Development of a Regional Hydrometric and Climate Monitoring Strategy and Implementation Workplan for the Cowichan Valley Regional District

Final Report

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MacHydro FOUNDRY SPATIAL

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MacDonald Hydrology Consultants Ltd.
Cranbrook, BC
machydro.ca

Foundry Spatial Ltd.
Victoria, BC
foundryspatial.com

Executive Summary

The Cowichan Valley Regional District (CVRD) delivers a Drinking Water and Watershed Protection Program (DWWP) to serve the needs of member municipalities and residents of the district. The goals and the objectives of the program are well described as a vision of 'One Water' (CVRD, 2020), with a series of areas of focus and associated actions to progress knowledge and awareness of the water resources of the region. Ultimately the objectives of the program are to ensure that sufficient drinking water is available to residents, and that healthy watersheds sustain ecosystems and provide clean and safe environments for recreation.

Core to achieving these objectives are data and knowledge describing the characteristics of water resources in the region. Environmental monitoring data collected from streams, lakes, rivers and aquifers, combined with weather data describing precipitation, air temperature, snow and other variables, have been collected by all levels of government, industry, academia, community groups and other stakeholders, but are scattered across different agencies and systems. Streamlined access to these data for regional and local government staff in the CVRD can support enhanced awareness and provide data for operational decision making. Integrating data describing different aspects of the water cycle, to produce water balance models creates enhanced knowledge for more complex decisions, but these models and other analytical outputs need clear and simple slices of information which can be easily extracted and used. This will support widespread adoption into planning, public engagement, or other initiatives that benefit from broad participation by stakeholders who may not have the technical expertise, or interest to engage with highly complex scientific information.

Therefore, the CVRD requires a *Regional Hydrometric and Climatic Monitoring Strategy and Implementation Workplan* that is designed and implemented across the region at regional, watershed, and surface/aquifer scales. The goal is to improve the understanding and management of water in the individual watersheds to assist with short-term watershed management and drinking water supply forecasting, and future water strategy development and planning within the CVRD. The strategy is expected to provide information to drive adaptive management and emergency response and has critical linkages to the climate adaptation program. In addition, the strategy should function to provide specific data to support future development of conceptual models, water balance calculations, relative stress assessments, hydrological modelling, and the development of Integrated Watershed Management Plans. The development of the strategy was divided into four phases with specific objectives:

- Phase 1 - Identification of stakeholders, technical team support and data collection
  - Identify all data collection agencies and potential partners that should be consulted for this project;
  - Support a multi-party technical oversight team made up of project partners who will provide input and support to the strategy development at key points;
  - Source and review all current and historical hydrometric and climate data from CVRD and other identified partners that includes location, status, availability, data format, and relevance to the project; and,
  - Identify any necessary memorandum of understanding (MOU) or data sharing agreements.
- Phase 2 - Develop supporting data management strategies
  - Develop a proposed data warehouse structure(s) that could effectively interface with other entities;
  - Identify necessary communications infrastructure to support effective data management; and,
  - Populate a cohesive historical dataset into a database with appropriate quality and relevance.

- Phase 3 - Preliminary assessment and gap analysis
  - Review of the available hydrometric and climate stations currently operating in the CVRD and undertake a gap analysis to identify strategic locations for investments in additional and relevant infrastructure;
  - Develop a framework to assess the need for additional monitoring locations to meet the overall strategy;
  - Recommend a ranked list of sites for the hydrometric and climate monitoring network using the framework;
  - Develop an implementation plan for the network that includes a budget for installation of new sites and reinstatement of inactive sites as well as on-going maintenance of monitoring sites; and,
  - Provide recommendations for proxy data collection for interim data while the monitoring network is being built.
- Phase 4 - Recommendations and strategy development
  - Identify logistics or agreements necessary to implement the network on lands managed by others;
  - Provide recommendations regarding data collection, data storage standards and operations with specific consideration of devices, comms and standards, analytics, analysis tool sets and data display; and,
  - Provide recommendations to the data warehousing and deployment.

To help assist in strategy development, a technical advisory group was formed that included CVRD staff and members from various external provincial and community organization. Meetings were held at each phase of strategy development to gain valuable insight and incorporate feedback.

The following recommendations were proposed for the strategy and implementation workplan:

Phase 1 –

- Engage with relevant organizations for data sharing agreements to assess monitoring data not publicly available.

Phase 2 –

- The data management system should:
  - Be inter-operable with other internal systems at CVRD and with external systems at partner agencies;
  - Be extendable to incorporate new monitoring data types, locations, partners, and use cases and to connect the system with new systems in the future;
  - Meet the information needs of end users and deliver results rapidly;
  - Continue to be updated and provide trustworthy data;
  - Simple to use so users can easily receive data in a format that is easy to work with and developers are able to adapt and extent the system with ease; and,
- Continue to identify, evaluate and prioritize use cases as they are discovered to decide on analytical or decision-support needs and instruct prioritization of new data collection efforts to ensure that these data support the highest priority use cases.

Phase 3 –

- Selected monitoring sites should have field reconnaissance to review conditions and suitability for installation;
- Connect with the provincial government to ensure there are no overlaps with identified potential station locations for the Provincial Groundwater Observation Well Network;
- Review cost estimates for installation of monitoring stations on a location-by-location basis after site reconnaissance due to differences in access, travel time, site conditions and preparation, cellular coverage, etc.; and,
- Continually track the operation of the climate stations operated by the cooperative community network to ensure that operation continues into the future as these stations may need to be replaced by CVRD operators.

Phase 4 –

- Initiate discussion with land owners for installation of sites on privately owned land to obtain access permission;
    - develop a standard CVRD land use right-of-way and covenant form for use of properties for hydrometric and climate network under a public amenity process;
- Submit appropriate applications with FrontCounter BC for installation of monitoring sites on crown land to obtain land lease or license;
- Confirm the First Nation consultation process with FLNRORD prior to submitting any applications;
- Consider the range of requirements for developers imposed by the CVRD for DPAs for protection of the natural environment for potential expansion to include planned right-of-ways to access watercourses for potential monitoring, or installation and maintenance of a groundwater observation well;
- Hire a skilled technologist that understands data collection, validation, correction, and evaluation;
- Adopt standardized procedures for data validation, correction (e.g., logging any changes), and evaluation;
- Adopt standardized procedures for cataloguing metadata and making site metadata publicly available;
- Assess hydrometric and climate data quality using the RISC hydrometric and ECCC climate standards; and,
- Implementation of the technology architecture should be conducted in phases and follow a 4-step plan that includes:
    1. Develop core database and information flows and connections to external datastores
    2. Finalize agreements prior to installation of monitoring stations, collect and publish data and connect to core database (distribution to external datastores)
    3. Define roles, responsibilities, and agreements of any partner data collection (on-going), data management plans and data collection, and incorporate into core database
        i. Reduce duplication of effort by sharing data and integrate monitoring efforts with partners where possible;
    4. Perform analytics, create interpreted products, provide visualizations or reporting for communication, and develop decision-support tools;
        i. Continue to collaborate with key municipal and community partners, academia, and First Nations moving forward to ensure the CVRD monitoring program meets their organization needs.

