Increasing availability of agriculturally relevant weather data
[Phase 1]

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Executive Summary

Weather INnovations Consulting LP was hired to provide a needs assessment of agricultural weather monitoring within the Peace River Region of BC. The study reviews agriculture-related decision support tools (DST's), meteorological monitoring, existing networks, gap analyses, data handling options, and provides recommendations for how to proceed.

Within the region, there are several existing monitoring networks and a few agriculture-related weather information providers. Between the existing weather stations, there are some significant monitoring gaps that would need to be addressed in order to provide adequate coverage of the region. To achieve reasonable coverage of the agricultural areas, a minimum of 10 additional weather stations are recommended. These new stations should be established in cooperation with local stakeholders, including producers, businesses, and local governments such as cities, towns, and the Peace River Regional District (PRRD). A cost-sharing program would be the most effective means of encouraging individuals and businesses to invest in weather monitoring. It is important to consider the ongoing costs of monitoring stations.

To make use of existing data, the region is strongly urged to collaborate with other weather providers. Part of this collaboration would be to participate in the Climate Related Monitoring Program (CRMP). The CRMP provides knowledge, information, methods, procedures, experience, and expertise, as well as data sharing and archiving. However, the CRMP provides data and not industry-specific tools such as those specific to agriculture. These tools would therefore need to be sought elsewhere. Of the existing providers, Farmwest and WeatherFarm are likely candidates as both of these services already provide data and agriculture-related tools to producers.

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1.0 Introduction

The BC Peace River region is a distinct area with unique features that set it apart from the remainder of BC as well as the prairie agricultural region with which it is normally associated. The region is characterized by short, warm summers, generally productive soils, and variable topography. With approximately 890,000 hectares of farmland, this region is the largest agricultural area in British Columbia. Given its northern latitude – among the most northerly of Canadian agricultural production, the region faces certain challenges. Generally these challenges are weather-related, including limitations in heat, moisture deficits or surpluses, and extreme weather. In light of a changing climate, these challenges are expected to increase, requiring constant adaptation on the part of the producer and the sector as a whole.

Through recent consultations and subsequent reports, including the *Grain & Oilseed Production Peace Region snapshot report* and the *Regional Adaptation Strategies Series – Peace Region,* weather monitoring, availability of weather data, and agriculture-related information were identified as key gaps.

> *"A range of informational gaps currently exist. One example is the limited weather data collection and availability to enable localized monitoring of patterns, trends and changes. Although some weather data is collected in the area by actors such as BC Hydro and oil and gas companies, it is currently unavailable to producers in a form that is straightforward for agricultural application."*
>
> Grain & Oilseed Production Peace Region Snapshot Report, 2012
>
> *"Availability of local and agriculturally relevant weather data is limited in the Peace region at present. Producers require improved local weather data for immediate and near-term decisions but also to evaluate shifts occurring over time."*
>
> Regional Adaptation Strategies Series – Peace Region, 2013

Action items that were presented within the *Regional Adaptation Strategies Series* recommend an evaluation of options for improving weather data collection and analysis and that these options are implemented to ensure availability of weather data to producers. This report is the first phase in this process, providing an assessment of meteorological monitoring, existing networks, agriculture-related decision support tools (DST's), data handling options, and recommendations on how to proceed.

2.0 Meteorological Monitoring

The following section very briefly describes some of the most common agriculturally-relevant information that is collected from a weather station. This list is not exhaustive, nor do the descriptions cover all aspects that should be considered. The intent of this section is to educate the reader on some of the basic concepts that are discussed later in this document.

In order to produce accurate, representative, and comparable data, weather and climate monitoring are extraordinarily reliant upon standards. These standards, often set by governing bodies such as the World Meteorological Organization (WMO), dictate siting of observing stations, methods of measurement, types of sensors, placement of sensors, and handing of data. These standards enable direct comparisons between different areas or timeframes. Each parameter has a set of standards, which include measurement height, distance from obstructions, and averaging/calculation methods. For example, the diagrams below, taken from Atmospheric Environment Services Guidelines for Cooperative Climatological Autostations, show the recommended siting requirements for a weather station. These include the region surrounding the station and the minimum setbacks from obstructions of the various elements within an observing site.

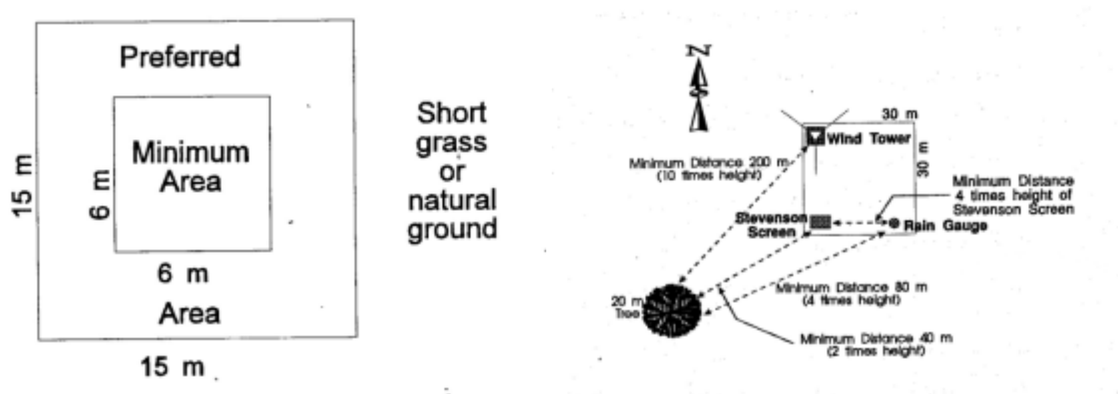

Figure 1: Environment Canada Climatological station siting guidelines and minimum distances

Despite the strict rules of monitoring, real-life situations will often lead to certain deviations from the standards. Additional considerations such as site restrictions, equipment access, convenience, and security must be taken into account. Regardless of whether a weather station is on private or public property, it must be in a location that will not be at risk of damage from nearby equipment or animals. Vandalism and theft must also be considered. Often, a remote site, despite being largely out of sight, can be more at risk of vandalism than a site that has frequent traffic and passive surveillance. Damage from vandalism can be very expensive and will likely result in lost data. Access to a site is important for maintenance, repairs, and inspections. A station that can only be accessed by a lengthy hike, an all-terrain vehicle, or by aircraft can get quite costly and time consuming to maintain.

Certain types of stations can also create restrictions. Stations that require hardwired power or communications must be within a reasonable trenching distance of the source. This is also the case for stations that communicate via short-range radio. Depending on the signal strength and obstructions, these stations may be limited in terms of how far they may be installed from buildings or yard-sites, which often have trees and other obstructions nearby.

In certain situations, whether due to security or lack of space, weather stations are placed on rooftops or on antenna towers. For some general applications this may be acceptable but, in most cases, it is not. Particularly for agricultural applications that often rely on temperature and relative humidity. Roofs, whether they are asphalt, metal, or other materials, generally emit a great deal of heat. This heat will affect the temperature readings as will the distance that the sensor is from the ground. Relative humidity above a roof, compared with that measured above a transpiring grass surface, will also be significantly different. Parameters such as rainfall may be affected due to the likelihood of stronger winds further above the ground. Wind affects a rain gauge by reducing the amount of "catch", resulting in under-estimation of the rainfall.

When monitoring meteorological conditions, it is worth considering the important distinction between weather and climate. By definition, weather is the day-to-day or perhaps minute-by-minute variations in the condition of the atmosphere. Climate is the long-term behaviour of the atmosphere. While climate is derived from the weather, climate is also more sensitive to longer-term trends, shifts, or variations in the weather. Therefore, to measure climate, extremely accurate and consistent weather monitoring is necessary. This is particularly important when studying climate change, as non-climatic factors such as sensor types, equipment lifespan, monitoring protocols, and site changes can introduce a tremendous amount of noise in the climate record, making it very difficult to isolate changes that are directly related to climate. For example, sensors that are not replaced or calibrated regularly will gradually degrade over time, often manifested as sensor "drift". If the issue is not identified and resolved, this "drift" could be interpreted as a shift in climate instead of simply being attributed to a bad sensor. Likewise, many weather stations are located at airports, which are often situated near cities. As urban populations have grown and cities have expanded, these airports, which were once far removed from urban centres, may now be completely surrounded by cities. The widely known "urban heat island effect" could start influencing the local temperatures at the weather station site, again causing artificial climate trends (DeGaetano and Allen 2002).

Acknowledging the intricacies and meticulousness required for proper climate monitoring, Environment Canada and other national meteorological bodies around the world have established reference climate stations (RCS). These stations have been built and are maintained to the highest standards in order to accurately document and understand climate change and variability. These stations are very expensive to establish and maintain; therefore there are not many of them. Within Canada, there are approximately 305 RCS's. Given the vastness of Canada, this does not provide a station density that is adequate to represent the many climates that exist.

Many organizations and individuals have recognized the limitations associated with the national network and, out of necessity, have established their own monitoring programs. These programs have generally been purpose-specific, enabling the organization to access the necessary data for their operational requirements. These requirements may be flood forecasting, avalanche risk, forest fire danger, evaluating road conditions, or for agricultural applications. Within BC, several groups have built and actively maintain their own networks. These networks will be discussed later in this document.

2.1 Weather Stations

A weather station is often defined as any location where meteorological observations are made, either electronically or manually. For the purpose of this report, only electronic automated meteorological stations with communications capabilities are considered. While there is tremendous value in manual observations or observations that are stored on-site to be manually downloaded, these have limited value for use in near-real-time applications, such as decision support tools.

The availability of real-time data is vitally important for many applications in order to adequately analyze current conditions and to make appropriate decisions and forecasts. The one disadvantage to real-time data is that this data is not normally subject to any sort of rigorous quality control. Most often, the data is passed through coarse filters that remove any values that are beyond a reasonable range (e.g. Air Temperature that is <-40°C or >+40°C). The other disadvantage to data from automated stations compared with human manual observers is that the quality control must often be more stringent. Most conscientious human observers will have the common sense to filter out any very bad values.

Traditionally, meteorological monitoring stations have been very complex and expensive. This was the main reason why very few organizations, other than national meteorological services, would operate their own networks. With the advent of integrated circuit chips and microprocessors, and as electronics and communications have become better and more affordable to manufacture and purchase, so to have many types of weather stations. Weather stations are now smaller, more reliable, and require less power to operate. This has enabled more organizations and individuals to operate their own monitoring stations or networks. This has also made available a greater spectrum of equipment, including a range of costs and quality. Improved communication methods, including more affordable options with higher levels of reliability, have also made real-time weather monitoring more feasible.

The actual definition of real-time vs. near-real-time tends to vary. Generally, real-time is referred to as data that is retrieved at least on an hourly basis. Data that is retrieved every few hours or several times per day would normally be considered as near-real-time. The frequency at which data is retrieved is different than sampling or recording frequency. Sampling frequency is how often the datalogger takes an actual measurement from the sensor. This could be several times per second, per minute, or per hour. The recording frequency refers to how often a value gets stored in the memory of the datalogger and that subsequently gets transmitted. A single record is often calculated from several samples. For example, an hourly average temperature record would be the calculated mean of all temperature samples taken within the past hour. Recording frequencies are generally between five minutes and one hour. Anything coarser than hourly is of limited use for some of the more complex decision support tools (DSTs) such as disease risk models. However many basic models, including growing degree days (GDD),, crop heat units (CHU), and crop evapotranspiration(some versions) only require daily data (i.e. Tmax, Tmin). Also, for many applications such as flood forecasting, drought assessment, and fire risk, parameters such as rainfall, even if recorded daily, can be extremely valuable.

Improvements in the communications networks and technology have allowed data to be affordably accessed on a real-time or near-real-time basis. Previously, satellite, UHF radio, dial-up modem, and analogue cellular modem were the only methods of transmitting data from a weather station to a central database. Today, digital cellular and internet have expanded those options in most regions. Of course, these regions must have adequate cellular or internet coverage, which is not a given, particularly in remote locations. Furthermore, reliability of the various communications options must also be weighed. For example, rural internet can be subject to outages, including those caused by power failures, which may cause the internet to not work. The cellular network, while improving, can also experience connectivity issues from time to time. Satellite and dial-up telephone are still considered the most secure and reliable methods of communication. Therefore, applications that cannot have delayed or missing data should use the most reliable communications available.

With lower power consumption and improvements to batteries and solar technology, most weather stations can now function without the need for mains power. This allows a higher degree of flexibility in station siting and lowers the cost of establishing a station. Some exceptions include Environment Canada auto stations, which are mainly still powered externally. This is in part due to heavier power requirements at the sites, including aspiration fans. Another exception is the display and datalogging console of the Davis Instruments Vantage Pro 2 station, which is normally plugged into a wall outlet and an internet connection. The unit can also run solely with batteries and can be configured to work with a cellular modem.

2.2 Air temperature

Air temperature is one of the most common parameters that is measured. Particularly for agriculture, the air temperature provides an indication of frost occurrence, which generally delineates the start and end of the growing season and heat for the growth and development of plants and other organisms, including pests and diseases.

Historically, air temperature was measured using a liquid in glass thermometer, the concept being that liquid expands with temperature and is forced up a fine-bore stem where its volume corresponds to a graduated, calibrated scale. This process was completely manual, requiring a human to observe and record the air temperature, either recording actual temperature at certain times of the day or by recording temperature extremes using minimum and maximum thermometers. With the advent of precision electronics, automated temperature recording is now standard using thermistors, thermocouples, or thermocapacitors combined with dataloggers. These systems enable very precise and more frequent observations.

An important consideration when monitoring air temperature is that the actual sensor must not be exposed to direct sunlight. A sensor that is exposed to solar radiation will heat up considerably and thus record temperatures that are much higher than those of the surrounding air. Therefore, temperature sensors must be shielded from solar radiation and terrestrial radiation (radiation that is emitted from the ground) as well as be protected from precipitation and be exposed to free flow of outside air. This has typically been accomplished by using a Stevenson Screen, a white wooden box with double-louvered sides and a double roof, providing shelter from the sun, while also allowing air flow. While conventional Stevenson Screens are still widely used, particularly by Environment Canada, smaller plastic gill-type shield versions have become common for most modern automated weather stations. Many Environment Canada sites and some other networks use aspiration fans to ensure that the sensor is continuously exposed to the outside air. This is particularly useful during very calm conditions when there is little natural air movement.


Figure 2: Examples of a Stevenson Screen and gill-type radiation shield for air temperature monitoring

The standard height for monitoring air temperature, whether from a Stevenson Screen or from a gill-type shield, is between 1.25m and 2.0m above ground level, preferably over a surface representative of the surrounding area. Short grass is the preferred and the most typical ground cover. Surfaces that emit heat should be completely avoided. These would include pavement/roadways, bare ground, rock, buildings and roofs.

2.3 Relative humidity

Relative humidity (RH) is the ratio of vapour pressure to saturation vapour pressure at a given temperature, expressed as a percentage. If the air is at its saturation vapour pressure, the RH is at 100%. If the temperature of the air rises, so does the saturation vapour pressure, thus reducing the RH. Likewise, lowering the air temperature will increase the RH. The temperature at which further cooling causes condensation to form is known as the dew-point temperature. RH is almost always measured within the radiation shield and is often integrated within the temperature sensor.

