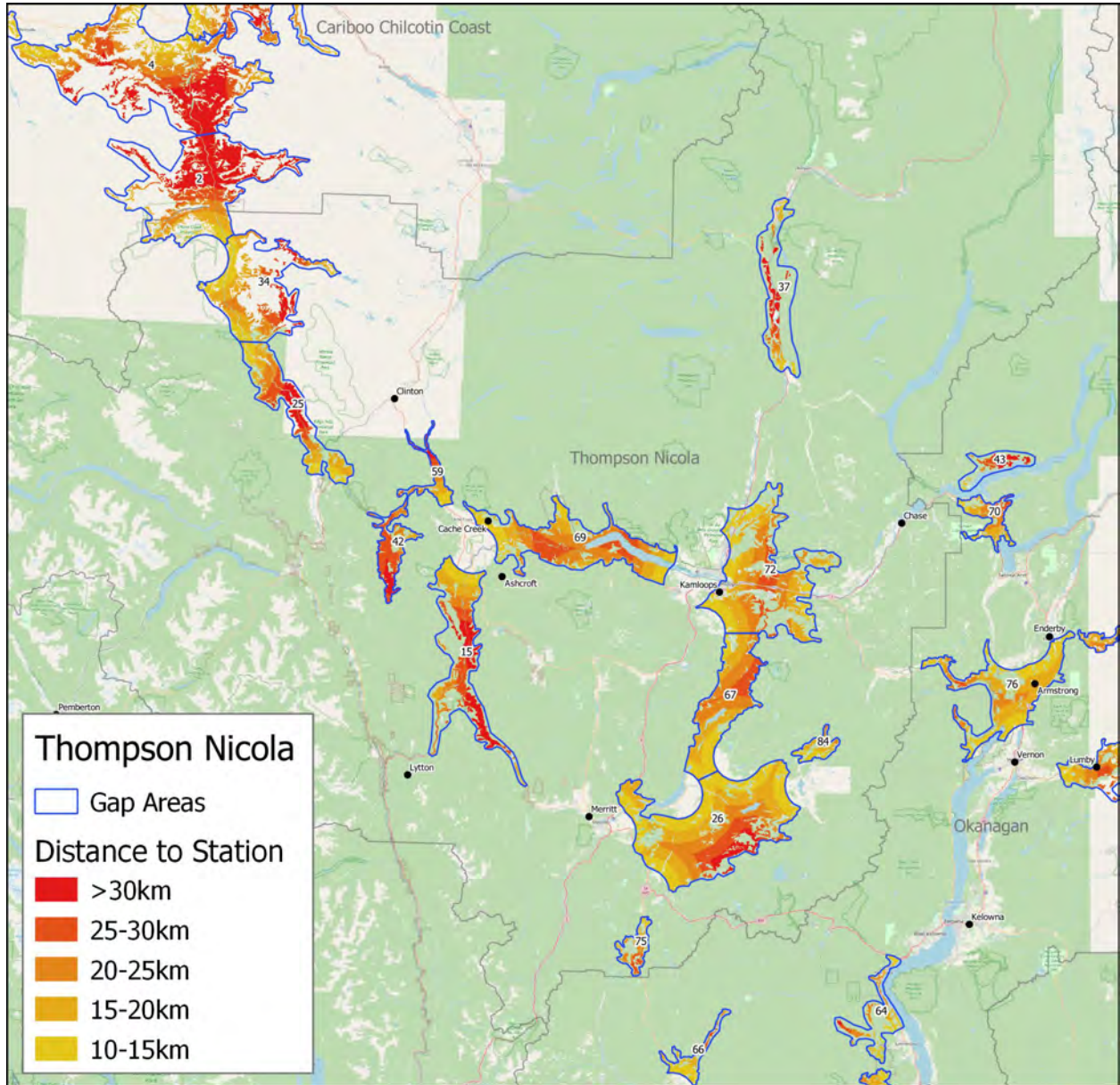


Figure 31: Gap Areas - Thompson Nicola

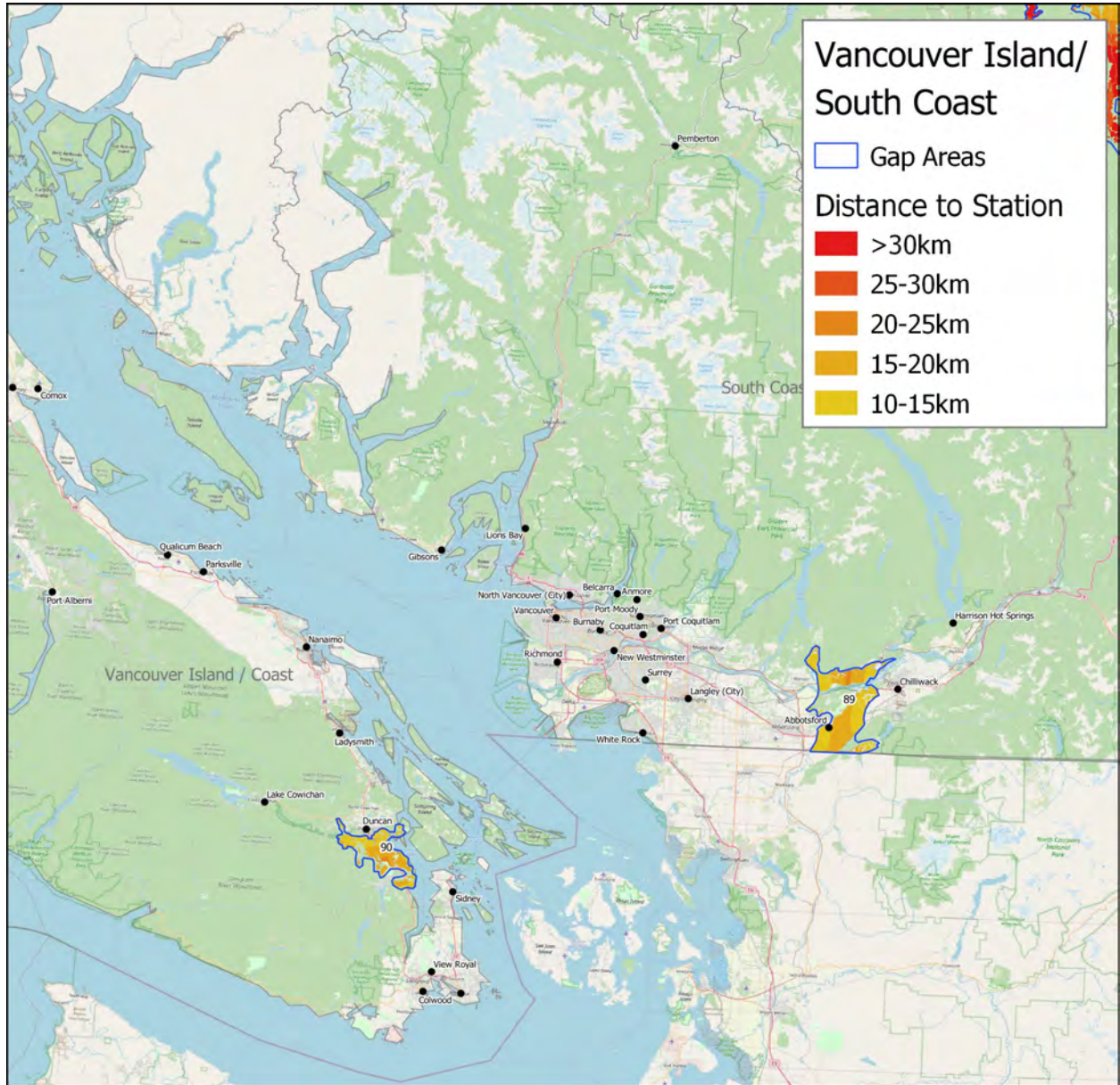


Figure 32: Gap Areas - Vancouver Island/South Coast