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1 Introduction

1.1 Introduction

The Cowichan Valley Regional District (CVRD) delivers a Drinking Water and Watershed Protection Program (DWWP) to serve the needs of member municipalities and residents of the district. The goals and the objectives of the program are described as a vision of 'One Water' (CVRD, 2020). Areas of focus and associated actions are to progress knowledge and awareness of water resources in the region gained through environmental monitoring.

Studies of long-term monitoring programs have recognized challenges that can sometimes reduce the efficacy of the monitoring in informing management (Lindenmayer and Likens, 2009; Arciszewki et al., 2017). Successful monitoring programs were adaptive, and had several features in common that included: high-quality data collection and careful attention to data storage; well-developed collaborative partnerships among scientists, resource managers and other key groups; access to on-going sources of funding; and, strong leadership (Lindenmayer and Likens, 2009). Within the CVRD, monitoring data collected from streams, lakes, rivers and aquifers, combined with weather data have been collected by all levels of government, industry, academia, community groups and other stakeholders, but are scattered across different agencies and systems. Streamlined access to these data for regional and local government staff in the CVRD can support enhanced awareness and provide data for strategic planning and operational decision making. Integrating data that describe the different aspects of the water cycle and produce conceptual water balance models provides enhanced knowledge for more complex decisions, but these models and other analytical outputs need clear and simple slices of information that are easily extracted and used. This will support widespread adoption into planning, public engagement, or other initiatives that benefit from broad participation by stakeholders who may not have the technical expertise, or interest, to engage with highly complex scientific information. Therefore, it is important that the monitoring strategy maintain interest, flexibility and does not degenerate into a data-collection exercise (Arciszewki et al., 2017).

MacDonald Hydrology Consultants Ltd. (MacHydro) in collaboration with Foundry Spatial (Foundry) were retained by the Cowichan Valley Regional District (CVRD) to develop a Regional Hydrometric and Climatic Monitoring Strategy and Implementation Workplan as part the Drinking Water and Watershed Protection program (DWWP; CVRD, 2020). The CVRD requires a strategy that is designed and implemented across the District at regional, watershed, and surface/aquifer scales. The goal is to improve the understanding and management of water in the individual watersheds to assist with short-term watershed management and drinking water supply forecasting, and future water strategy development and planning within the CVRD. The strategy is expected to provide information to drive adaptive management and emergency response and has critical linkages to the climate adaptation program. The development of a monitoring strategy was divided into four phases:

- Phase 1 - Identification of stakeholders, technical team support and data collection
- Phase 2 - Develop supporting data management strategies
- Phase 3 - Preliminary assessment and gap analysis
- Phase 4 - Recommendations and strategy development

1.2 Project Scope

This report summarizes Phase 1 through 3 of the development of a regional hydrometric and climate monitoring strategy and includes recommendations to develop an integrated strategy. The objectives of Phase 4 include:

- Provide recommendations regarding data collection, data storage standards and operations with specific consideration of devices, comms and standards, analytics, analysis tool sets and data display;
- Identify logistics or agreements necessary to implement the network on lands managed by others; and,
- Provide recommendations to the data warehousing and deployment.

1.3 Project Team

The project team for the development of the CVRD climate and hydrometric strategy include:

- Jeff Moore, CVRD Environmental Services - project manager
- Kate Miller, CVRD Environmental Services
- Ryan MacDonald, MacDonald Hydrology Consultants
- Amy Goodbrand, MacDonald Hydrology Consultants
- Matt Chernos, MacDonald Hydrology Consultants
- Rachel Plewes, Clear Viz Aquatic Consulting
- Ben Kerr, Foundry Spatial
- Hailey Eckstrand, Foundry Spatial

1.4 Acknowledgements

The project team would like to the thank the members of the technical advisory group for their input, guidance and feedback. The members include:

- Brian Dennison, CVRD Water Management
- Lisa Daugenet, CVRD Water Management
- Jason Molyneaux, CVRD Water Management
- Todd Etherington, CVRD Water Management
- Dave Preikshot, Municipality of North Cowichan
- Clay Reitsma, Municipality of North Cowichan
- Brian Murphy, City of Duncan
- Ryan Bouma, Town of Ladysmith
- Ira Adams, Town of Ladysmith

- Dave Parker, Town of Lake Cowichan
- Jarolsaw Szczot, FLNRORD – West Coast Region (Fish & Wildlife Division)
- Neil Goeller, BC Provincial Hydrometric Operations
- Jessica Doyle, BC Water Protection
- Silvia Barroso, BC Water Protection
- Mingyang Zhao, BC Water Protection
- Ted Weick, BC Provincial Climate Network
- Robert Williams, BC Provincial Data Systems
- William Shuba, Islands Trust
- Darryl Tunnicliffe, Cowichan Tribes
- David Beleznay, Mosaic Forest Management
- Tom Rutherford, Cowichan Watershed Board

2 Cowichan Valley Regional District

The Cowichan Valley Regional District (CVRD) is located on southern Vancouver Island, and stretches from the west to east coast of the island, north of the Capital Regional District. The CVRD contains several communities, the largest of which is Duncan, located on the Cowichan River near its outlet to Cowichan Bay. Major watersheds in the region are drained by the Cowichan, Chemainus, and Koksilah Rivers, with numerous smaller watersheds interspersed. The larger rivers typically are more diverse in elevation and climate, from low elevation Mediterranean climates in the east to high elevations in the center of the island that receive substantial accumulations of snow and rain on an annual basis. For example, mean annual precipitation is 1248 mm at Shawnigan Lake (159 m.a.s.l.) with 6% falling as snow, while mean annual precipitation is 3546 mm at Heather Mountain (1,190 m.a.s.l.) with 45% falling as snow. Overall, the climate is characterized by warm, dry summers and mild, rainy winters, and infrequent air temperatures below freezing. Future climate change scenarios project warmer, drier summers, wetter winters with a reduced fraction of precipitation as snow, and more intense rainstorms (Zhang et al., 2019).