For agricultural or agrometeorological applications, specifically in crop disease modelling, RH is quite useful as most diseases thrive in moist environments. A high RH for a specified duration, combined with appropriate temperatures, will often result in elevated disease risk. Alternatively, for crop disease modelling, the leaf wetness sensor is also commonly used. As the name suggests, the sensor simulates a leaf surface and detects whether it is wet or dry. From a disease perspective, some have argued that the presence of free water (droplets) is more applicable to disease risk than the amount of moisture within the air. The leaf wetness sensor is normally located closer to the ground than the temperature/RH sensor in order to represent a typical crop canopy as well as to catch the dew that may form closer to the ground or on the vegetation. For some applications, the leaf wetness and RH sensor may be located within the actual crop canopy.

Figure 3: Example of a flat-plate-style leaf wetness sensor

2.4 Precipitation

Precipitation is the most important parameter for many applications, including agriculture. Too little can result in drought; too much can cause flooding, both of which result in widespread agricultural losses. Precipitation includes rain, drizzle, snow, and hail, measured as the sum of all liquid, including melted snow or hail, expressed as the depth that it would cover on a flat surface. It does not include various forms of condensation such as dew, fog, hoar frost, or rime.

Figure 4: Standard (very accurate) Environment Canada Type B manual rain collector and small diameter (less accurate) rain gauges

Prior to automation, rainfall measurements were taken using various types of rain collectors that would simply catch rain within a basin or cylinder, which could then be measured as a depth. This manual method is still going strong and can be done with a high degree of accuracy, provided that the gauge diameter is at least four inches (10cm). Anything less is believed to be inaccurate (Strangeways, 2003).

As automated weather stations gained prominence, the tipping bucket rain gauge (TBRG) became the standard method of measurement as it could easily be connected to a strip chart, counter, or datalogger. The basic concept of a TBRG is that rain enters the funnel and drains into one of the two buckets. When a certain volume of rain accumulates in the bucket, the weight of the liquid causes the mechanism to tip, which then gets counted and recorded as the corresponding amount of rain (normally 0.1 or 0.2mm) as calibrated from the diameter of the orifice.

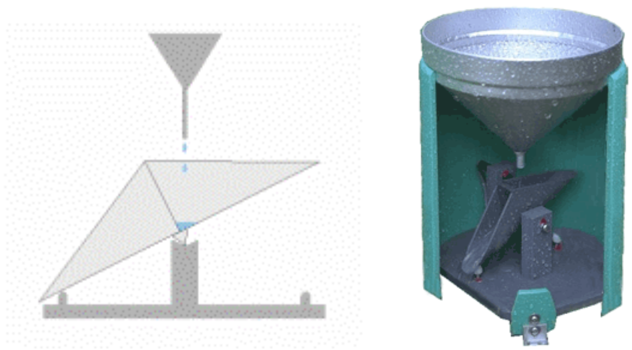

Figure 5: Basic mechanism of a tipping bucket rain gauge (TBRG)

There are many known problems with most TBRG designs. One of these issues includes under-catch during high-intensity rainfall events. When the rate of rainfall is beyond the measuring capacity of the gauge, the gauge will under-report the actual amount of rain. Another problem is when the tipping bucket becomes only partly filled during a minor rain event or at the end of a larger rainfall. The water is then left standing and may evaporate without being measured. Despite those issues, TBRG's are very simple and quite effective.

The standard siting protocol for a rain gauge is that it must be far enough from an obstruction that "rain shadowing" does not occur. The recommended distance from an obstruction is at least four times the height of the obstruction. Therefore if there is a 2m tree, a gauge should be no closer than 8m from the tree (remembering of course that the tree is likely to increase in height, thus requiring further setbacks over time). The height of the top of the gauge is recommended to be as low to the ground as possible, generally at a height that does not exceed 1m.

As the height of the gauge increases, the amount of rain that is caught within the gauge will decrease (Middleton and Spilhaus, 1953). Kurtyka (1953) found that gauges at 1.5m caught an average of 5% less than a lower gauge and that gauges at heights of 6m caught 10% less. Wind speed increases with height, which can introduce considerable errors in rainfall measurement (Groisman and Easterling, 1994). As wind blows around and across the top of the gauge, its velocity will increase over the top and around the sides, causing small eddies to form within the orifice. These eddies can prevent some rain drops from falling into the gauge or even lift drops out of it. This effect is more pronounced for drizzle than for heavy rains. This is the greatest challenge for snowfall measurement since the light flakes are very easily diverted outside of any collection basin. Figure 6: Snow under-catch related to gauge exposure and wind speed (Groisman and Easterling, 1994)shows that during windy conditions, a catch deficiency of 35-40% is possible; this can introduce a substantial error in snow estimates.

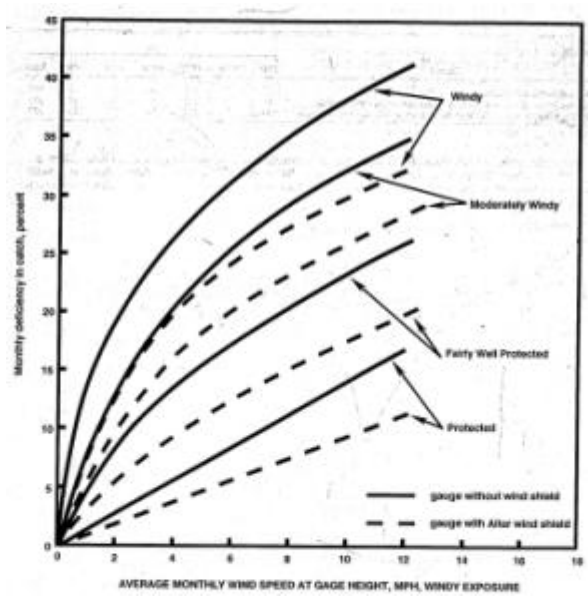

Figure 6: Snow under-catch related to gauge exposure and wind speed (Groisman and Easterling, 1994)

Another source of error related to rainfall measurement is the accuracy of the rain gauge itself, particularly in relation to accurate measurement of rainfall events that are very intense. As the intensity of the rainfall event increases, meaning that more rain falls within a given period of time, the accuracy of nearly all rain gauges decreases. Table 1 provides the published specifications for three commonly used rain gauges. Depending on the intensity, accuracy tends to vary by up to ±5%.

Table 1: Three rain gauges and their rated accuracy

Model	Price	Accuracy
Davis Instruments Rain Collector II	~$75	±4% (0-50mm/hr)
Texas Electronics TE525M	~$480	±1% (0-10mm/hr) +0%, -3% (10-20mm/hr) +0%, -5% (20-30mm/hr)
Hydrological Services TB3	~$1500	±2% (0-250mm/hr) ±3% (250-500mm/hr)

Figure 7: Three commonly used rain gauges; the Davis Instruments Rain Collector II, Texas Electronics TE525M, and the Hydrological Services TB3

Worth highlighting is that nearly all automated weather stations measure rainfall, but not necessarily precipitation. While rain is, in fact, precipitation most rain gauges, whether automated or manual, do not adequately accommodate snow or hail. This can be a limitation for agricultural applications, particularly since snowpack and snow cover can have significant impacts on soil moisture, soil temperatures, and runoff. The main reason that snow is not adequately addressed is that TBRG's are the most common method of measuring precipitation and their design requires that the precipitation be liquid. One way to overcome this dilemma is to use a rain gauge heater, which causes the snow to melt so that it may be measured. This option is generally ineffective in very cold climates and is not ideal.

When budget is less of a restriction, snow is often measured using a weighing gauge. These devices normally consist of a basin filled with antifreeze sitting upon load cells. As snow enters the basin, it melts, causing an increase in the basin's mass. This change in mass is then converted to a precipitation amount. Currently, the cost of these gauges is between $3,000 and $4,000. There are several other methods of monitoring snow. For example, in the Peace Region, the Ministries of Transportation and Environment uses a vertical PVC pipe charged with antifreeze. A pressure transducer within the pipe is used to read the depth of fluid in the gauge, which is equivalent to the snow water equivalent (SWE). This method costs approximately $1,300 to build. They also use optical precipitation occurrence detectors to help verify the gauge data, as well as ultrasonic sensors to monitor the depth of snow on the ground. Snow pillows are also used; these devices consist of large bladders containing an antifreeze solution. As snow accumulates on the pillow, the weight of the snow pushes an equal weight of the antifreeze from the pillow up a standpipe, which is measured to derive the weight of the water content of the snow, or the SWE.

As winter precipitation is less spatially variable than summer rainfall, the network of all-weather collection gauges does not need to be as dense as the network of rainfall-only gauges. Therefore, for agricultural applications, the Peace region would be advised not to focus on all-weather precipitation gauges. Depending on the type of weather stations, these sensors can be added afterwards if deemed necessary.

2.5 Wind speed/direction

Wind is another element that is important to agriculture. From an operational perspective, it may dictate certain field operations such as spraying. From an agronomic point of view, wind dictates the rate of evapotranspiration as air movement is necessary to move moist air away from the leaf surface. Brisk winds will generally increase the rate of evapotranspiration as well as increase the rate of drying.

Wind speed is most often measured using an anemometer (cup or propeller) and direction with a wind vane. The height at which wind is measured is quite important. Because wind speed increases with height, what is recorded near to the ground may be quite different (less) than what is recorded higher up. Ten metres is considered the international standard height at which wind should be measured for most meteorological applications. However, according to the Food and Agriculture Organization (FAO), the standard for agrometeorological applications is two metres. For proper siting, the distance of a wind sensor to any obstruction should be at least 10 times the height of the obstruction.

2.6 Costs

The costs associated with purchasing and operating a weather station, or with running a weather monitoring network, are completely variable. The purchase of a weather station can range from a few hundred dollars to tens of thousands of dollars. Annual per-station operating budgets can be similar. In general, an individual or organization should consider their monitoring needs and invest in equipment that suits those needs. However, the most important consideration, one that is often overlooked, is the ongoing operating and maintenance costs, both in the short-term and the long-term – the total cost of ownership. All too often, organizations have a one-time budget to invest in monitoring equipment, but have not considered the ongoing costs. These costs are for data management, station upkeep, calibrations, repairs, and replacement. If the network operation and maintenance is done in-house, an organization must also consider retaining the appropriate skill sets and training. More basic equipment, or equipment that has been preconfigured, can often be installed by someone with less technical training. More advanced systems that may need custom programming and wiring, often require specific training and expertise. These ongoing commitments can be as expensive as the upfront costs of purchasing hardware. If any of these factors are ignored, networks degrade and data quality and completeness suffers. Therefore, any decisions to invest in monitoring must take into account the ongoing costs.

While there are many types of weather stations available, there are only a few brands that tend to be used extensively in western Canada. These stations range from professional-grade to more basic. The station package that is offered by Farmwest includes the cabled or wireless Davis Vantage Pro weather station ($1900 to $2400) either stand-alone or combined with ROM MicroCom cellular hardware, antenna, solar panel, and battery ($1880). The total hardware cost ends up being $3780 to $4280. There is also a $22 monthly transmission charge ($264/year). WeatherFarm also uses the wireless Davis Vantage Pro 2, but only the internet version, and offers it with a subscription model of $100 to $150 per month. Both Farmwest and Weather INnovations also use Adcon Telemetry equipment. These stations are more robust and of higher quality and communicate by cellular or by radio. Campbell Scientific instruments are used by many researchers, Environment Canada, and BC Ministry of Transportation. Table 2 provides a breakdown of the common station types.

Table 2: Common weather stations used in Western Canada

Brand	Users	Hardware Cost Per Station	Comments
Campbell Scientific	Environment Canada, BC Transport, Researchers	CR1000 datalogger, cell modem, solar panel, battery, enclosure, T/RH, rain, wind speed/direction: ~$7500 (hardware only)	Research-grade. Highly configurable, accepts all sensors, more complex to operate. Multiple telemetry options.
Adcon Telemetry	Weather INnovations, Okanagan Fruit Growers, Researchers	A753 addWAVE GPRS logger (cellular), solar panel, T/RH, rain, wind speed/direction: ~$5000 (hardware only) or ~$2500/yr through Weather INnovations, including all hardware, installation, maintenance, warranty	Rugged and well-suited to agricultural monitoring. Cellular or UHF radio telemetry.
Davis Instruments	WeatherFarm, Farmwest	Vantage Pro 2 wireless weather station (communication), T/RH, rain, wind speed/direction: Internet Version: ~$2,500 (hardware only) or ~$1500/yr through WeatherFarm, including hardware, installation, maintenance, warranty Cell Version: $4,280 (ROM Communications)	Simple to operate. Requires nearby internet connection or cell module.

When purchasing weather equipment, the decisions about cost often comes down to quantity versus quality. In some respects with weather instruments, one does get what one pays for. However, the law of diminishing returns certainly applies. Perhaps on the low-end of weather equipment, paying twice as much for a weather station (going from $100 to $200) may buy equipment that is double the accuracy, functionality, or capabilities. In contrast, paying a premium of several thousands of dollars on a high-end meteorological monitoring station is likely to increase the accuracy by only a fraction of a percent. Granted, this accuracy comes with certification and traceability, a necessary component for some applications, including climatological analyses. However, this cost premium does not necessarily pay for increased durability, longevity, or user-friendliness.

3.0 Meteorological Monitoring Networks in BC

The following section provides an inventory of operational meteorological monitoring stations within the Peace River Region. Operational stations include only those that are currently functional, being maintained, and transmitting data on a regular basis. Going through various archives, there are numerous monitoring sites that have been active at various times, many of which have been decommissioned for one reason or another. While this data is certainly valuable, particularly for studying the climate of the region, it is of limited use for any assessments of current conditions or for near-real-time decision support applications.

Along with a brief description of each network, maps of the region are included, showing the locations of the weather stations within the specific networks. Within each map, the 2013 crop inventory is also shown in order to identify the approximate extent of agricultural production. The crop inventory data is produced by the Earth Observations Team of the Science and Technology Branch (STB) at Agriculture and Agri-Food Canada (AAFC) using optical (Landsat-5, AWiFS, DMC) and radar (Radarsat-2) based satellite images. This approach delivers a crop inventory with an overall accuracy of at least 85% nationally at a final spatial resolution of 30m. Within BC, the average accuracy is 79%. For these maps, the crops were simply categorized into annual crops (shaded in orange), perennial pasture/forage (shaded in green), water (blue), and non-agricultural land. The land elevation is also shown on the maps to provide perspective of the broad-scale topography within the region.

3.1 Environment Canada

Environment Canada (Meteorological Service of Canada - MSC) was, for a long period, the sole provider of weather information. The department has a rich history in climatic expertise, dating back to the 1870's. In the early days, observations were manual, either taken by MSC observers or by the extensive network of volunteer observers across Canada. Today, their real-time network is made up of automated meteorological stations. These stations record all basic meteorological parameters and are generally well sited and World Meteorological Organization (WMO) guidelines are closely followed. Temperature and RH sensors are generally aspirated and wind measurements are taken at the recommended 10 metre height. Many of the sites collect all-weather precipitation using a weighing gauge. The dataloggers are manufactured by Campbell Scientific. Within the agricultural area of the BC Peace Region, there are four MSC sites; these are located at the Fort St. John airport, Dawson Creek airport, Chetwynd airport, and Sikanni Chief.

It should be noted that not all Environment Canada stations consistently provide reliable data. According the Environment Canada's Climate Data Online service, the Sikanni station has been reporting between zero and four hourly data slots per day for at least the past year. Chetwynd has been reporting about 12 hourly slots per day, resulting in the remaining hours of the day missing. Stations with this extent of missing data do not provide any value to users and cannot be used for any applications. The Airport stations at Fort St. John and Dawson Creek have relatively complete archives, indicating that they are generally functional and can be assumed to be providing reasonable data.