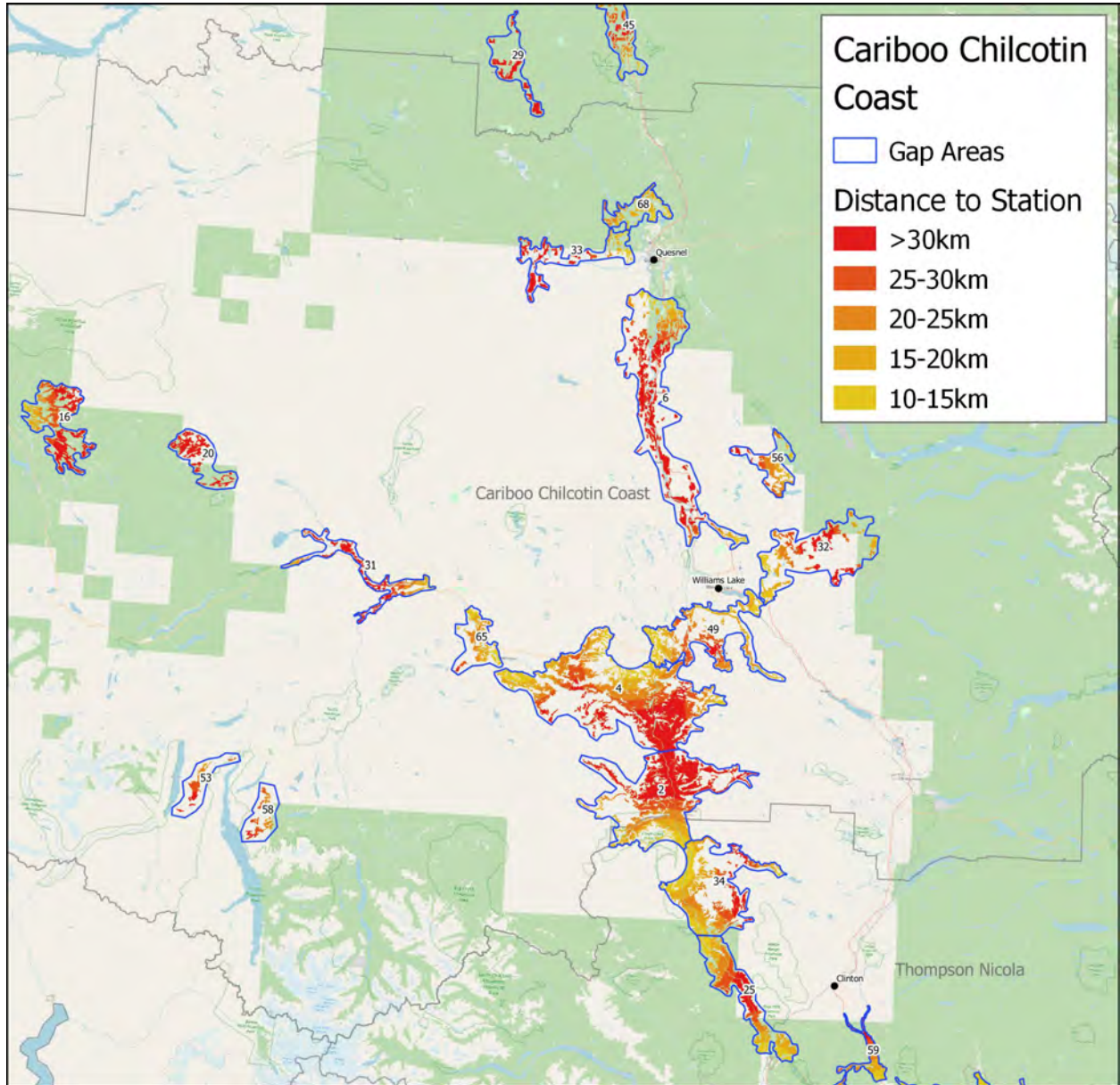


Figure 33: Gap Areas - Cariboo Chilcotin Coast

Overall Network:

Climate information is foundational to all other work to be done; needing to outline variability and have a good understanding of what climate information we need to help make decisions.