Outside of the major watersheds, the benchlands make up much of the east coast and drain into the ocean. The most populated places are on the shores of large lakes or along the east coast (the benchlands). Within the more populated parts of the CVRD region along the eastern side of Vancouver Island, supply and demand pressures vary as a result of the water balance within each water supply area. As a result, during times of drought the risk and impact of shortages are not evenly distributed.

The project study area was determined by selecting 20 Watershed Planning Areas (WPAs) that intersect the CVRD. There were five additional WPAs that were excluded from the study area because they had only small overlaps with the CVRD boundary. In total, this study area is approximately 503,410 hectares (Figure 1), which is larger than the regional boundaries of the CVRD (~350,000 hectares).

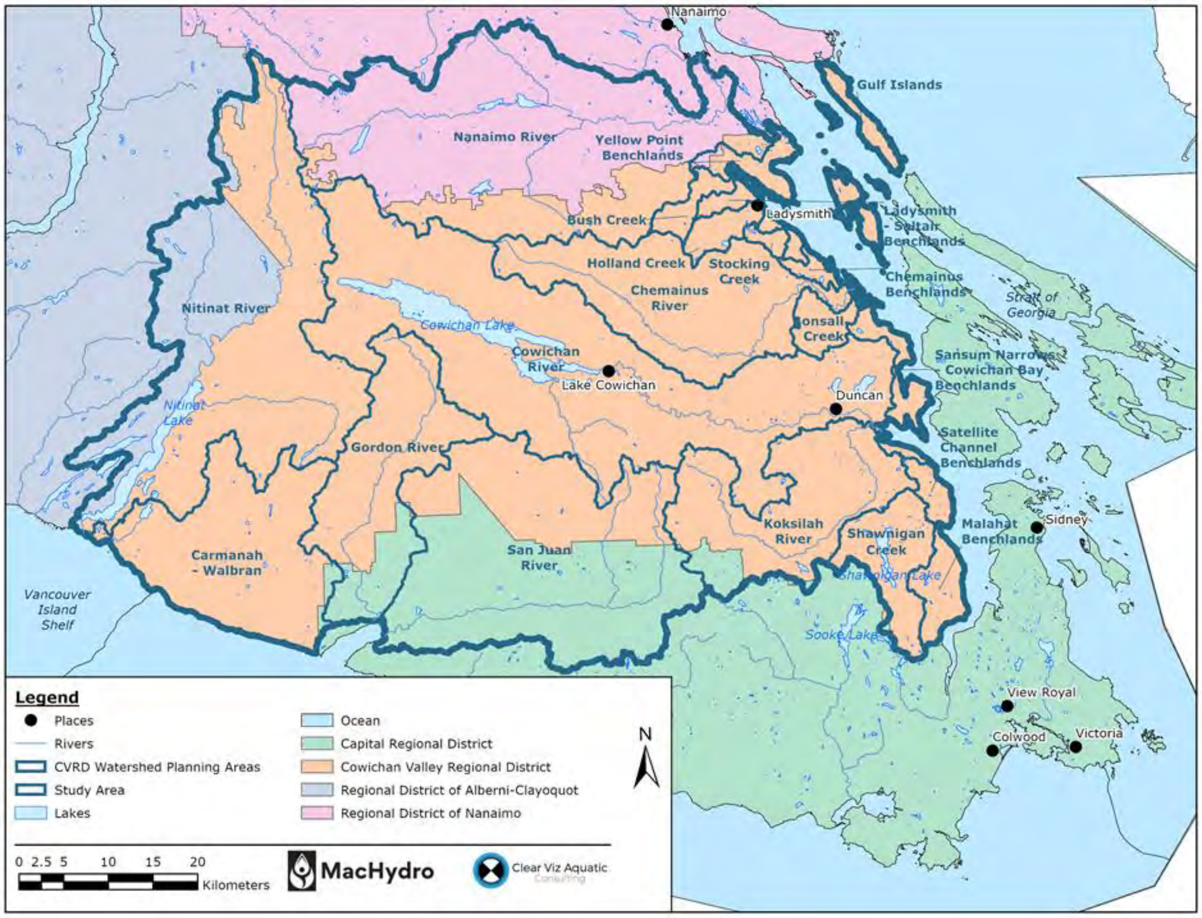

Figure 1. Study area map showing major population centers, Regional Districts, and CVRD Watershed Planning Areas.

3 Identification of Stakeholders, Technical Team Support and Data Collection – Phase 1

Phase 1 identified all data collection agencies and potential partners that should be consulted for this project and supported a multi-party technical oversight team. In addition, all current and historical hydrometric and climate data were sourced and reviewed from CVRD and other identified partners. Lastly, any necessary memorandums of understanding (MOUs) or data sharing agreements were identified. Refer to Appendix A for the Phase 1 memo.

3.1 Identification of Stakeholders and Technical Team Support

A list of potential stakeholders and data partners were identified by the Project Team consultants and sent to the CVRD (Project Manager – Jeff Moore, Environmental Services). The list contained organizations that would be both beneficial to engage (e.g., partnership for purposes of monitoring, data collection, data sharing) or track (e.g., aware of organization's activities, but no formal partnership). From there a list of Technical Advisory Group members were contacted by the CVRD to discuss data sharing and opportunities for data acquisition partnerships.

3.2 Data Collection

The BC Water Tool (BCWT) and R were used to compile hydrometric, climatic data, and water quality data from various sources. A list of networks who maintain and provide the data gathered for this study and accompanying metadata are provided in Table 1. The BC Water Tool (BCWT) acquired historical data from the Pacific Climate Impacts Consortium (PCIC) Data Portal, as well as publicly available datasets (generally provided as CSV's) from Federal and Provincial open data servers. The BCWT received a data package in 2017 of the DFO and CVRD datasets and as such they are temporally limited as they haven't been updated since 2017.

Publicly available spatial datasets were downloaded from Pacific Climate Impacts Consortium (PCIC) Data Portal, the CVRD website, and the BC data catalogue using bcdata R package (Teucher et al. 2019). We requested spatial data from the CVRD for the Preliminary Groundwater Study and the Watershed Risk Analysis study because the data from these studies were not available through the CVRD website.

Table 1. Networks and observations available that have been collected for this study.