The near-real-time data is retrieved hourly and is made available online (www.weather.gc.ca) within about 10-12 minutes after the top of the hour, along with the daily forecasts. Past data, which has received a slightly higher degree of quality control, becomes available soon after it has been collected. Data that makes it into the official climate archive often takes a substantial amount of time to become available – sometimes years.

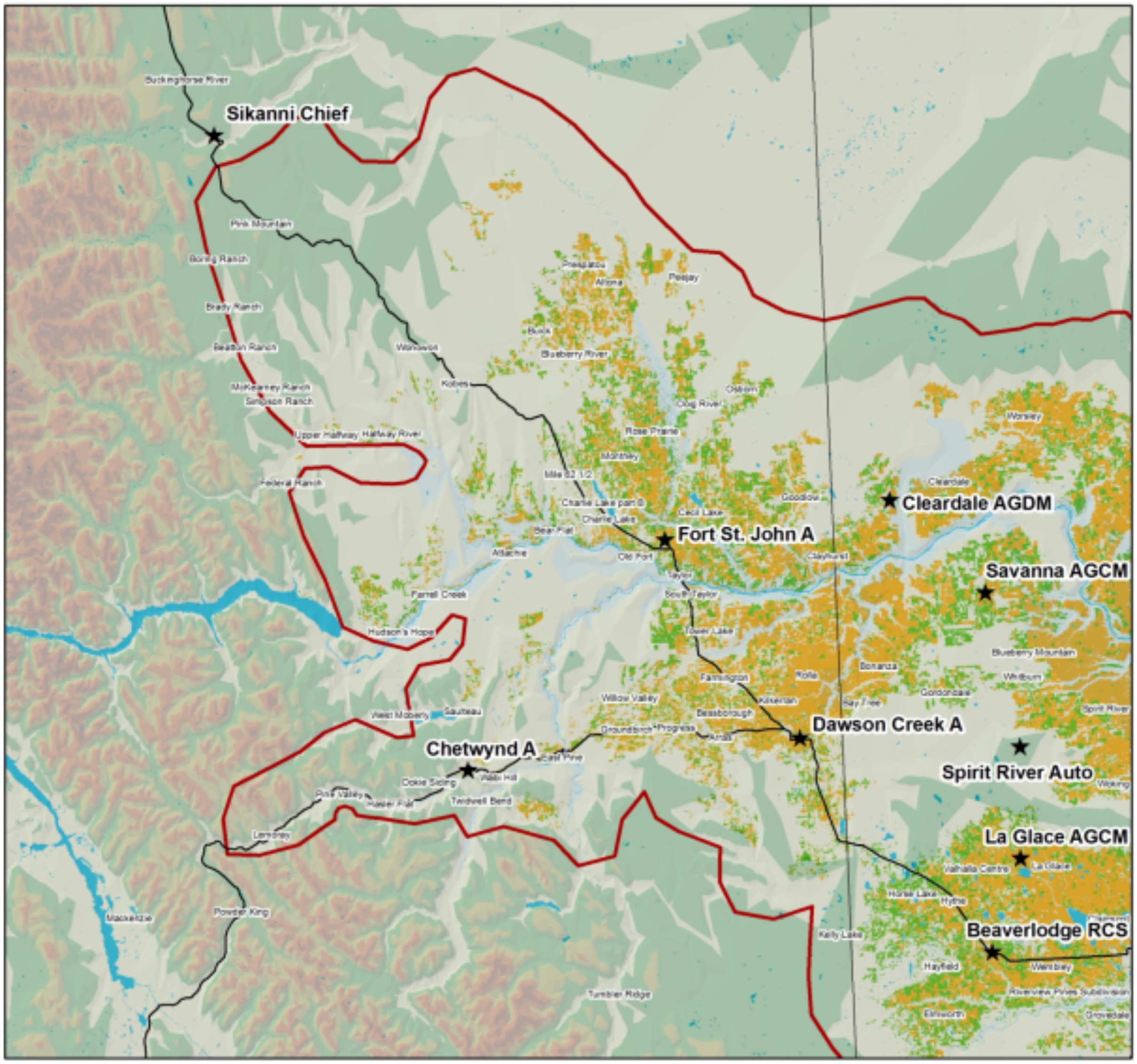

Figure 8: Locations of Environment Canada weather stations in relation to crop and pasture land

3.2 Wildfire Management Branch

The Wildfire Management Branch, within the BC Ministry of Forests, Lands and Natural Resource Operations, operates approximately 230 weather stations across the province to support fire weather forecasting and the Canadian Forest Fire Danger Rating System (CFFDRS). These weather stations are manufactured by FTS and collect air temperature, relative humidity, precipitation, and wind speed/direction on an hourly basis. Currently, approximately 24 stations have all-weather weighing precipitation gauges, while the remainders have standpipes. Over time, additional sites will be retrofitted with weighing gauges. During the active forest fire season, April through October, the data is transmitted hourly. During the off-season, data may be transmitted less frequently. The stations communicate using a mix of Geostationary Operational Environmental Satellite (GOES), Globalstar satellite, or UHF radio combined with a dial-up telephone modem. Data is managed and quality assured in-house using custom database applications.

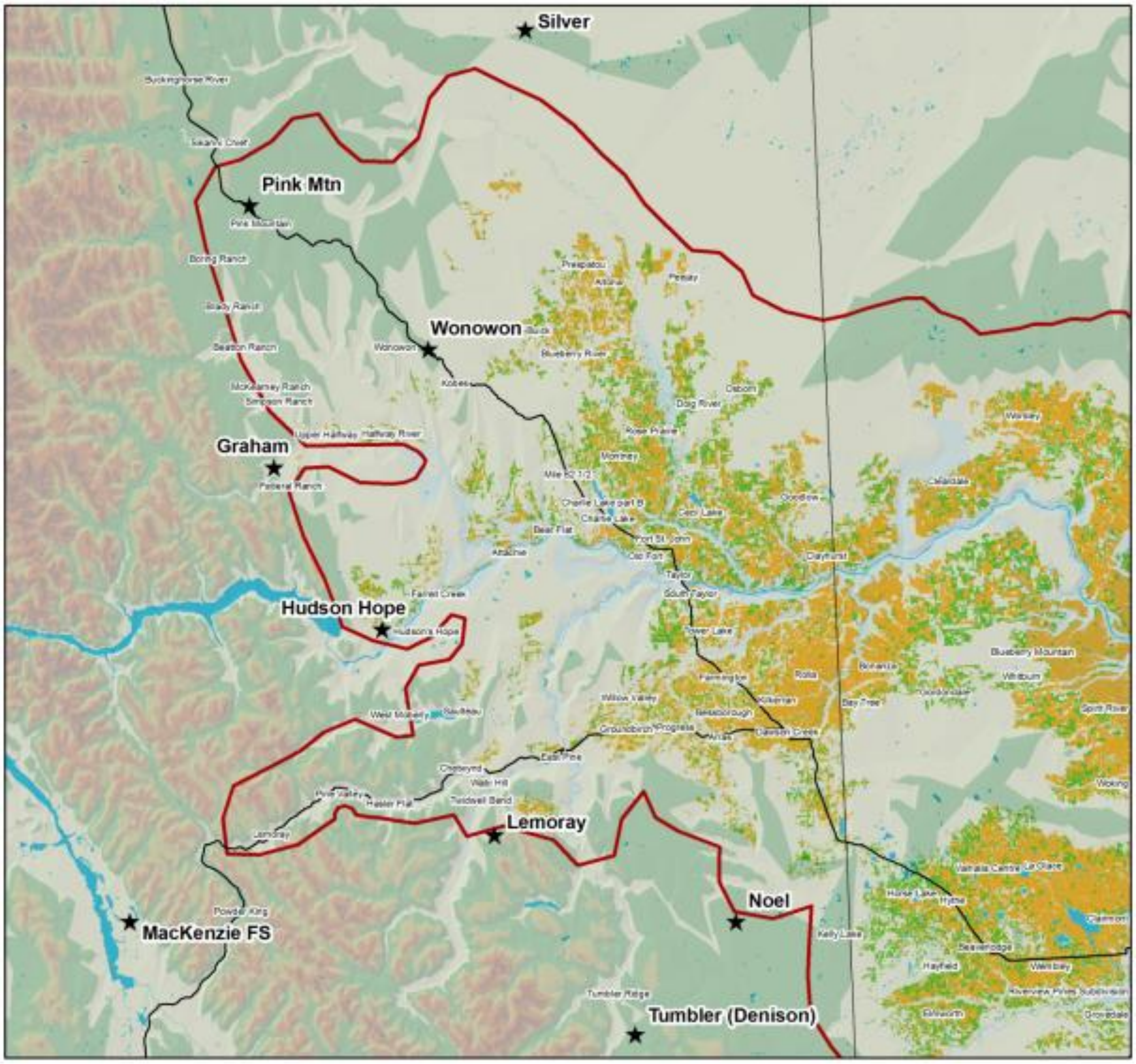

Figure 9: Locations of Wildfire Management Branch weather stations in relation to crop and pasture land

The weather stations used for wildfire management generally conform to the standards set out by the WMO for agrometeorological observations in forest areas, including 10m wind towers. For station siting, this is normally in a place that represents the general area with respect to elevation, topography, vegetative cover, and local weather patterns. These stations are generally not to be located within sheltered valleys, exposed peaks, or ridge tops. Standard setbacks from nearby obstructions apply, such as ensuring that the diameter of a forest clearing surrounding a station is at least 10 times the height of the surrounding timber. Stations must also be at a suitable distance from any sources of moisture (i.e. a lake, stream or swamp), buildings, pavement, gravel, or rock outcrops. The area immediately surrounding the station should be mown grass or cropped natural vegetation.

The national standards are intended to ensure that a weather station represents the region and terrain in which it is located. In the case of forest weather stations, the intention is to monitor regional forest conditions – not necessarily the adjacent agricultural land. The Wildfire Management Branch actively shares their data with various organizations and would likely be open to sharing their data with users in the BC Peace. However, integrating the data from these stations into agricultural applications must be done with caution, considering the siting, exposure, and elevation of each station in question. As demonstrated in Figure 9, many of the forestry stations are located beyond the fringes of agricultural land, often at high elevations.

3.3 BC Ministry of Transportation

The BC Ministry of Transportation operates and maintains their own network of environmental monitoring equipment as part of their Avalanche and Weather Programs. These stations are primarily for winter operations to monitor avalanche and highway conditions. Within the Peace Region, there are two Road Weather Stations, Braden Road and 73 Mile. These two sites are located very close to the agricultural areas of the region and would be reasonably representative of their surrounding areas. These stations collect parameters that are also relevant to agriculture, including air temperature, relative humidity, precipitation, and wind speed/direction.

Figure 10: Example of a road weather station (Braden Road). Photo courtesy of Simon Walker.

The Ministry of Transportation is open to sharing their data freely. According to their website, the data is shared with a variety of external stakeholders, the Meteorological Service of Canada, other Provincial Government agencies, a number of university based research programs, the Canadian Avalanche Centre, and the travelling public through the DriveBC Weather Pages.

There does not appear to be any plans to expand this network in the Peace Region, at least within the next year. However, within the Ministry of Transportation there was mention of possibly expanding the Road Weather Network through Pine Pass and other parts of the Peace in the future.

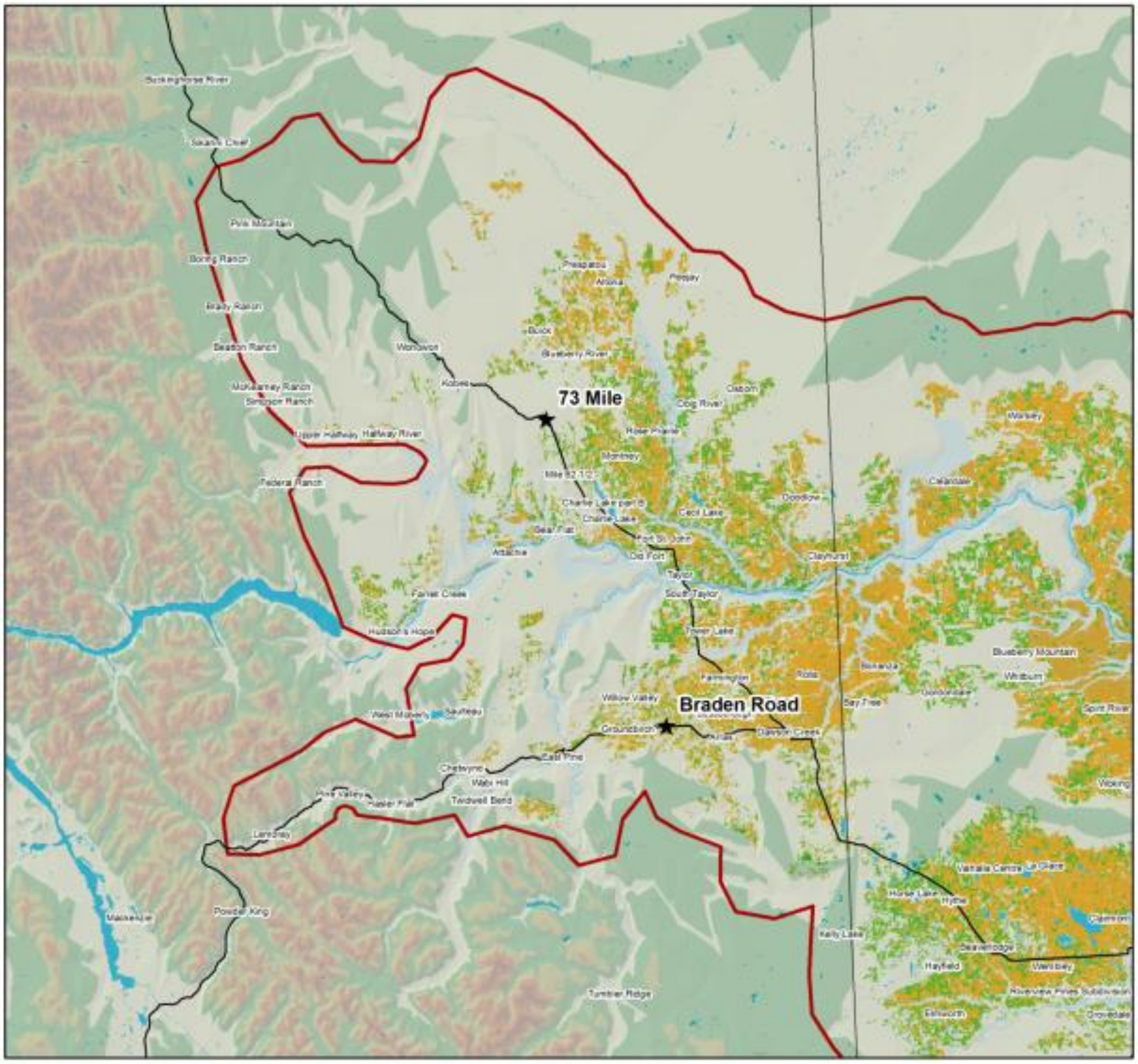

Figure 11: Locations of BC Ministry of Transportation weather stations in relation to crop and pasture land

3.4 BC Hydro

BC Hydro operates and maintains approximately 84 monitoring stations within BC. About a third of these stations are located within the Peace River watershed and surrounding Williston Lake. There are seven monitoring stations within and directly adjacent to the Peace region. Within the past year, five additional sites, three equipped with snow gauges, have been set up to monitor conditions for the proposed Site C project. These stations are not yet online.