Density of stations is challenging due to so many microclimates. Starting to see more expansion of planting in areas that were fallow previously. Going into higher geographic areas. Beyond traditional areas.

PCIC has a need for particular parameters and standardization but other tools (like DAS or for IPM) need different scales of coverage.

Weather stations are proving to be very important to producers; more and more are being used.

Existing weather network is good. More stations would be better. We don't have adequate information on elevational changes or proximity to the lakes.

What people had been collecting wasn't found easily (data exists and not put online).

A public or accessible network would benefit across many sizes of producers. Especially would be of benefit to small producers.

If there are private networks or producers have their own station, this means only large and more economically viable farms will use weather data and tools.

If data is useful more widely shouldn't it be a public cost?

Many growers comment that their stations are in different microclimates. Difficult to capture variability. Only a small group of growers will adopt their own systems.

Frost - making a temperature measurement near the ground vs. the typical meteorological height; making measurement near the ground is key for vegetable producers. Multiple inputs needed for near surface temperature.

The Okanagan has a high density of weather stations. The major gaps are around Prince George, Williams lake, and the Nechako Valley.

Storms blowing through Vernon that aren't observed in other areas. More is better, but not always financially feasible.

Data QC is very important! Filters out nonsense data.

We have a lot of forage growers that could use more accurate weather data.

In some forage areas, there are 40 km gaps in coverage.

Decision Support Tools:

DAS does a very good job at taking complex weather information and making it simple.

Once the growing season gets going, I am consulting DAS daily. ... I have appreciated the support I have received and value this tool immensely.



I think the way to get DAS out there is education and demonstration. Observation of success in using new tools by other farmers/growers will lead to the shift to more widespread use.

The tool on Farmwest is good but could be improved to make it more farmer-friendly.

Ensuring that this data is being collected properly is key for modelling.

Leaf wetness - needs to be properly measured but is extremely valuable.

AAFC's mandate is research. Once a model is ready, there should be a common platform to deploy models for growers.

Blueberry phenology would be useful for predicting harvest timing.

In the Maritimes, low bush blueberry growers receive a monilinia (mummy berry) forecast that is triggered by rain events. This would be useful for Fraser Valley blueberry growers. Combined with phenology, this could be used to plan sprays.

Detection of impending frost and in general big temperature swings would be an area where we could use more decision support tools.

Blueberry and raspberry growers wouldn't necessarily benefit from winter hardiness as they aren't using frost protection.

One of the biggest struggles with cranberry production is that cranberry fields are often low-lying, which makes in-field temperatures quite different from nearby weather stations. In-field weather stations are necessary.

In cranberries, timing of fungicides is based on percentage bloom. Accurate in-field temperatures could be used with phenology models to develop bloom predictions.

Adding grape grower stations [to DAS] would be excellent.

Local accurate weather data - degree day modelling would be valuable for pest management.

Something that has definite practical importance [for wine grape growers], and is related to climate, is to conduct measurements of vine water status using soil moisture and leaf potential data. Several of us are collecting that kind of data, to improve our irrigation practices, avoid water stress, etc.

We have had some [vegetable] growers with issues such as carrot rust fly, cutworm and raspberry yellow rust (Smithers area).

First cut alfalfa quality models would be interesting to investigate.

General Comments:

There are a number of tree fruit entomologists at AAFC who will be retiring. These positions are important, and replacements are needed.

Forecast accuracy is not good. This needs both more stations (to capture microclimates) and probably better models too.

Precipitation prediction is especially bad.

Accurate forecasts are extremely important for forage production.

Need dedicated staff to get that information to the growers.

There has been a shift in perspective. Growers are having to take ownership of their management. There are fewer government horticulturalists. Some packers still have extension.

It would be helpful to have audio tips and explanations in Punjabi (not all Punjabi speakers read Punjabi). Especially difficult with technical information (tree fruit guide/labels).

Our agricultural organizations could easily help disseminate the information.

One of the key roles of industry associations is communication to their members. Providing that route for demonstrations and workshops - getting the information out.