Network Name	Station Count	Status	Parameters	Period
Climate				
Agricultural and Rural Development Act Network *Retrieved from PCIC*	47	Historical / Inactive	Precipitation Amount Surface Snow Depth Air Temperature	1970-1991
BC ENV - Air Quality Network *Retrieved from PCIC*	2	Historical	Temperature Wind Speed Relative Humidity Wind Direction	1990-2021
BC ENV - Automated Snow Pillow Network	2	Current	Precipitation (Cumulative) Surface Snow Depth	1995-2021

Network Name	Station Count	Status	Parameters	Period
			Air Temperature Snow Water Equivalent	
BC ENV - Manual Snow Survey	4	Historical	Snow Depth Snow Water Equivalent	1959-2016
BC FLNRORD - Wild Fire Management Branch *retrieved from PCIC*	17	Current	Precipitation Amount Air Temperature Wind Direction Relative Humidity Wind Speed Dewpoint	1971-2021
BC MoTI	2	Current	Precipitation Amount Rainfall Amount Snowfall Amount Surface Snow Depth Air Temperature Wind Speed Relative Humidity	1988-2021
Environment Canada	37	Current	Precipitation Amount Rainfall Amount Snowfall Amount Surface Snow Depth Air Temperature	1894-2021
Forest Renewal British Columbia	4	Historical network (no longer active)	Precipitation Amount Temperature	1999-2010
Hydrometric				
BC ENV - Groundwater Observation Well Network	22	Current	Groundwater Level	1954-2021
BC ENV - Real-time Water Data Reporting	16	Current	Flow Water Levels Water Temperature Water Turbidity	2011-2021
BC FLNRORD – Water Rights Database	1373	Current	Water Licence	1902-2020
Cowichan Valley (Regional District)	3	*Unknown*	Water Levels	2015-2017
Department of Fisheries and Oceans	2	*Unknown*	Water Levels	2015-2017
Water Survey of Canada	37	Current	Flow Water Levels	1913-2021
Water Quality				
BC ENV - Environmental Monitoring System	672	Current	Various chemistry parameters	1968-2021
ECCC – National Long-term Water Quality Monitoring Data	1	Current	Various chemistry parameters	2000-2019

Several types of hydrometric and climate datasets have been compiled during this phase of work. Data sources and licensing are provided in Appendix A.

3.3 Data Sharing Agreements

Follow up with the Technical Advisory Group indicated some future potential memorandums of understanding or data sharing agreements (Table 2). Follow-up with members of the Technical Advisory Group helped to direct the scope and focus of the project, particularly by providing information regarding potential data partnerships, existing data available, and the needs of data users.

Table 2. Information provided from follow up with potential data partners of the Technical Advisory Group or other identified organizations. The need for memorandums of understanding or data sharing agreements were identified. Only locations of relevant monitoring stations (active, proposed) were collected. No data were collected from the potential data partners in the table.

Potential Data Partner	Comments
Town of Ladysmith	Data from climate station at Public Works, potential climate stations at Holland Lake and Stocking Lake installed no earlier than 2023. Installing climate station, flow monitoring and water level at Holland Lake with potential communication system between reservoir and Public Works. All work is budget dependent.
Municipality of North Cowichan	Data from hydrometric stations on Chemainus River and its tributaries. Water level data available from Somenos Creek and Richards Creek from 2005 – 2020. Data available for water quality at South Quamichan Lake, Elkington Creek, Stanhope Rd Ditch, Stamps Rd Ditch. Data available from water quality sampling (water temperature, dissolved oxygen, pH, conductivity) in Somenos Basin via Somenos Marsh Wildlife Society (ginahoar@somenosmarsh.com)
City of Duncan	Data from hydrometric station at Fish Gut Alley and from groundwater monitoring program at a number of wells in downtown Duncan.
B.C. Ministry of Transportation and Infrastructure	Andrew Anderson (Water Resources) - Data from hydrometric station installed on Dry Bend Creek (tributary to Cowichan River) in October, 2021
B.C. Water Protection	Data from monitoring wells near Cowichan River part of research project will be posted to Aquarius when finalized. Some sites may be suitable for long-term monitoring and would be posted to Aquarius. Water Protection Group (WPG) measures low flow at Glenora Creek (2015 – present), Patrolas Creek (2021 – present), and a hydrometric station at Averill Creek

Potential Data Partner	Comments
	(2021 – present). The WPG operates a levelogger in Dougan Lake (headwaters of Patrolas Creek). The WPG monitored the low flow season in Bonsall Creek from 2015 – 2017. The Water Authorization Group has a hydrometric station at Bannon Creek Falls that only provides low flow data.
B.C. Provincial Climate Network	Province working with ECCC and all data posted to ECCC MSC's DataMart. They expect that all data would be shareable through PCIC, but good to be at the table signing on. Participating networks have stations range from 4 to >200.
B.C. Provincial Hydrometric Operations	Non-digital data of miscellaneous hydrometric measurements in filing cabinets in Nanaimo warehouse. Data reports from old water survey branch in EcoCat.
FLNRORD – West Coast Region	All regional hydrometric and climate data collected by Water Protection, Water Authorizations, Environmental Protection or Fish & Wildlife managed by provincial Aquarius database. Most of these data collected in last 6 to 7 years, but have uploaded some manual station data from historical locations. The system includes third party data from other organization, municipalities, and communities and data sharing agreements and QA/QC protocols are currently being developed.
CVRD Water Management	Jason Molyneaux – CVRD has ~50 water/sewer that could be added to existing SCADA system. Monitoring a few wells to SCADA system, while others are not being logged. He mentioned an unknown third party with lake level monitoring project on Shawnigan Lake. Lisa Daugenet – data from hydrometric station installed at Stocking Creek (currently operated by Palmer). Data from two wells near Saltair water treatment facility in process of water license application to provide 1/3 – 1/2 of the water demand.
University of Victoria	Data from the six climate stations within the CVRD operated as part of the Vancouver Island School-Based Weather Station Network is publicly available; however, there is a fee charged to prepare data in specific formats for commercial users, which would need to be discussed in more detail. The network has been historically underfunded and maintenance of climate stations has always been done on an as-needed basis.

Potential Data Partner	Comments
Department of Fisheries and Oceans	Updated information from their website indicates three active climate stations with water level and water temperature monitoring. The data are not currently available as published data up to 2021. Discussions between DFO and CVRD for a data sharing agreement would be needed to include in the database. Potential contact: Philip Pereboom.