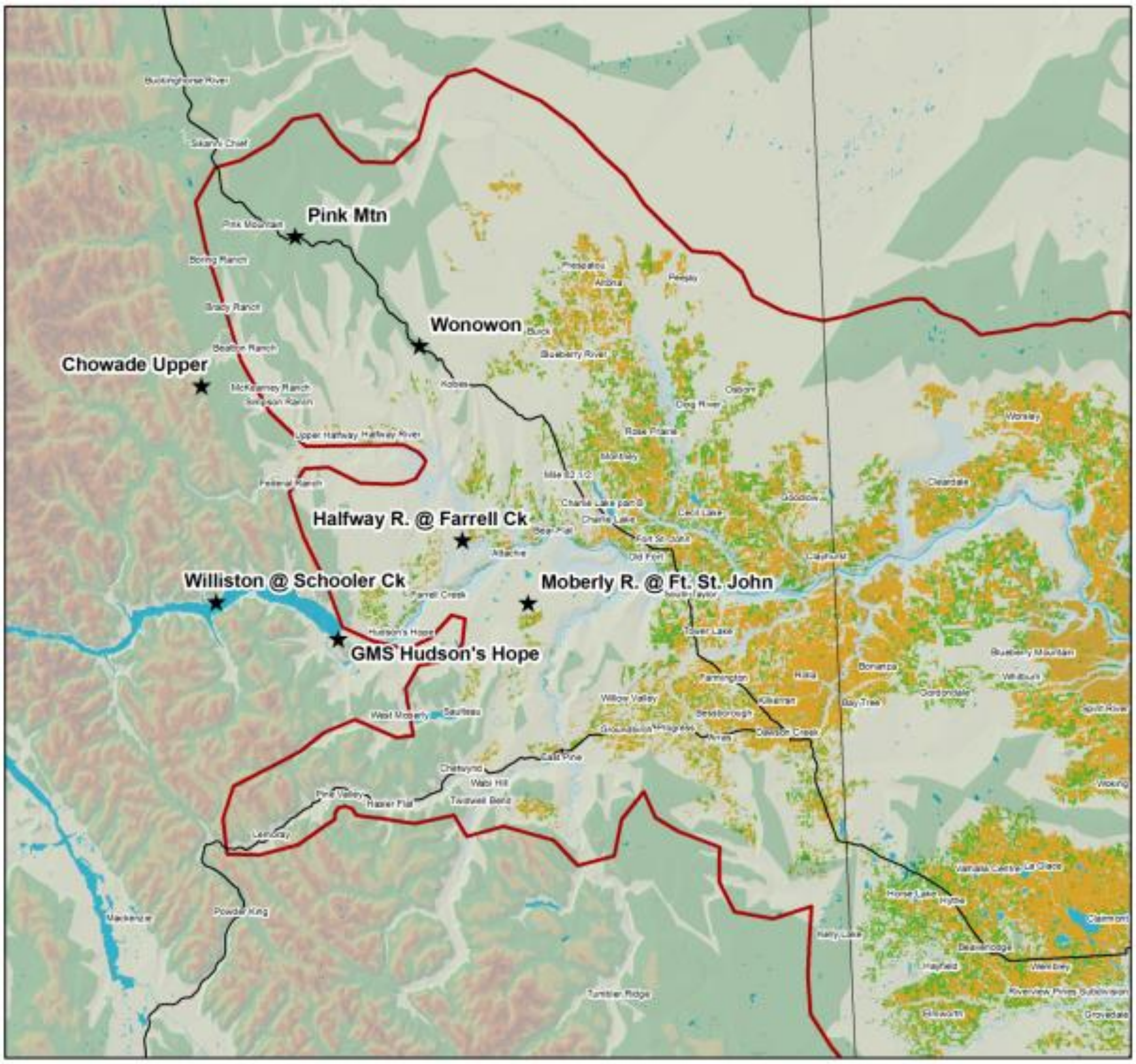

Figure 12: Locations of BC Hydro weather stations in relation to crop and pasture land

The stations are used to forecast water supply and mainly monitor air temperature and precipitation. Some of the newer sites also have weighing gauges to record precipitation while others use standpipes with pressure transducers. Due to heavy snow accumulation in the mountainous regions, the stations and sensors may be installed much higher off the ground than what is recommended. This prevents the station from being buried in snow and thus becoming ineffective. For precipitation collection, many of the gauges do not have wind screens to baffle the wind near the gauge. This, combined with elevated gauges would be expected to result in underestimation of precipitation at these sites. Depending on the sites, other obstructions may also be present. The stations themselves mostly have satellite communications on the GOES system.

3.5 WeatherFarm

The WeatherFarm program began as an initiative of the Canadian Wheat Board (CWB) around 2007. Around that time, the CWB was seeking to enhance its profile among the agricultural community as well as to increase the amount of weather data available for crop assessments and forecasts. In partnership with WeatherBug (later to become Earth Networks), the CWB aggressively marketed on-farm weather stations. These stations were the Davis Instruments Wireless Vantage Pro 2, complete with temperature, relative humidity, wind speed/direction, and barometric pressure sensors. Because they were wireless, these stations transmitted data approximately 300m to a console with an integrated display and datalogger. Initially, the console was hooked up to a PC computer, which ran software that would send the data to a central server through the computer's high-speed internet connection. This station data was then available on the WeatherFarm website, along with some agronomic tools.

Over time, operators realized that relying on a PC and often intermittent rural internet and power resulted in frequent data delays and gaps. Around 2010, the CWB decided to phase out the PC solution in favor of a dedicated network appliance that had data buffering capabilities and a battery backup. This retrofit increased the reliability of the monitoring network and decreased the amount of missing data. By 2012, the WeatherFarm network had grown to approximately 850 weather stations throughout western Canada. Following the CWB's loss of monopoly and subsequent restructuring, the WeatherFarm program was purchased by a joint venture of Weather INnovations and Glacier Media (Western Producer, Grainews, Country Guide, AgCanada) in 2013. The real-time data and some basic agronomic tools are freely available on the Weather site (www.weatherfarm.com). Archives and additional tools are available for station-owners and paying customers.

Currently, there are seven WeatherFarm stations operating within the BC Peace Region. Of these seven stations, two are at research facilities (BC Grain Producers), two are located on farms, two are owned by the City of Fort St. John, and one is at an agricultural retailer. Since the WeatherFarm program relies on individuals or businesses to purchase a weather station, the distribution of stations is not uniform. Within the region, most of the stations are clustered along highway 97, leaving little coverage of the north, northeast, or southwest.

Despite all of the WeatherFarm stations being located within agricultural areas, station siting is an important consideration. Depending on the specific site and intended use, some of these stations are located on rooftops. Data from rooftop stations, particularly the temperature and RH data, should be used with caution for any agricultural applications. For this reason, Weather INnovations has been working towards re-siting some of the weather stations to more appropriate locations. This has proven to be a challenge in some situations where few options exist. In those cases, it is important that the end-user know the station limitations so that they may decide whether the data is suitable for their purposes.

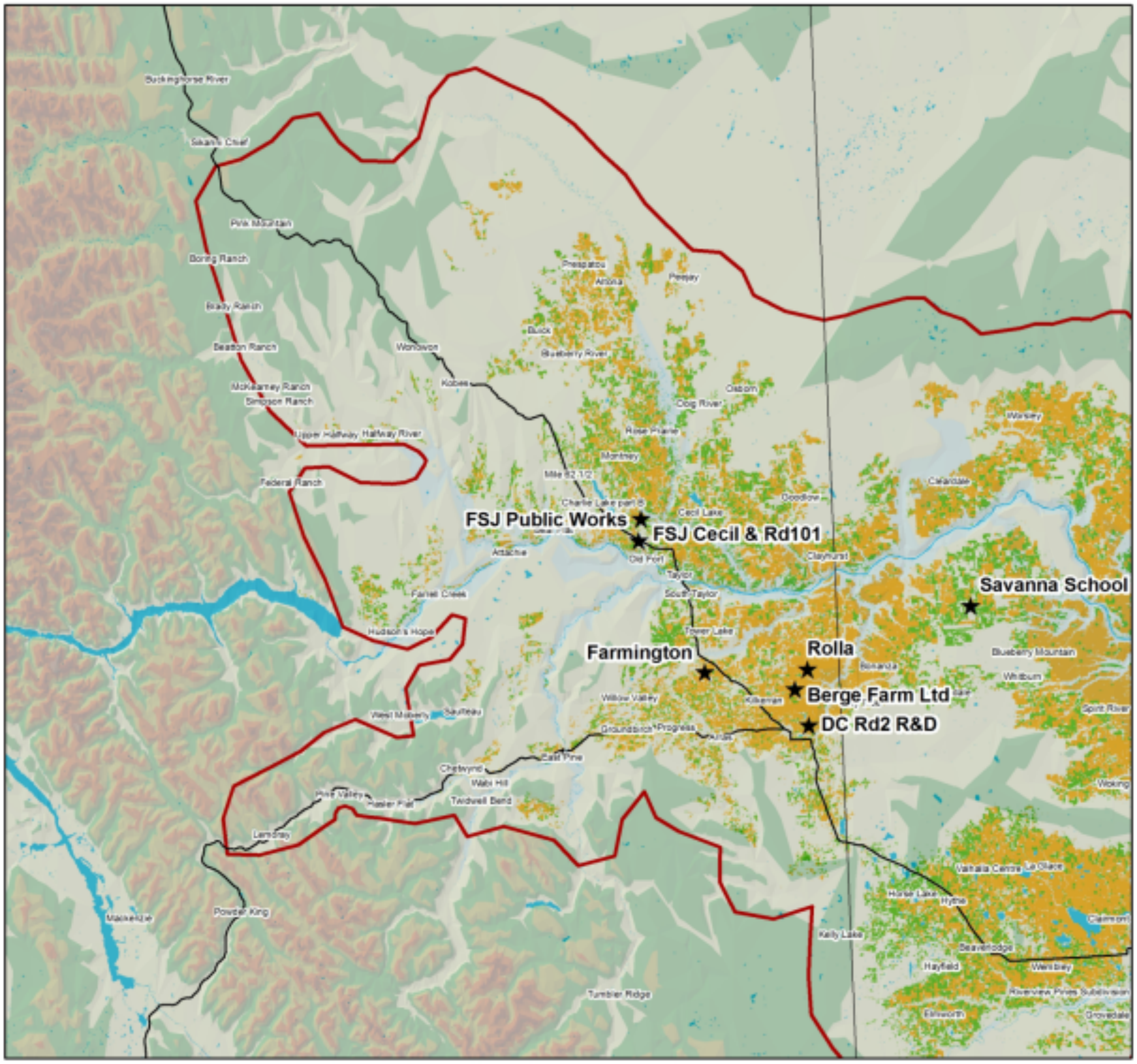

Figure 13: Locations of WeatherFarm weather stations in relation to crop and pasture land

3.6 River Forecast Centre

The River Forecast Centre relies on automated snow pillow (ASP) stations located throughout the province. This network is comprised of stations that are operated by the Ministry of Environment, BC Hydro, Rio Tinto Alcan, and the Greater Vancouver Water District. The Forecast Centre itself does not operate its own network. There are a total of 51 ASP sites throughout the province, with four in the Peace Region (Pine Pass, Pulpit Lake, Kwadacha River, and Aiken Lake). None of these are in close proximity, or at similar elevations to, agricultural land. In addition to snow pillow data, these stations also monitor snow water equivalent (SWE), snow depth, air temperature, and precipitation. The data is collected hourly and transmitted through GOES every one hour or three hours, depending on the site. It is then brought in to the River Forecast Centre's satellite receiving station in Victoria. The data collected from this network is freely available online as real-time data and graphs, and openly shared with stakeholders, including the Climate Related Monitoring Program (CRMP).

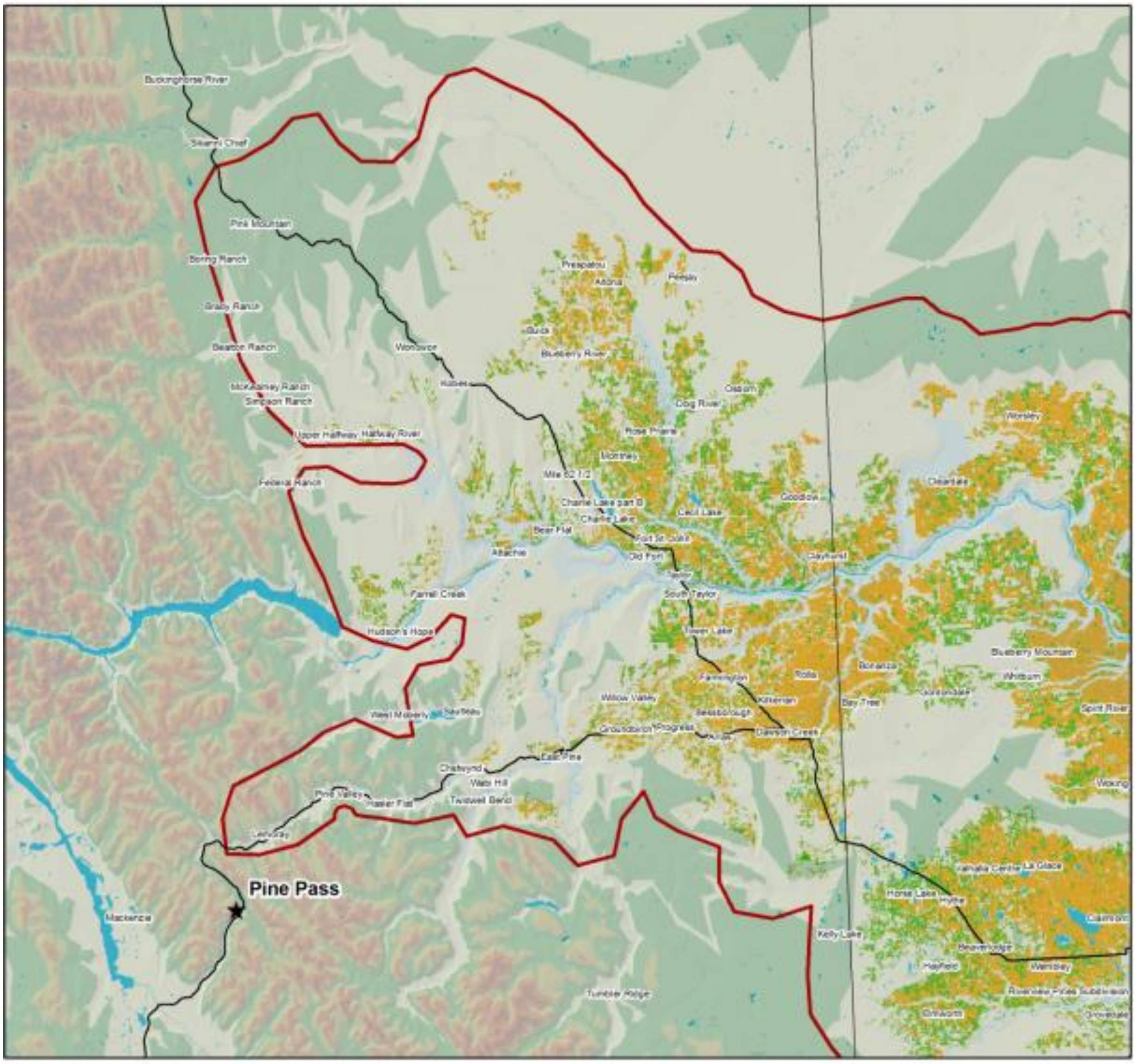

Figure 14: Location of the automated snow pillow in relation to crop and pasture land

3.7 Summary of Networks

There are approximately 20 weather stations run by six operators within the agricultural zone of the Peace River region. Figure 15 shows the locations of all stations, including those in Alberta. Table 3 provides a summary of these individual networks.