4 Data Management Strategies – Phase 2

Phase 2 developed a proposed data warehouse structure, in consultation with the Technical Advisory Group, that could effectively interface with other entities such as the province. Internal data systems were also identified for data that do not fit with the provincial warehouse metrics (additional information or restricted). In addition, necessary communications and infrastructure were identified to support effective data management. Lastly, a cohesive historical data set was populated in a CVRD approved database format where data are available and of appropriate quality and relevance. Refer to Appendix B for the Phase 2 memo.

4.1 Technology Systems

Technology systems play a critical role in helping people collect, store, understand, and communicate information for a range of applications. In the context of hydrometric and climatic monitoring, technology systems can include field sensor hardware, communications technology, and information systems, broadly defined as those which support the collection, storage, processing, and dissemination of information. Information systems can include data management systems, geographic information systems, modeling systems, or decision support systems (among others). The important characteristic of each, is the structured and repurposable components which can be used and applied across a broad range of applications.

Data-driven decision-making is a core objective of many organizations, but remains an emerging opportunity, due to the inherent complexities embedded organizationally and technologically with existing systems and practices. It requires clear connections from source data through to the dissemination of interpreted products which often presents challenges where this requires cross-cutting of organizational departments or collaboration with external entities. When these challenges are acknowledged and addressed from the outset, with careful planning the desired outcomes can be achieved.

Data management strategies should be developed for every new data collection effort - they are of particular importance for collaborative efforts with other organizations, to ensure that roles, responsibilities, ownership and distribution of the data is discussed and agreed upon in advance of program implementation, ensuring clear understanding amongst contributors of the final objective of the data collection effort.

4.2 Use Cases

The primary internal users of hydrometric and climatic data, and interpreted information products in the CVRD are expected to be found within the planning, utilities, and environmental departments. They may desire to know the current state of surface water and groundwater from a quality or quantity perspective, and may desire to know present weather conditions within the CVRD. They may also need short- or long-term records of historical measurements, analyses of how current conditions fit within expected variability, and seasonal or inter-annual trends in certain characteristics. This information can be used for both operational and long-term planning.

Interpreted products which may be produced from these data could include custom analysis and associated static reports, analytical models and associated reports. Data and/or interpreted products may also contribute to broader products and initiatives such as watershed management plans, or other administrative focused plans produced by local or regional government agencies.

Use cases are often used in systems development to create narratives that drive the definition of functional requirements of the system to be implemented. These narratives are then used to evaluate the success of the system after it is developed; does it do what it set out to do.

A huge number of potential use cases for applying intelligence derived from hydrometric and climatic monitoring data exist within the CVRD. In collaboration with CVRD staff, a selection of use cases were identified which describe how hydrometric and climatic data or interpreted products could be applied in the region. The two main thematic areas were in support of land use planning, and in support of water utility operations.

Use Case 1: Support Environmental Planners evaluate water supply

- New subdivisions
- Mid-long term community planning

Use Case 2: Track conditions in aquifers and streams/rivers which supply water to utilities

- Current conditions in historical context
- Trends
- Thresholds

Use Case 3: Communicate current environmental conditions (drought / flood)

- ‘How are flows in Shawnigan Creek doing this year?’
- ‘Is the Chemainus River at the 50-year flood level?’

These use cases are not suggested to be the only use cases which exist; a fulsome exploration of use cases for public and/or external government agencies was not conducted as part of this work. Regardless, the CVRD should not aim to address all use cases in one single effort, as this would expand the complexity of the objective to the degree that the chance of success in addressing any individual use case effectively, would be at risk. The three use cases listed above are believed to be indicative of the types of functions where hydrometric and climatic data and interpreted products could be used, and their implications for system requirements for data management should provide a solid foundation for most other use cases. Going forward, the CVRD should continue to identify, evaluate and prioritize use cases as they are discovered; this priority list may be useful not only at the stage of deciding on analytical or decision-support needs, it can also instruct prioritization of new data collection efforts to ensure that the data required to support the highest priority use cases is what is being collected. In addition to the use cases described above, which focus on ways in which the CVRD may effectively use data in their own work, use cases exist outside of the organization and partner municipalities, such as supporting the work of provincial water authorizations staff.

High quality data to support the delivery of these use cases is critical, and new data collection efforts should be complementary and informed by past and present efforts ongoing in the district, much of which has and continues to be performed by third parties. Recommendations provided elsewhere in this report on new data collection efforts have been informed by a gap analysis of existing data collection efforts.

4.3 System Recommendations

Based on our current understanding of the needs of the CVRD, we recommend development and implementation of an open-source technology system, to collect and store the variety of environmental monitoring data available within the CVRD, support access to this data from other internal systems such as GIS or other desktop applications, provide the ability to consume the data from this system in public facing or internal web-tools, and support dissemination of the data through Application Programming Interfaces (API's) to external datastores such as the provincial Aquarius real-time water database.

For the purposes of new data collection efforts, the CVRD may desire in future to invest in specific tools to support the work of technical staff in cleaning, adjusting and quality-assessing data derived from live sensors. These systems would publish QA/QC'd data into the central open-source database system, integrating with the archive of historical and real-time data derived from external sources. Where the CVRD relies on external consultants to collect and provide data, the CVRD should ensure that the consultants provide QA/QC'd and graded data following provincial Resource Information Standards Committee (RISC) protocols. The graded data can then be loaded into the central open-source database for storage, analysis and distribution. The same considerations regarding the process of collecting and QA/QC'ing data apply to municipal partners within the CVRD. Depending on the relationship between the CVRD and the specific municipality, there may be opportunities to collaborate and share technical or other resources. Once the central open-source database is configured and operational, data will arrive from various sources, in various formats, and at varying frequencies.

4.4 Consolidate Existing Available Data

Historical and ongoing efforts by numerous government and other organizations have collected, in some cases, decades of data describing hydrometric and climatic conditions at specific locations in the CVRD. These data archives are typically provided under open license arrangements with no impediment to further use of the data. These data will comprise the majority of the knowledge base within the district.

One-time bulk loading of historical data from the archives will be required. For networks which publish live/real-time data, data acquisition scripts will need to be configured to maintain the flow of newly collected data into the system. When QA/QC'd data is available from these networks, the archived data should be updated, and stored live/real-time data overwritten with the final QA/QC'd data available from the archive.

4.5 New Data Collection

This strategy recommends new data collection efforts to fill gaps in the existing body of knowledge. Some data collection efforts may be conducted in partnership with senior levels of government, to augment gaps in their monitoring networks, and designed to produce a similar level of high-quality data. In other cases, new data collection may develop more organically or may be conducted with partners with limited professional oversight over methods and standards. In some cases, the CVRD may be required to collect data that must remain private, due to legal or other regulatory requirements or concerns. The CVRD may collect data independently, in a leadership capacity in partnership with others, or in a supporting role. Where possible, data should be collected collaboratively to maximize opportunities for leveraged funding and resources amongst partners.