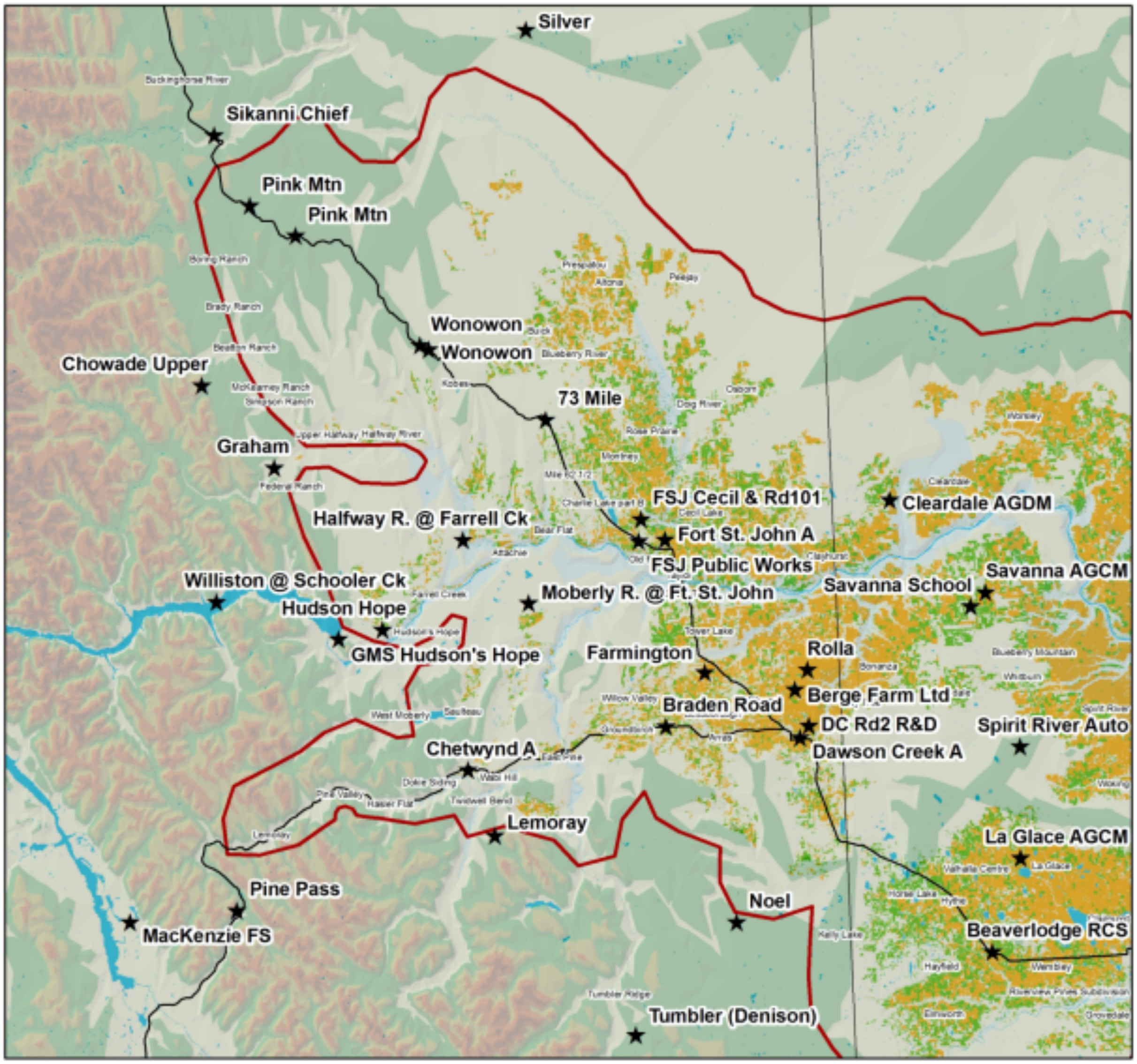

Figure 15: Locations of all weather stations within the Peace Region

Table 3: Summary of meteorological monitoring networks within and near the BC Peace Region

Network	Stations in/near BC Peace	Elements Measured	Season of Operation
Environment Canada	4 in BC Peace	T/RH, Wind, Precip	Year-round
BC Forestry	9 in BC Peace	T/RH, Wind, Precip	Some season, some year-round
BC Hydro	7 in BC Peace (plus some new sites)	T/RH, Wind, Precip	Year-round
River Forecast Centre	1 near the Peace	Temperature, snow	Winter
Infrastructure and Transportation	2 in BC	T/RH, Wind, Precip	Year-round
WeatherFarm	7 in BC	T/RH, Wind, Rain	Year-round

3.8 Station Densities/Gap Analysis

Clearly, there are gaps in the monitoring network, particularly related to the coverage within the agricultural land area. These gaps in monitoring may result in the non-detection of weather events that are different from the regional (mainly airport) weather stations. In terms of emergency response or assistance programs, some areas may get overlooked due to the lack of hard data. From an agronomic perspective, farmers that are located far from weather stations cannot benefit from the weather-related tools that may be available. This will translate to recommendations and forecasts that are not suited to local climates.

A key part of this study was to conduct a gap analysis of the current monitoring within the agricultural portion of the BC Peace Region. The gap analysis is based on an assessment of current monitoring stations, their applicability to the needs that have been identified, and their proximity to, and representativeness of, the agricultural land base. Knowing the locations of the monitoring stations and understanding where the gaps exist is important for identifying subsequent steps towards collaborating with other organizations to enhance the level of monitoring.

One of the greatest challenges related to accurately characterizing and reporting the weather and climate of a region is that data from a limited set of point measurements, meteorological monitoring stations, must be extrapolated to provide estimates of a larger region that consists mainly of un-monitored locations. The key assumption when extrapolating station data is that a relationship exists between one station and the next. According to Tobler's first law of geography, "Everything is related to everything else, but near things are more related than distant things" (Tobler 1970). Based on this principle, two weather stations that are very close to one another should have very similar data, likely similar enough that one of these stations may be redundant. If these two stations were to be placed at greater distances apart the weather, and hence the weather data, will become progressively more different, eventually to the point at which the two datasets are unrelated. At this point, the inter-site correlation is said to have decayed to zero. To complicate this concept, the degree of difference between stations varies by parameter, by temporal scale, and of course, by physical factors such as elevations, topography, and local features. For example, over a given distance, rainfall will normally vary more than temperature, particularly during the summer months when precipitation is dominated by local convective storms with a high degree of spatial variability (Topp et al. 1996). Differences in altitude, slope, and aspect may also increase the spatial variability by means of rain shading and winds (Buytaert et al. 2006).

With the diverse topography within the Peace Region, it is important to consider the elevations of individual monitoring stations and the elevation of the areas that they are to potentially represent. Obviously, the local climate near the top of a mountain or at the bottom of a valley will be much different than the areas in between. Within the BC Peace Region, about 90% of all agricultural land is between 500 and 900 metres above sea level (MASL). Table 4 shows a breakdown of the annual and perennial cropland by elevation. By comparison, Figure 16 shows the elevations of the 40 individual weather monitoring stations that have been identified within and surrounding the region. Of those stations, 14 or 35% are at elevations above 900 MASL. Some are at much higher elevations. This factor must be considered when doing any sort of regional interpolations. Therefore, those at higher elevations, while they should not be entirely omitted from the dataset, would not be considered adequately representative of agricultural land. Figure 17 shows the existing networks with the higher and lower elevation stations crossed out.

Table 4: Percent of agricultural land within elevation ranges

Elevation Range (MASL)	% of Agricultural Land
< 400	1.4
400 - 499	7.3
500 – 599	20.3
600 – 699	30.4
700 – 799	28.8
800 – 899	11.3
≥ 900	0.5

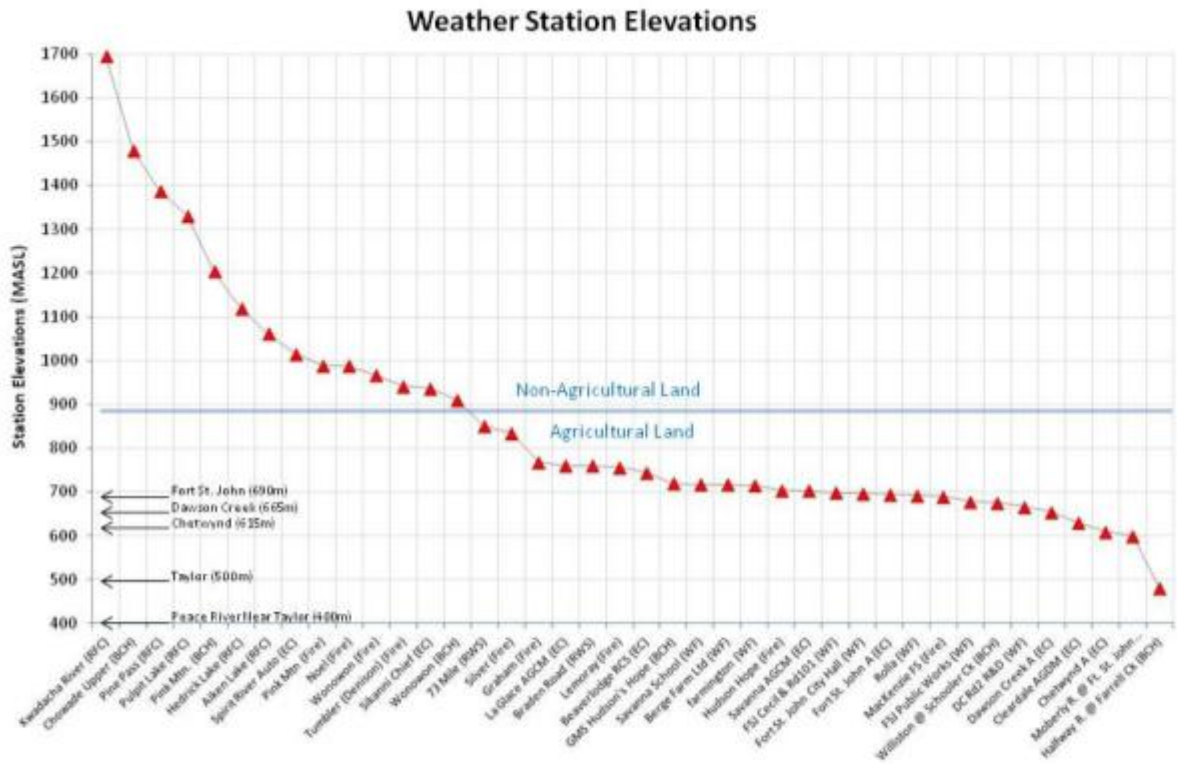

Figure 16: Weather station elevations in relation to the majority of agricultural land

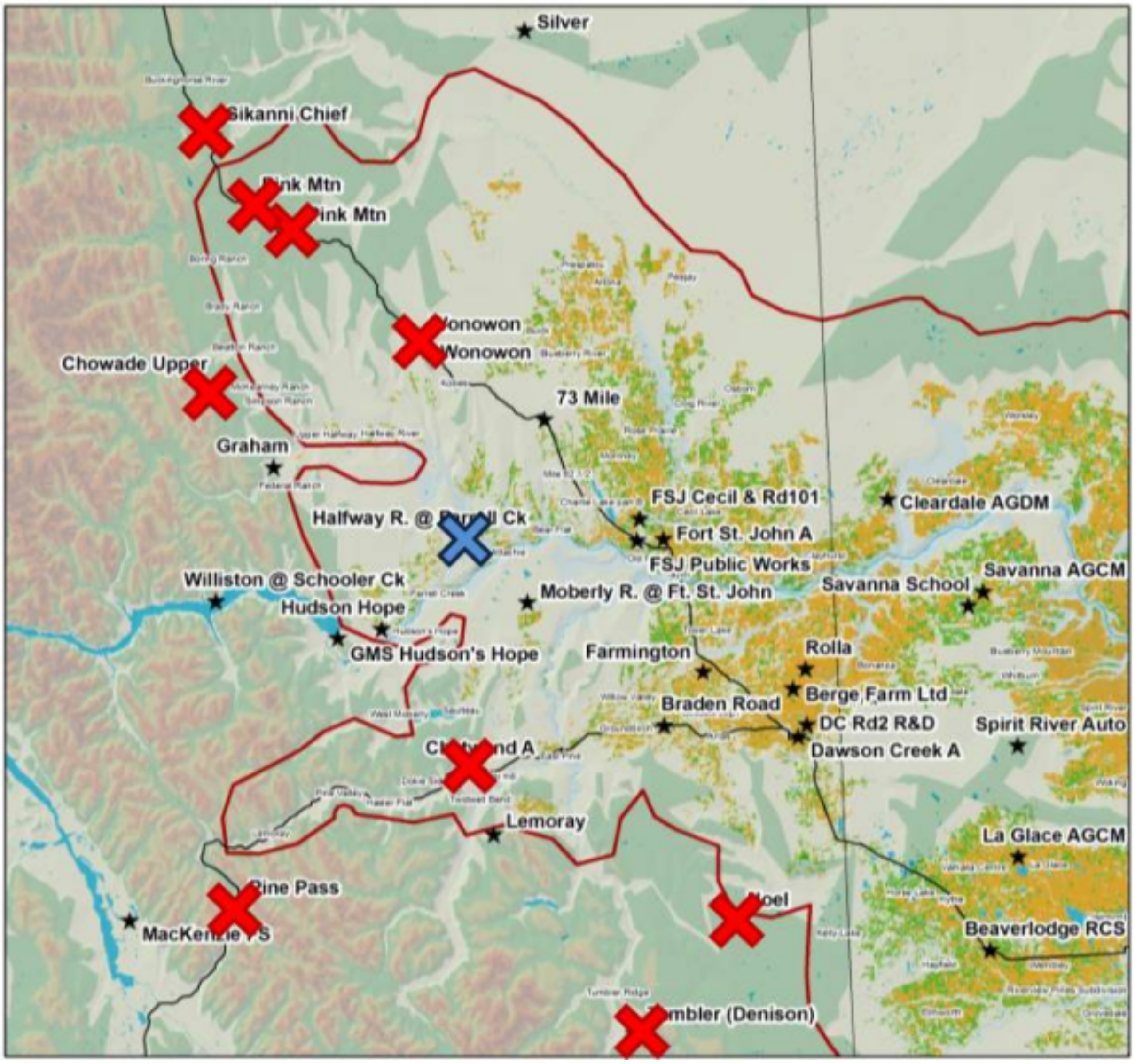

Figure 17: Existing networks with stations above 900 MASL, below 500 MASL, and with data gaps (Sikanni and Chetwynd Environment Canada stations) crossed out

Rainfall and other weather parameters will also vary depending on the temporal scale. For example, daily rainfall totals will vary to a higher degree than monthly or seasonal rainfall. Based on a comparison done by Raddatz (1987) of multiple rain gauge data from the City of Winnipeg, Figure 18: Average estimation errors for daily (solid line) and monthly (dashed line) rainfall amounts based on distance between stations of 10km to 32km (Raddatz 1987) shows the average estimation error (%) over various distances. For daily rainfall, this error was observed to be ±126% (or ±7mm) for distances of 10km. Over distances of 32km, this error was ±165% (or ±10mm). Monthly rainfall amounts were lower, ranging from ±36% (or ±26mm) over 10km to ±48% (or ±35mm) over 32km.

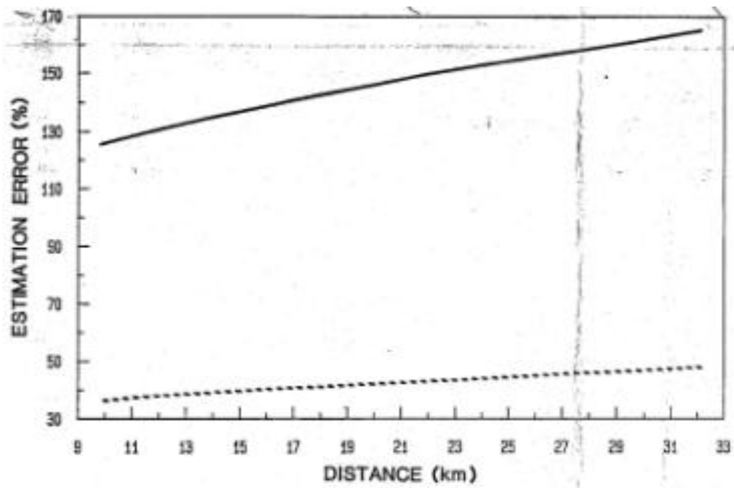

Figure 18: Average estimation errors for daily (solid line) and monthly (dashed line) rainfall amounts based on distance between stations of 10km to 32km (Raddatz 1987)

Clearly, the estimation errors associated with rainfall can be significant, and increase dramatically with distance from a weather station. While there are no universal standards for an acceptable level of error, some of the literature suggests that between 10% and 30% is reasonable (Panchang and Narayanan 1962, Johnstone 1983, Furman 1984). Based on the results of Raddatz (1987), achieving better than 30% error on daily rainfall would require station spacing of far less than 10km. For monthly rainfall amounts, station spacing would need to be slightly less than 10km. Ahrens (2006) observed daily rainfall data throughout Austria and reported that on average, mean station spacing of 20km produced an R^2 of 0.61, spacing of 36km produced an R^2 of 0.05. The R^2 refers to the coefficient of determination where $R^2 = 1.0$ is perfect correlation and $R^2 = 0.0$ suggests that there is no correlation. It is important to acknowledge that estimation errors, including those that are associated with spatial variability, propagate through the analyses, models, and decision support tools upon which the data is based.

Similar to margin of error, there is also no magic threshold for appropriate station spacing. Ideally, more stations are always better. Therefore, the obvious solution to improving spatial estimation is to increase the number of sample points by installing more weather stations. However, reality dictates that having and maintaining a very large number of stations is simply not feasible, particularly in a large region. One of the densest regional networks in North America is that of The Delaware Environmental Observing System (DEOS). This network consists of 53 monitoring stations within an area of 6421 km^2. This results in an average distance between stations of 12km (Quiring 2011). With this density, almost any location within the state, on average, would be within 6km of a weather station. The well-known Oklahoma Mesonet claims a station spacing of about 30km, which would indicate an average maximum distance of 15km from a weather station. For the purposes of this analysis, agricultural land within 15km of an existing weather station is considered as adequate coverage. Figure 19 shows the locations of the weather stations, each surrounded by a 15km radius buffer. The agricultural areas that are between 15km and 20km from existing stations are colored yellow. Areas from 20km to 25km are colored orange. Areas beyond 25km are shown in red. This provides a visual representation of areas that lack monitoring. Table 5 provides a breakdown of the percent of the agricultural lands that fall within various distances from the weather stations. Currently, 33.6% of the land is within 15km of a weather station. 17.6% falls between 15km and 20km, 12.7% is within 20km to 25km, and 36.1% is further than 25km from a weather station. With over a third of the agricultural land beyond 25km from a weather station, if would seem obvious that certain areas are severely under-represented. For this reason, it is highly recommended that actions be taken to enhance the monitoring within the region, primarily in the areas identified in Figure 19.

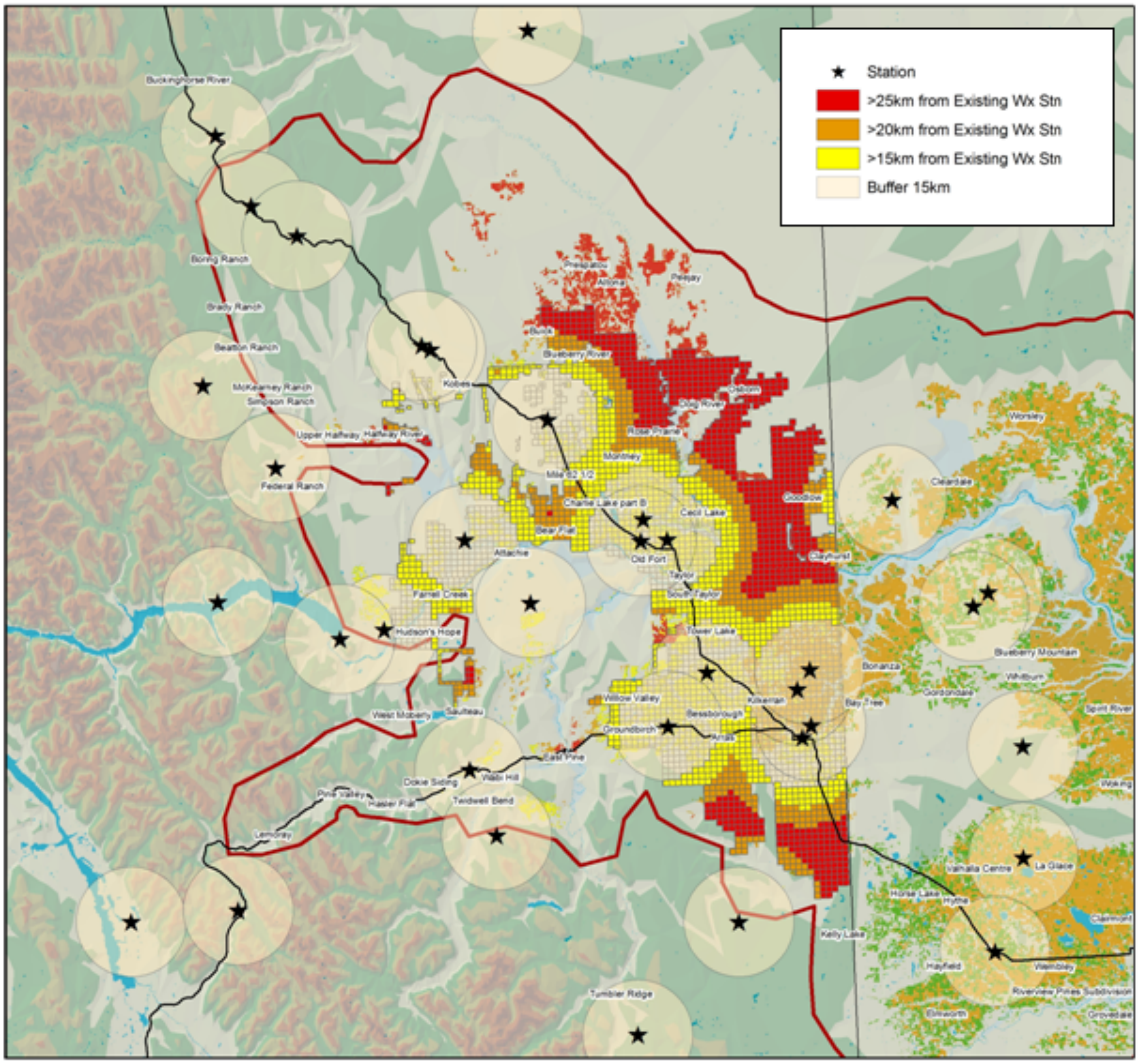

Figure 19: Agricultural land that is further than 15km (yellow), 20km (orange), and 25km (red) from an existing weather station

Table 5: Percent of agricultural land within various distances from existing weather stations

Distance from an Existing Weather Station	Percent of Agricultural Land
0 to 5km	3.4%
5 km to 10 km	11.0%
10 km to 15 km	19.1%
15 km to 20 km	17.6%
20 km to 25 km	12.7%
25 km to 30 km	14.3%
30 km to 35 km	7.3%
35 km to 40 km	4.9%
> 40 km	9.6%

3.9 Options for Improving the Monitoring Network

Within the BC Peace Region, there are two acceptably reliable automated Environment Canada stations (and two that are unreliable). Fortunately, there are other networks to enhance the monitoring within the region. Some of these additional networks provide superior coverage of the area and should be made use of. However, individual station characteristics such as siting, exposure, and elevation need to be considered to ensure that these stations are representative of their surrounding agricultural region. Factoring in these additional networks, some gaps remain. Over 35% of cropland is further than 25km from an existing weather station; nearly 50% of cropland is further than 20km from an existing weather station. Only one third of cropland falls within 15km of a weather station. Clearly, the meteorological monitoring network with the BC Peace region can be improved, particularly as it relates to agricultural applications. Having most agricultural land within 15km of a weather station would be a reasonable and achievable goal for the region. This would reduce the inevitable estimation error, particularly associated with rainfall, which increases dramatically with distance.

Specific locations of new monitoring stations are dependent upon several factors, including willingness of potential cooperators, area representativeness, site suitability, access, security, and communications. As such, a point that is suitable on the map, does not always translate to a viable location on the ground. Likewise, a willing cooperator or an excellent potential site may not completely fill an existing gap. This is not necessarily a problem as more stations, even clusters of stations, provide increased granularity and provide valuable backups in case a station or sensor malfunctions. The agricultural areas shown in red within Figure 19: Agricultural land that is further than 15km (yellow), 20km (orange), and 25km (red) from an existing weather station are more than 25km from any weather station. These areas should be considered as highest priority for new stations. The most notable area without any recognized monitoring is the northeast region from Clayhurst to Prespatou - also south and southwest of Dawson Creek and north of Highway 29, west of Highway 97. Areas shown in orange and yellow, those more than 20km and 15km from weather stations, respectively, would also benefit from having closer monitoring stations. Given the existing monitoring gaps, approximately 10 strategically-placed additional weather stations could improve the coverage dramatically. More than 10 stations would provide even better coverage.

There are different ways to go about resourcing these 10 or more stations. One option would be for one of the main stakeholders, such as the BC Grain Producers to simply purchase additional weather stations and to install and maintain these stations either by using their own personnel, or by contracting out this work. Unfortunately, this solution falls to one organization even though these stations would benefit many through enhanced coverage of the region.

Another option would be to promote or encourage, perhaps through cost-sharing, businesses or individuals within the region to establish their own weather stations and then the associated data would need to be made available. In this situation, the station-owner would pay a portion of the total cost and would benefit by having site-specific weather data and tools. The region would benefit by having better monitoring coverage. For example, if it were a Farmwest or WeatherFarm station, the average annual cost would range from $1,500 to $2,500, depending on the type of station. If there were a 50% cost-sharing, the producer would pay between $750 and $1250 per year, while the remainder of the cost would be contributed by other stakeholders. The contribution agreement would be contingent upon proper station siting, reasonable upkeep of the station site, and the willingness to contribute data.

A risk associated with this scenario is that either the station-holder or the contributing organization either runs out of funding or decides that they no-longer want to pay to maintain the station. This is particularly probable if the contributing organization is dependent upon funding programs, none of which are ever permanent. Unfortunately, this is a risk inherent with all weather monitoring programs – they require long-term funding or else they die. A one-time cost instead of an annual cost would not be solution. Many monitoring programs have started out with an influx of funding, allowing an organization to purchase new equipment and set up their network. All too often, within a few years, the funding has run out, the equipment becomes old and in need of replacement or calibration, and there are inadequate resources to continue to improve the network and tools, let alone maintain them to a minimum level. Therefore, treating a weather station or monitoring network as an ongoing commitment rather than a one-time purchase reinforces the need for continued and long-term investment.

Another viable option that should be considered is to collaborate with the Peace River Regional District (PRRD). Within the next year, the District will be consolidating its landfill sites to a number of staffed regional locations that will have power and an internet connection. These sites will generally have reasonable exposure, accessibility, security, and communications. Establishing stations at some of these sites would fill many of the existing monitoring gaps. Specific sites that should be considered include Buick Creek, Prespatou, Doig, Rose Prairie, Cecil Lake, Goodlow, Toms Lake, and Upper Halfway. Optional sites would include Kelly Lake, Groundbirch, and Doe River. Figure 20: Agricultural land at various distances from an existing weather station along with PRRD landfill sites (green dots)shows the locations of the PRRD landfill sites in relation to agricultural land and its corresponding distance from existing weather stations.

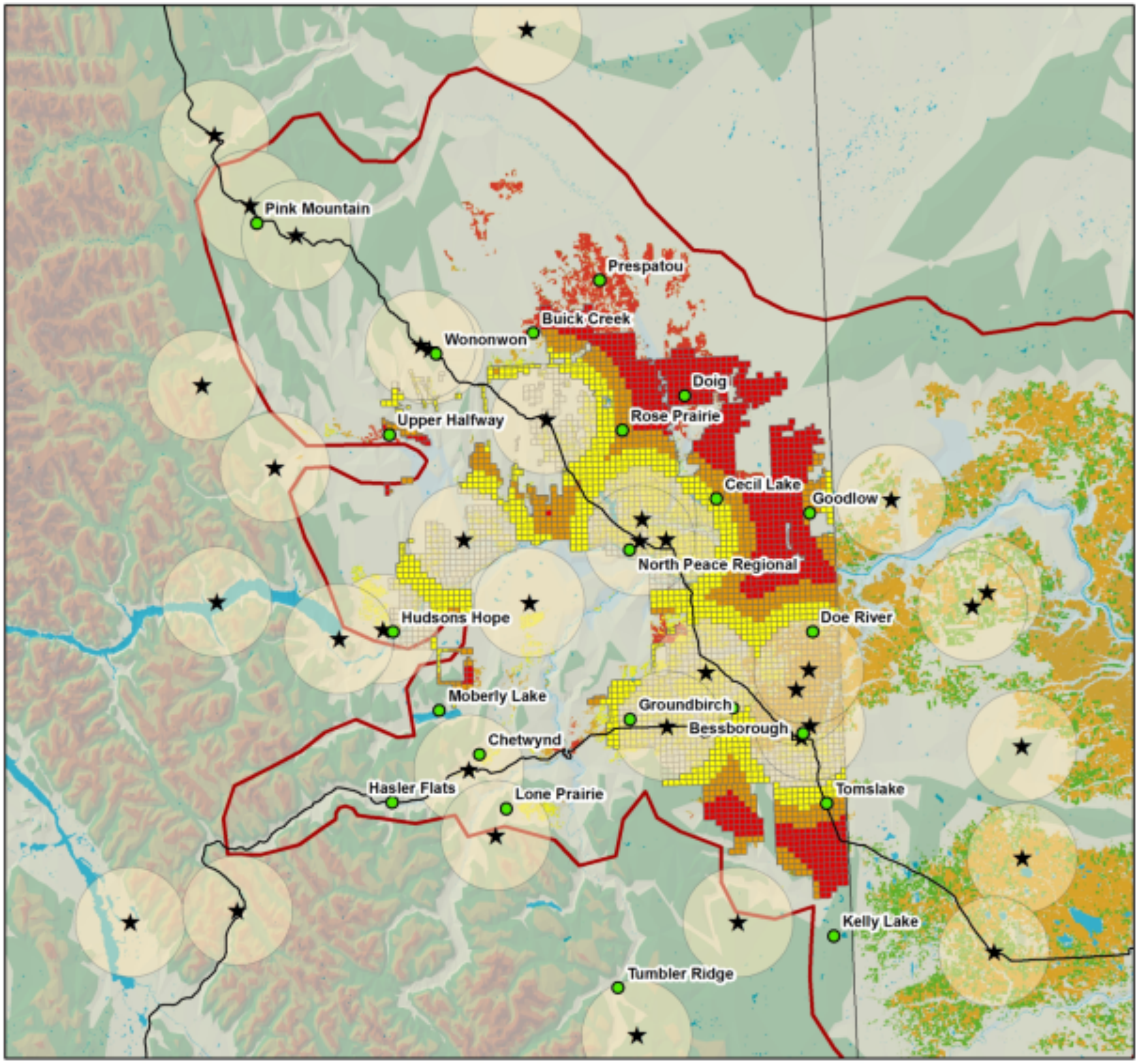

Figure 20: Agricultural land at various distances from an existing weather station along with PRRD landfill sites (green dots)

Valuable supplementary rainfall data could also be acquired through the recruitment of volunteer observers. A model that has been successful in the United States, and more recently in Manitoba, Saskatchewan, and the Maritime provinces, is the Community Collaborative Rain, Hail and Snow (CoCoRaHS) program. This initiative involves members of the general public recording and reporting daily precipitation measurements. The program is a very low-cost method of gathering valuable rainfall information. Furthermore, such a program engages the public and educates them about the weather and natural environment.