For each data collection effort, consideration should be given to the values and interests of all participants regarding ownership and access to data. In principle, we recommend that the CVRD take an ‘open by default’ position - operating on the assumption that new data collected will be freely available to all, unless specific concerns require otherwise. Considerations and agreement around the data management strategy for each new collaborative engagement should be sought before initiating any data collection efforts, to ensure that all parties are in alignment before funds are invested.

4.6 Access to Data

Simply collecting and storing data will not support the use cases and objectives of the CVRD; data must flow from the centralized database into other systems, into models or derived products, and to people for their own independent use. The centralized open-source database must support these objectives, broadly broken down into four categories:

1. Direct access to CVRD staff for analysis
2. Accessible to models or analytics to support creation of derived products
3. Available for visualization, reporting and other systems for internal and/or public use
4. Accessible to external data systems at partner organizations

These objectives can be met through the creation of an API specification and technical implementation. The API will provide a set of protocols and definitions for systems or people to use to request data from the centralized database. Based on needs, additional bulk data exports may be required and can also be configured, such as dumping regular extracts from the database for distribution via FTP or other methods.

5 Gap Analysis and Preliminary Assessment – Phase 3

Phase 3 reviewed the available hydrometric and climate stations currently operating in the CVRD and undertook a gap analysis to identify strategic locations for investments in additional and relevant infrastructure. A framework was developed to assess the need for additional monitoring locations to meet the overall strategy, then a ranked list of sites was recommended. An implementation plan for the network was developed that included budget for installation of new sites and reinstatement of inactive sites as well as on-going maintenance of monitoring sites. Lastly, recommendations were provided for proxy data collection for interim data while the monitoring network was being built. Refer to Appendix C for the Phase 3 memo.

5.1 Assessment Framework

A framework was developed to compare potential sites against a set of criteria to prioritize potential monitoring locations for additional hydrometric and climate monitoring sites. These criteria reflect the goals of the DWWP strategy (CVRD, 2020) and should function to provide specific data to support future development of conceptual models, water balance calculations, relative stress assessments, hydrological modelling, and the development of Integrated Watershed Management Plans. Therefore, the framework prioritized monitoring locations to ensure the network strategically collects data to evaluate both land use planning and water use (Watershed Planning Areas), and water balances (Watershed Groups). Watershed Groups were identified (seven in total) by statistically clustering provincial assessment watersheds that have similar runoff generation interpreted from physical watershed characteristics (see Appendix C, section 3).

Watershed risk analyses conducted by SNC Lavalin (2019) for the east-ward flowing WPAs were also used to prioritize site selection of climate and hydrometric monitoring stations. The risk rating was a combination of the likelihood or probability of occurrence of an undesired event (hazard) and the consequences of that event occurring [Risk = Hazard (or likelihood) x Consequence]. Risk was quantified for riverine and coastal flooding, surface water supply and groundwater contamination. Flooding included hazards such as streams (riverine), flood depths or floodplain mapping (riverine), inundation (coastal), coastal flood sensitivity, while consequences included permanent land use zoning. Surface water supply include the hazards around aquifer type and potential connection to streams, agricultural water demand, sensitive streams or protected rivers, aquifer demand (i.e., the level of groundwater use at the time of aquifer mapping) and aquifer productivity (i.e., aquifer’s ability to transmit and yield groundwater), while the consequence was water license points of diversion. Groundwater contamination hazards included DRASTIC vulnerability (i.e., aquifer’s relative intrinsic vulnerability to impacts from human activities on land surface), land use zoning, federal and provincial contaminated site inventory, the area extent of municipal sewage systems, and the consequences were aquifer demand and municipal water supply wells.

To prioritize site selection for climate and hydrometric (surface water) monitoring, we used SNC Lavalin’s (2019) reported prioritized future assessment of WPAs for riverine and coastal flooding and surface water supply that included an assessment of projected population estimates (rate of change from 2006 to 2036) (Figure 2).

To prioritize site selection of groundwater monitoring, it was important to evaluate risk related to both groundwater supply (aquifer demand/productivity, connection to streams, etc) and quality (land use zoning, extent of sewage systems, development on land surface, etc), because groundwater contamination will limit water supply. Therefore, the median risk rating of surface water supply (Figure 2), groundwater contamination and projected population were equally-weighted for each mapped aquifer within the CVRD to produce an "aquifer rating". Not all aquifers within the study area were rated, because some of the data needed for rating did not exist outside the CVRD boundary. Risk ratings for the Gulf Islands within the study area (Penelakut, Thetis, Hudson, Dayman, Scott, Ruxton, Valdes, Reid, Pylades) were estimated using the methodology in the SNC Lavalin (2019) report as they were not included in the original risk assessment.

The following sections outline all criteria used to prioritize site selection of monitoring stations:

5.1.1 Hydrometric (Stream Discharge)

- Was there currently a hydrometric station installed within an east-ward flowing WPA or within the representative watershed of each Watershed Group?
- Does a municipal, improvement district or community watershed divert surface water from the stream as a drinking water source?
- Was the watercourse used as a primary, supplemental, or backup drinking water source?
- What was the riverine/coastal flooding and surface water supply risk rating for the WPA?
- Was there an active climate station near the watershed that would be representative of precipitation and air temperature?
- Does the recommended hydrometric network cover a range of watershed scales?
- Does the recommended site within the representative watershed of each Watershed Group drain a large lake or wetland complex (store runoff) that would not represent discharge in another ungauged watershed?
- Was there a discontinued hydrometric gauge within the WPA or within the representative watershed of each Watershed Group?
- Was there an active water quality monitoring site?

5.1.2 Hydrometric (Lake Level)

- Does a municipal or improvement district or community watershed divert surface water from the lake as a drinking water source?
- Was the lake used as a primary, supplemental, or backup drinking water source?
- Was there a discontinued water level monitoring station within the lake?

5.1.3 Hydrometric (Groundwater Level)

- What was the equally-weighted median risk rating between surface water supply, groundwater contamination, and projected population (rate of change 2006 to 2036) for the mapped aquifer (i.e., aquifer rating; SNC, 2019)?
- Was there an active continuous groundwater monitoring well in each aquifer subtype by aquifer rating?
- Does the mapped aquifer have high population and/or development pressure or a high density of groundwater wells relative to others?
- Was there an inactive PGOWN well that could be re-activated to expand the groundwater monitoring network to collect data from more aquifers?