3.9.1 Monitoring Equipment

Regardless of equipment type, proper and relatively uniform station standards are imperative. These standards include station siting, exposure, and sensor placement, along with good record-keeping. The margin of monitoring error that can be attributed to these factors far outweighs the less significant sources of error introduced by various lower-cost equipment types. That being said; better equipment will generally provide more accurate and precise data. However, this will come at a higher upfront cost and, quite likely, a higher ongoing cost.

There is also the question of having a high-quality regional weather station compared with a somewhat lower quality local or on-farm weather station – or, more likely, a dense network of local weather stations. While the margin of error associated with the regional climate station may be very low, this would only apply to the immediate area surrounding that climate station. The further away from a station, be it several meters or kilometers, the stochastic nature of weather will prevail, thus decreasing the representativeness of that station (recall the Tobler's law "Everything is related to everything else, but near things are more related than distant things"). Therefore, a weather station is only accurate within its immediate area. A weather station that may technically be considered less accurate will provide superior local weather than a highly-accurate station that is located tens of kilometers away. Figure 21 provides a comparison of the relative margin of rainfall error associated with sensor accuracy, sensor siting, and distance from the actual weather station. Clearly, the further away one is from a station - even an extremely accurate station, the greater the margin of error associated with estimating rainfall at that un-gauged location.

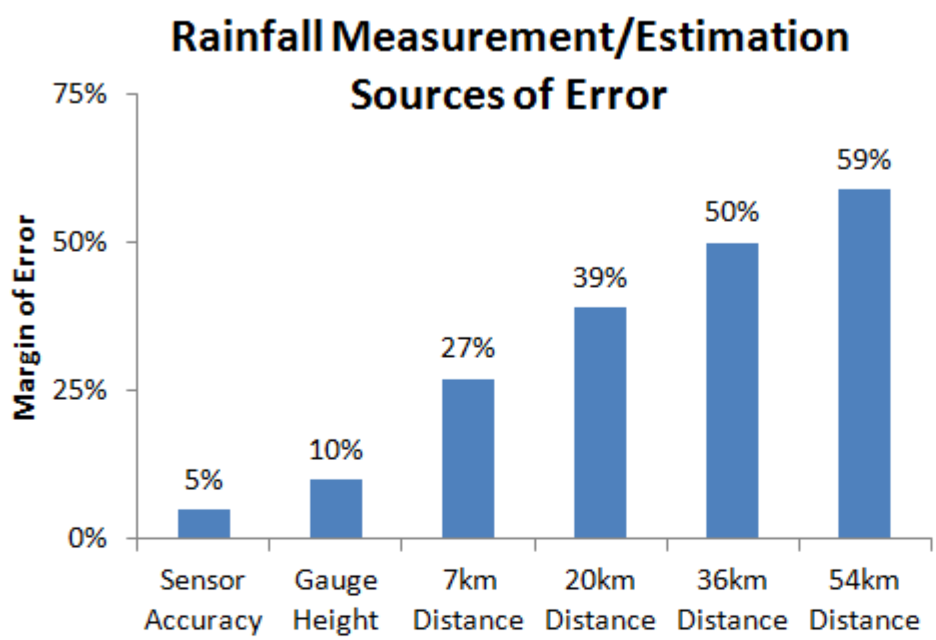

Figure 21: Approximate measurement and estimation error associated with rainfall collection. Based on Ahrens 2006, Kurtyka 1953, and published sensor specifications

It is important to recognize one's needs prior to investing in monitoring infrastructure. If the requirement is to monitor climate over an extended period of time, then a climate station is in order. The operator would have to consider the cost premium to purchase highly accurate monitoring instruments, along with the responsibility of a rigorous maintenance program, regular calibrations, and the required expertise. In contrast, a supplementary weather station that is meant for day-to-day on-farm decision-making, or to provide better insight into local conditions, may not need to be of such a high standard. Particularly for agricultural decision support tools that deal with biological processes that inherently come with a margin of error. This error can be greater than that of even the most basic weather stations. Therefore, to enhance the level of monitoring within the region, it is recommended that good quality equipment with reasonable specifications be used – though it need not be of the highest specifications available. This leaves some degree of latitude as to the actual brand of station as there are several good quality brands available. From a budgeting perspective, a full weather station with communications and capability for monitoring temperature, relative humidity, rainfall, and wind speed/direction could quite reasonably be purchased for $2,500 to $7,500 per station (refer to Table 2: Common weather stations used in Western Canada). Any of these equipment options, or something similar, would be completely adequate.

3.9.2 Network Operation

Network maintenance and upkeep costs can also be extremely variable. Whether done in house or contracted out, one must consider the many tasks involved and the resources required. For example, monitoring data to identify issues that need to be addressed, travel to and from stations for both regular and unscheduled maintenance, time spent travelling and on-site, and replacement of equipment due to damage or age. Given that weather stations are located outdoors and are exposed to the elements, they occasionally get damaged by severe weather, animals, or humans – whether accidental or intentional - and they also tend to wear out. A common recommendation for equipment replacement is to budget approximately 10-15% of the station value per year towards upgrades and replacement equipment. On a $5,000 station, this would amount to $500 to $750 annually. This realistically puts the equipment lifespan at seven to ten years.

Another consideration is data transmission costs. In order to collect data from the observing site, some sort of telecommunications or telemetry is necessary. Depending on the remoteness of the site, these costs can be high. However, a station located in a relatively populated area may be able to take advantage of an existing high-speed internet connection, thus eliminating the communications cost. It is important to ensure that the internet connection is reliable and even reliable internet connections are subject to occasional outages.

Cellular communications are another viable option as cellular networks have improved in coverage and as data transfer rates have become quite affordable. Within the Peace River region, the cellular coverage is reasonably good (Figure 22: Cellular coverage (GSM/GPRS/HSPA) in the Peace region). Depending on the provider, monthly data rates can be as low as $10 to $15. Cellular communications are quite reliable and tend to have few issues if the signal is of adequate strength.

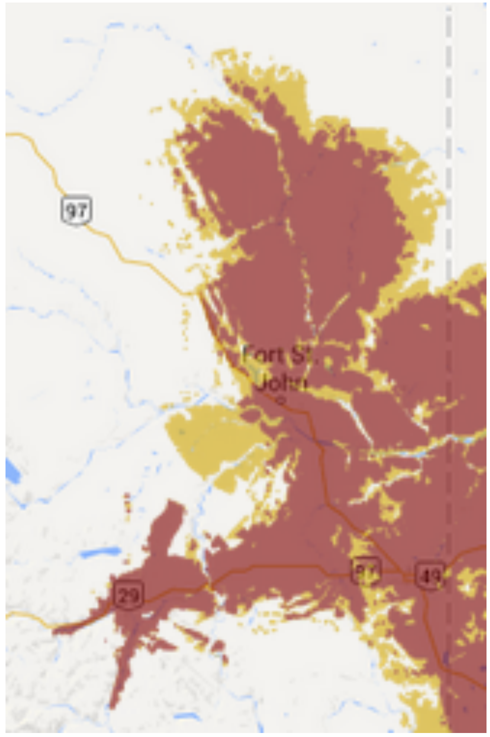

Figure 22: Cellular coverage (GSM/GPRS/HSPA) in the Peace region

Where internet, cellular, and land-lines are unavailable, the only remaining option is satellite. In remote areas, particularly in mountainous regions where line-of-site telemetry is difficult, satellite provides a very robust and reliable means of transmitting data. Satellite is generally the most costly option, often in the range of $30 to $50 per month. Given that most of the agricultural area of the Peace River region has reasonable cellular coverage, as well as locations with high speed internet, satellite communications would likely not be necessary.

While there are no standard rates for network operations or station upkeep, an average contracted cost would be around $800 to $2500 per station per year. This would depend on the type of station, remoteness, and frequency of visits. Depending on the contractor, this may include all costs (communications, replacement parts, upgrades), or it may only include service, whereby the customer must pay the additional costs. Even if maintenance is done in-house, it is still important to factor in the additional costs, including labour. Complete packages, such as those offered by Weather INnovations, include all hardware, communications, maintenance, repairs, replacement parts, upgrades, and data flow. As part of the Farmwest network, station-owners are expected to maintain their own station regularly and to ensure that their station is operating properly. Farmwest carries out some data checking and will notify a station-owner if data problems are detected. The owner should be willing to visit the climate station and examine the output to ensure high quality data.

To ensure station standards and consistency, we would recommend that for any newly established network, some sort of formalized maintenance program be implemented rather than relying solely on station owners. Table 6 provides some estimates of annual station costs, both as outright equipment purchases with maintenance and full leasing options that include equipment. In order to provide a multi-year estimate, the total five-year costs and the annual averages of the five-year costs are provided in the last two columns. It should be noted that different contractors or service providers may include different levels of data management and delivery. For example, the lease programs offered through WeatherFarm include all data management and a suite of agronomic tools. This will be discussed in the next section.

Table 6: Estimated annual costs for station operation

Station Type	Purchase/ Lease	Hardware Costs	Service/ Maintenance	Comm-unications	Replacement Parts (10%)	Cost: 5-Yr Extended	Annual Cost (avg of 5-yr)
Davis Vantage Pro 2	Purchase	$2,500	$800	$0 (Internet)	$250	$7,750	$1,550
	Lease	Included	$1,500	$0 (Internet)	Included	$7,500	$1,500
Davis Vantage Pro 2 Cell	Purchase	$4,280	$800	$264 (Cell)	$428	$11,740	$2,348
	Lease (Not available)						
Adcon Telemetry A753	Purchase	$5,000	$1,000	$180 (Cell)	$500	$13,400	$2,680
	Lease	Included	$2,500	Included	Included	$12,500	$2,500
Campbell Scientific CR1000	Purchase	$7,500	$1,500	$180 (Cell)	$750	$19,650	$3,930
	Lease (Not available)						

Table 6 provides estimated annual and five-year costs of operating weather stations. Whether purchased or leased, the average annual costs for basic to higher-grade stations range from $1,500 to $2,500. For a minimum of 10 new weather stations, this would amount to a total annual cost of $15,000 to $25,000. As stated earlier, the higher-grade stations are always preferable as they will be more robust and slightly more accurate. Over five years, this would amount to a total cost of $75,000 to $125,000. If these stations are to be operated on the Farmwest and/or the WeatherFarm networks, data management would be included in these costs.

If a cost-sharing mechanism can be established, whereby stakeholders within the region share the annual costs, this total amount could either be reduced or be put towards additional monitoring stations. The contribution agreement would be contingent upon proper station siting, reasonable upkeep of the station site, and the willingness to contribute data. Table 7 provides some overall costs based on quantities of monitoring stations and levels of cost-sharing, from 40% to 60%.

Table 7: Total network costs, including cost-sharing options

Total # of Stations	Annual Cost per Station	Total Annual Cost	40% Cost-Share	50% Cost-Share	60% Cost-Share
10	$1,500	$15,000	$6,000	$7,500	$9,000
	$2,500	$25,000	$10,000	$12,500	$15,000
15	$1,500	$22,500	$9,000	$11,250	$13,500
	$2,500	$37,500	$15,000	$18,750	$22,500
20	$1,500	$30,000	$12,000	$15,000	$18,000
	$2,500	$50,000	$20,000	$25,000	$30,000

4.0 Decision Support Tools and Data Management/Product Delivery

4.1 Decision Support Tools (DST)

In most cases, raw weather data will not satisfy the needs of users. Rather, users demand a certain degree of analysis, summation, modelling, or other methods of adding value, depending on their specific needs. For example, drought assessment would likely require precipitation accumulations over various time periods, comparisons to long-term climate normals, estimated evapotranspiration over time, soil moisture, and various drought indices. Likewise, raw numbers, such as rainfall and temperatures do not provide a great deal of insight into on-farm management, agronomical choices, or market decisions. Rather, the value is in decision-support tools (DST). Therefore, while a dense network of high-quality weather stations may be attractive, it is not likely to benefit agricultural producers to a great extent in that it will not provide crop or livestock-specific information that can be applied to farm management. Conversely, the best set of weather-based DST's are of little value if the weather data is not local, timely, and accurate. Therefore, in order to provide valuable tools for producers, a combination of good weather data and effective DST's are needed.

There are many agronomic tools that are offered in various jurisdictions, few of which are currently available in the BC Peace Region. Some of these tools are crop or commodity-specific, while others are more general. Models can use a variety of data sources. Some tools are based on actual current or recent weather conditions; some are based on weather forecasts; while others use long-term climate or normal data to come up with a recommendation. There are also models that use combinations of the above data types.

According to consultations with various agricultural stakeholders, there are a number of decision support tools (DST) that would be of benefit to the industry. Of highest priority were those that address crop pest and disease issues. These include disease risk models and indicators of potential pest presence that would help to advise producers of whether they should scout their crop or take preventative action. Given that the major annual crops in the region are cereals and oilseeds, models for sclerotinia stem rot and lygus bug in canola and fusarium head blight and midge in wheat would provide value to the sector. For forage crops, heat unit indicators such as growing degree days would be helpful, along with temperature and precipitation and how they relate to yield. The following section lists and describes several DST's that could potentially be offered within the Peace Region, including the necessary meteorological parameters to run such models. It is important to consider the necessary parameters when sourcing data and establishing new weather stations. In general, temperature, relative humidity, and rainfall are the data requirements for most models. Some of the disease models also require leaf wetness, while equations to predict evapotranspiration also require wind speed and solar radiation.