5.1.4 Climate

- Does the current climate station network capture the most frequent or dominant hydrologic process that will contribute to surface and subsurface runoff generation across the region: snowmelt (>800 m.a.s.l.), rain-on-snow (300 – 800 m.a.s.l.), or rain (<300 m.a.s.l.) (Figure 3)?
- Does the current climate station network provide sufficient coverage to characterize the variation in climatic conditions within the WPAs?
- Was there a climate station within a representative watershed of each Watershed Group?
- Was there an active climate station near the hydrometric gauges that would be representative of precipitation and air temperature?
- Was there a discontinued climate station with a long-term data record that could be re-activated?
- Does the proposed site location have road access and relatively easy site preparation (i.e., within a forest clearing, top of roof)?

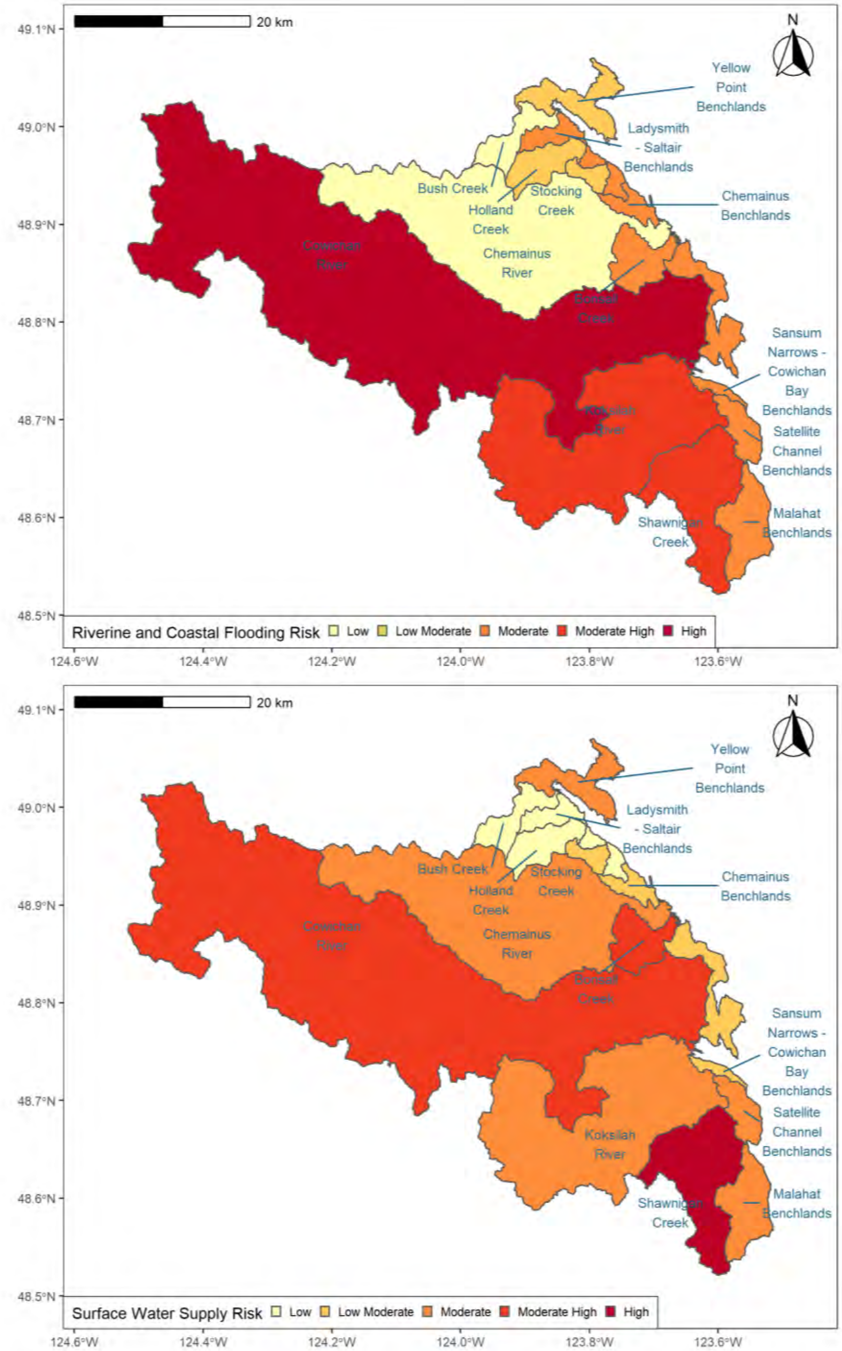

Figure 2. Prioritizations for risks of riverine and coastal flooding and surface water supply risk from SNC Lavalin (2019), where high represents a high priority for future assessment and low represents a low priority for future assessment. Note that this assessment was completed prior to two more recent flooding events in the Chemainus watershed and may not adequately consider the flooding impact on roads that link south Vancouver Island to the rest of the island.