Table 8: Potential Decision Support tools that could be offered

Tool	Crop	Description	Necessary Parameters
Fusarium Head Blight (FHB)	Wheat, Barley	DONcast is a weather-based prediction tool developed in Ontario to predict pre-harvest Deoxynivelenol (DON) accumulation in wheat. The model has not been validated in Western Canada, but could potentially be adapted if adequate validation data were to be available.	Hourly air temperature, relative humidity, leaf wetness. Hourly forecast.
Sclerotinia stem rot (SSR)	Canola	Sclerotinia is dependent on weather during flowering; however, agronomic variables, micro-climate, and presence of pathogen also influence the incidence of the disease. Currently, no accurate SSR models exist for western Canada.	Hourly air temperature, relative humidity, leaf wetness. Hourly forecast.
Insect Pest Forecasts	All	Prairie Pest Monitoring Network provides survey and forecast maps for the prairies, including the Peace Region of BC. Pests include bertha armyworm, grasshopper, wheat midge, cabbage seedpod weevil, wheat stem sawfly, and pea leaf weevil.	Actual field scouting or insect traps
Growing Degree Days (GDD)	Most	Growth of plants can often be estimated using GDD. GDD can be applied to many crops, including canola, wheat, barley, and other small grains and used to predict certain growth stages.	Daily maximum and minimum air temperature
Corn Heat Units (CHU)	Corn, Soybean	Development of warmer-season crops, such as corn and soybean are most often estimated using CHU. CHU differs from GDD in that it uses separate maximum and minimum temperature thresholds of 10°C and 4.4°C, respectively.	Daily maximum and minimum air temperature
Pest Degree Days	All	Pest degree day calculators can be used to estimate the emergence of many insect pests.	Daily maximum and minimum air temperature

Foliar disease models	Wheat, Barley	Decision support tools are available for several foliar diseases of wheat and barley. WHEATcast is a risk forecast model for Septoria leaf spot and powdery mildew in Ontario. North Dakota State University has developed an advisory for foliar diseases (tan spot and Septoria leaf spot).	Hourly air temperature, relative humidity, leaf wetness. Hourly forecast.
T-SUM	All	To determine when to make the first application of nitrogen fertilizer in spring. 'T-Sum' is the accumulated mean daily temperatures above zero, starting on January 1. Currently offered on Farmwest.	Mean daily air temperature
SPRAYcast	All	Spray advisory that uses detailed hourly forecast to provide an indication of conditions related to spraying. Identifies times of day that are suitable for spraying in order to reduce the risk of spray drift. Currently offered on WeatherFarm.	Hourly forecast
BINcast	All	Grain storage management tool to assist with grain drying and conditioning. Provides forecast of the predicted equilibrium moisture content (EMC).	Hourly air temperature and relative Humidity
Alfalfa cutting models	Alfalfa	Developed by Michigan State University and has been used in Michigan and Ontario to harvest alfalfa. Work on a relative feed value models has also taken place in MB and BC	Daily maximum and minimum air temperature
Evapotranspiration/Irrigation Tools	Irrigated crops	At present, irrigation is not considered a practical or cost-effective option in the Peace region, but irrigation infrastructure may become viable in the future. Farmwest offers a number of irrigation tools, including evapotranspiration, effective precipitation, and moisture deficit.	Hourly air temperature, relative humidity, wind speed, solar radiation, soil moisture. Hourly forecast.
Cattle comfort advisories	Cattle	Cattle comfort models, such as the Cold Advisory for Newborn Livestock (CANL) are currently not offered in Canada, but could be implemented.	Hourly air temperature, relative humidity, wind speed. Hourly forecast.
Moisture Indicators	All	AAFC provides maps of moisture-related indicators, including precipitation (accumulated, percent of normal, difference from normal, percentiles, and dry spell), temperature, and drought indicators.	Daily rainfall. Climate normals.
Frost risk	All	Long-term climate records can be used to calculate the risk of last spring frost, frost-free days, and frost-free period.	Climate normals and climate projections.
Thermal Indicators	All	Calculation of probability of receiving a certain amount of heat during the growing season to be used for crop adaptation.	Climate normals and climate projections.

4.2 Data Management/Product Delivery

The importance of data management should not be underestimated. Data management, quality control, modelling, product delivery, and data archiving is a substantial undertaking – one that is often beyond the capabilities of most organizations. These are also activities that can take a great deal of time to develop and implement. This process requires programming, database design and management, data manipulation, modelling, web programming, and server support. For these reason, it would make sense for the region's agricultural community to partner with an existing entity that is already performing these activities. This would also reduce the amount of lead time required in getting a comprehensive program up and running. Within the BC Peace Region, there are some online farm-specific weather services that are currently available. These include Farmwest, WeatherFarm, and Farmzone (The Weather Network).

A priority that has been brought forward by producer organizations is the need to access data from different networks without having to go to several sources. Therefore, a method of aggregating the data from the various providers is necessary. Another entity that performs data management and dissemination, but is not agriculture-specific is BC's Pacific Climate Impacts Consortium (PCIC) in its support of the Climate Related Monitoring Program (CRMP). This project does not provide management tools, but rather is a multi-organizational group that provides data management, archiving, and a data portal. Farmwest, WeatherFarm, Farmzone, and the CRMP are described below.

4.3 Farmwest

Farmwest is an agricultural weather service that is operated by the Pacific Field Corn Association and the BC Ministry of Agriculture. The program mostly uses weather data from existing networks, where applicable. These networks include Environment Canada, the Greater Vancouver Regional District (GVRD), BC Ministry of Transportation, and a network in the Okanagan Valley. Within the BC Peace, Farmwest uses the two main airport Environment Canada stations and the two Road Weather Stations that are operated by the BC Ministry of Transportation. Some of the other networks are not used due to the limitations associated with the data. These limitations include networks that only operate on a seasonal basis (avalanche network) and station representativeness. There are also five stand-alone stations located in Abbotsford, the Okanagan, and Washington State. These stations are Davis Vantage Pro and communicate over the internet or via cellular modem. There are no dedicated Farmwest stations in the Peace Region. If a customer were to want their own weather station, they must purchase it. Farmwest does not provide station maintenance, repair, or warranty.

Personnel acknowledge that many more weather stations are necessary to represent the many topography-related microclimates in BC and that a closer station provides more relevant data. For areas that are inadequately covered, Farmwest encourages users to invest in their own weather stations in order to have real-time data from their immediate area. According to the Farmwest website, having real-time climate data can "pay for itself in increased production and water savings" and it can help a grower decide when/how much to irrigate, when to plant, when to apply fertilizers, and provide pest management information.

Farmwest is one of the few networks that cater to agricultural applications. Using the weather data, the site provides several DST's, including a T-Sum calculator, an ammonia loss from manure model, evapotranspiration and irrigation tools, growing degree days and corn heat units calculators, pest degree days calculators (generally for fruit crops), and a weather forecast. The general consensus among the agricultural community in the BC Peace Region has been that Farmwest is primarily focused on agriculture in the southern parts of the province and has little relevance in the Peace. However, a representative from Farmwest has stated that the program would be willing to expand its offerings to better represent crops that are grown in the Peace region if resources were made available. The level of required resources remains unknown. Also not known is Farmwest's capacity to quickly develop additional tools.

4.4 WeatherFarm

In addition to operating monitoring stations, WeatherFarm also provides agriculture-specific tools for producers. WeatherFarm, in addition to using the Environment Canada stations in the Peace Region, also gathers data from the seven WeatherFarm stations. WeatherFarm has recently (2014 season) changed its pricing structure. Previously, a station was purchased outright for between $1800 and $2800. This price included all necessary equipment, installation, maintenance and warranty. As the program moves towards a service and information-based model, the station package has transitioned to a monthly or annual subscription-based approach. In addition to a weather station, maintenance, repairs, upgrades, and basic data, station-owners receive summaries, reports, agronomic DST's, and related information. This service ranges in price from $100 to $150 per month (~$1,500 per year), depending on the level of service. From a network operator and user perspective, this model is more sustainable as it ensures that the network is maintained and that adequate resources are put towards network operation and improvement, particularly beyond the period of maintenance and warranty. WeatherFarm is also supported by sponsors and advertising, which offset some of the end-user costs. WeatherFarm operates across western Canada and can benefit from efficiencies related to data management, model development, and information delivery.

4.5 Farmzone

Farmzone provides some agriculture-specific weather information, but at the region scale. For example, the BC Peace Region is all in a single zone, represented only by the Fort St. John airport weather station. Farmzone appears to have very few farm decision support tools (a drying index, a daily calculation of GDD and CHU, and a sclerotinia forecast that appears to run year-round). Farmzone does not address any of the regional concerns about monitoring gaps.

4.6 Climate Related Monitoring Program (CRMP)

British Columbia has made significant progress in data sharing among the various network providers – quite possibly further than any other province. In 2010, following several years of planning and negotiation, several organizations with interests in weather data signed a memorandum of understanding, entitled Agreement on Management of Meteorological Networks in the Province of British Columbia. These organizations include BC Hydro, Rio Tinto Alcan Inc., Pacific Climate Impacts Consortium, BC Ministry of Environment, BC Ministry of Transportation, BC Ministry of Forests, Lands and Natural Resource Operations, and BC Ministry of Agriculture. According to the memorandum of understanding, the organizations, most of which manage monitoring networks, have acknowledged that they would benefit through the "exchange of meteorological data and sharing of information, methods and procedures, experience, expertise and knowledge of meteorological observations and network operations." Through this agreement, the stakeholders retain responsibility to operate and maintain their own networks and agree to share meteorological data and information between members while also agreeing to implement recognized network operating and management standards wherever possible.

Further, the agreement states that: *Collaborations between network operators will optimize the value of existing data and networks, by:*

- *Increasing the availability and effectiveness of meteorological data and information through a shared meteorological resource in BC;*
- *Improving and adding value to available sources of climate data in BC and Canada;*
- *Identifying and addressing spatial gaps in the meteorological network coverage;*
- *Addressing risks of error or misunderstanding of the impacts of climate change and climate variability; and,*
- *Creating a climate data set to enhance understanding of the scope of climate change and climate variability within BC.*

Source: Agreement of Management of Meteorological Networks in the Province of British Columbia, July 6th, 2010

The meteorological dataset itself is to be made available through the Pacific Climate Impacts Consortium (PCIC) which collects data, performs quality assurance/quality control, and provides analysis and interpretation. Currently, some of the contributed datasets are available in near-real-time. Others have yet to be implemented. Therefore, the amount of current data is limited. However the archive of past data, including climatological averages is expansive and impressive. Recognizing that better collection of weather data is the only way to improve climate datasets (and resulting analyses and assessments) PCIC, through the development of a Provincial Climate Data Set (PCDS), is working towards implementing near real-time data ingestion and on further steps toward quality control. In addition, PCIC is developing high-resolution climate maps from the PCDS, including analyses of seasonal weather and monthly, and then daily, weather variables. These datasets and maps will be valuable on their own, as well as for further analyses related to agricultural planning and production within the Peace region.

4.7 Summary of Data Management and Delivery Providers

	Farmwest	WeatherFarm	Farmzone	CRMP
Operational in BC	Yes	Yes	Yes	Yes
Organizational Structure	Commodity Assoc./BC Gov.	Private industry	Private industry	Multi-Stakeholder
Dedicated weather stations	Yes	Yes	No	No
Maintains weather stations	No	Yes	No	No
Performs data QC	Yes	Yes	?	Yes
Agriculture-related tools	Yes	Yes	Yes	No
Cost	Free	Free (basic)	Free	Free

4.8 Recommendations on Data Management

There can be substantial costs associated with data management and in developing and offering DSTs. Developing and providing these tools requires research, analysis, modelling, computer programming, and a delivery system. These requirements are beyond the capability of most organizations. Therefore, it makes sense to work with existing providers (such as Farmwest and WeatherFarm) towards offering enhanced agronomic tools. Farmwest and WeatherFarm should continue to coexist and both providers should have a presence in the Peace region, thus providing users with a choice. The open sharing of data would facilitate this option and should be a requirement for any funding. Within both Farmwest and WeatherFarm, the user does not pay specifically for data management. Rather with Farmwest, data management is included; with WeatherFarm, it is bundled in the monthly or annual package. For individuals that do not subscribe to any packages, there are a number of tools that are freely available. These generally include current conditions, maps, and general weather-based tools.

For the delivery and archiving of raw climate data, the CRMP, through the PCIC data portal, is an excellent option and should play a part in the management of data.

5.0 Recommendations

The current monitoring gaps are attributed to both a shortage of actual monitoring stations in certain areas, as well as a lack of integration of existing datasets. Clearly, there are various networks, beyond the standard Environment Canada stations, that have potential to be valuable in filling some of the gaps. However, caution must be exercised about which stations are integrated and whether their data is relevant for agricultural conditions.

There are a number of key stakeholders that require meteorological data for various purposes. Agriculture is only one sector with data requirements; hydrological forecasting, forest fire management, transportation, emergency management, climate change, power generation, and resource extraction are others. As the region looks toward enhancing its monitoring capacity, collaboration will be valuable and mutually beneficial. The Climate Related Monitoring Program (CRMP) is an agreement amongst seven parties that have an interest in meteorological monitoring in BC. The participating parties manage, operate, and maintain independent meteorological data collection and data management systems, data archives, reporting systems, and web sites. However, this group is working towards standardizing data collection and management and providing a central hub for data access, and is a resource within the province. Any network expansion plans within the Peace region should be done in collaboration with this group. A member of the agricultural sector within the Peace region should participate in this group.

The BC Grain Producers Association should look to partner with stakeholders within the region. This may include local governments, businesses, and individual producers. Specifically, the Peace River Regional District (PRRD) also has a need for additional meteorological monitoring for resource allocation and emergency response. Other stakeholders, such as the urban centres, also have a need for monitoring.

For example, Fort St. John currently has two WeatherFarm stations to provide better urban coverage. Individuals, whether producers, businesses, or members of the general public may have interest in having their own weather stations that could contribute to the overall network. A cost-sharing incentive should be explored.

In terms of feasible options to improve agricultural monitoring in the Peace region, it is important to first determine realistic budgets. This process can often narrow the list of available options. The range of suitable weather stations does enable some scalability with regards to budget, allowing flexibility.

5.2 Summary of Recommendations

General	A weather station or weather monitoring network must be treated as an ongoing commitment rather than a one-time purchase. This reinforces the need for continued and long-term investment.
Weather Network	Approximately 10 new weather stations would provide a considerable improvement in addressing the current monitoring gaps. Many of these stations could be installed at regional landfill sites.
Weather Stations	Given the monitoring requirements of agriculture, additional high-end climate stations are not necessary. Rather, good quality equipment will suffice. Estimated hardware cost per station is $2,500 to $7,500. Emphasis should be placed on proper station siting and exposure.
Network Operation	Station operation and maintenance can either be done in-house or it can be contracted out. Station leasing packages provide all operational components. Average annual leasing costs range from $1,500 to $2,500.
Funding Model	A cost-sharing incentive should be explored to promote producers, businesses, schools, or members of the general public to have their own weather station that could contribute to the overall network.
Collaboration	Any network expansion plans within the Peace region should be done in close collaboration with the CRMP. This group provides standards, expertise, and data distribution. The Peace region should participate in this group.
Decision Support Tools	Delivery of disease-related agronomic tools is a priority. These tools would be best offered though one or both of the existing providers – Farmwest and WeatherFarm.
Other data sources	A network of volunteer precipitation observers would further enhance the monitoring within the region. The Community Collaborative Rain Hail and Snow (CoCoRaHS) program should be explored.

5.3 Next Steps

In order to move this initiative forward, there are a few steps that should be taken:

- Establish an appropriate budget that will go towards enhancing the level of monitoring. Decide whether this strategy will include cost-sharing and to what level. The budget amount will help determine station quantity and what sort of equipment is most suitable.
- Gather regional stakeholders to determine which groups would like to collaboratively work towards increasing the level of monitoring in the region.
- Appoint a representative from the Peace region to the Climate Related Monitoring Program.
- Communicate with Farmwest and WeatherFarm and request either separate proposals or a joint strategy to provide the necessary agronomic tools for the Peace region.

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