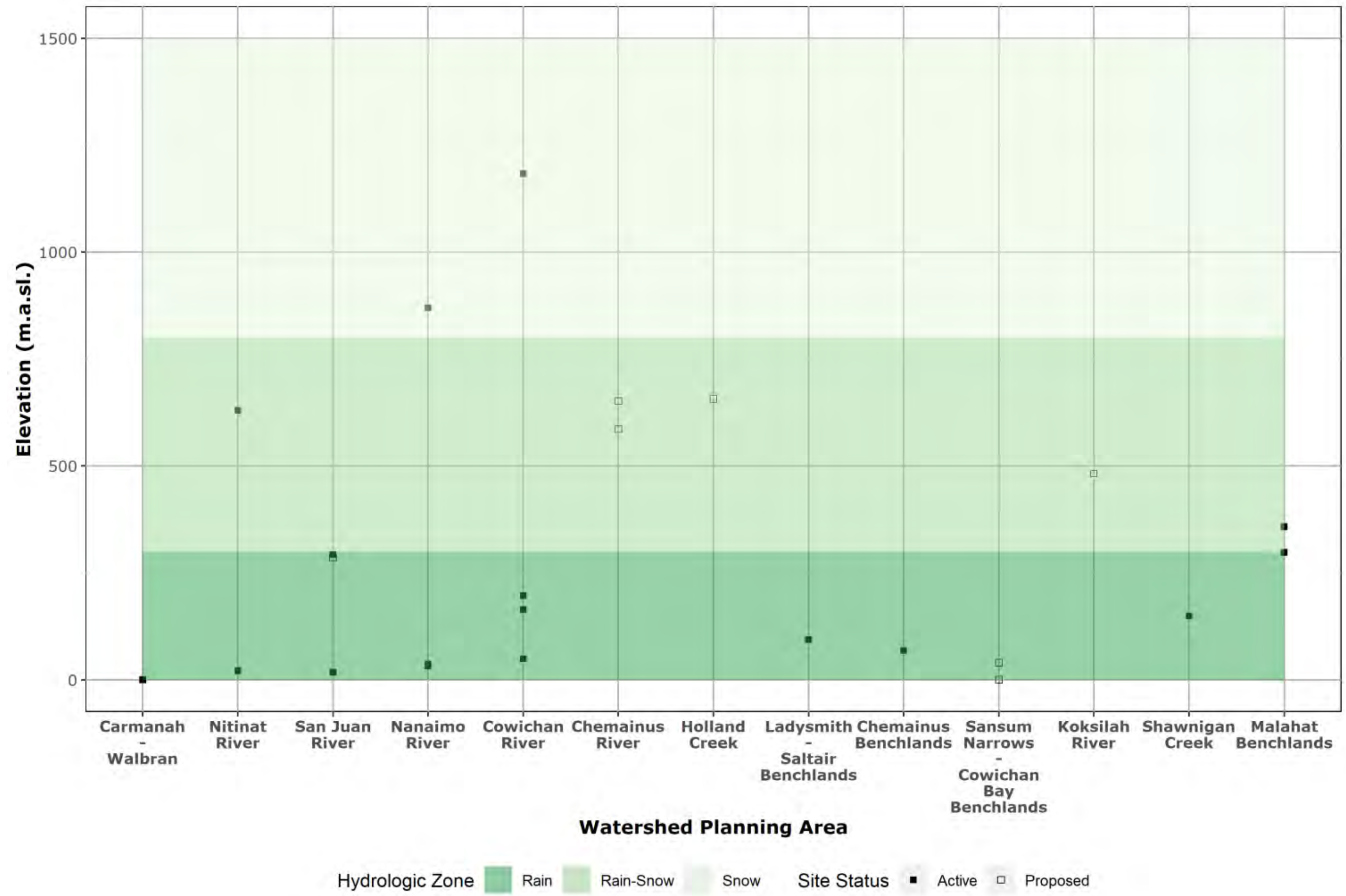

Figure 3. Active precipitation gauges by Watershed Planning Area and dominant hydrologic process that contributes to surface or subsurface runoff generation: snowmelt (>800 m.a.s.l.), rain-on-snow (300 – 800 m.a.s.l.), or rain (<300 m.a.s.l.) (Hydrologic Zone). Proposed climate stations (open squares) recommended in the site selection section (see 5.3 and Appendix C). There are seven WPAs with no active or proposed precipitation gauges: Gordon River, Bush Creek, Bonsall Creek, Yellow Point Benchlands, Stocking Creek, Satellite Channel Benchlands, Gulf Islands.

5.2 Gap Analysis

The CVRD has a reasonably good baseline network of existing climate and hydrometric monitoring stations that provide data to assess regional water vulnerability. However, review of the active hydrometric and climate monitoring stations has identified key gaps in the network to evaluate short-term watershed management and drinking water supply forecasting, and future water strategy development and planning at smaller scales. The most notable gaps include:

- a lack of climate stations above 300 m.a.s.l. that measure precipitation at elevation bands that receive a higher proportion of snowfall;
- a lack of groundwater monitoring in unconfined sand and gravel (deltaic) aquifers (also high-risk rating) and fractured crystalline bedrock as well as limited monitoring in fractured sedimentary bedrock aquifers and unconfined sand and gravel – late glacial outwash aquifers;
- a lack of groundwater monitoring in areas of high population and/or development pressure or high groundwater reliance (i.e., well density);
- a lack of groundwater monitoring to understand surface water – groundwater interactions in aquifers or layered aquifer systems that are hydrologically connected to Cowichan and Chemainus River systems;
- a lack of monitoring of surface waters that are supplemental or backup municipal drinking water sources;
- a lack of monitoring for Holland Lake (proposed station by Town of Ladysmith), which is part of their designated Community Watershed that supplies drinking water to residents of Diamond/Ladysmith Waters Systems;
- a lack of hydrometric stations in the smaller WPAs including the six Benchland WPAs, most of which have potential for future land use development; and,
- a lack of hydrometric stations in the middle and upper reaches of the Chemainus and Koksilah rivers (Group 3 and 4 watersheds).

5.3 Site Selection

The gap analysis and site selection identified monitoring stations to add to the existing monitoring network in a phased implementation:

- High Priority (1 – 2 years) - 5 stream discharge, 4 groundwater wells, 3 climate stations and 3 snow survey transects;
- Moderate Priority (within 5 years) - 3 stream discharge, 1 lake level, 7 groundwater wells, 2 climate stations (1 station install with rainfall gauge only), and 1 snow survey transect; and,
- Low Priority (after 5 years) - 3 stream discharge, 2 lake levels, and 3 groundwater wells.

There was a priority to add real-time hydrometric and climate stations to the Chemainus and Koksilah watersheds in an effort to set up the infrastructure for flood response in downstream reaches, in addition to other water use and water balance objectives. Several monitoring stations have been recommended as manual data collection. This strategy reduces the costs associated with initial station installation and on-going data retrieval. However, there is a higher risk with manual stations of not detecting a technical problem until after the data are collected. Therefore, manual downloads by field technicians during more frequent maintenance visits would be needed to minimize both the delay in collecting data and potential loss of data due to equipment malfunction. Upgrading to a real-time system would allow technical staff to monitor equipment performance and better plan for maintenance visits.

5.4 Monitoring Station Costs

The costs for equipment and installation of monitoring stations will range based on specific site selection (access, site preparation, location, power, data retrieval, etc.). Equipment recommended for monitoring is an investment that meets industry standards (e.g., high data quality rating for sharing) with a potentially longer replacement period (degrade slower) compared to other monitoring equipment on the market (personal comm., Hoskins Scientific). Typical installation costs (on-going maintenance) per station (details on equipment costs in Appendix C, section 6) would be:

- Hydrometric (Stream Discharge) – Manual $14,750 ($5,500/year), Cellular $18,950 ($5,815/year), Satellite $22,050 ($6,100/year);
- Hydrometric (Lake Level) – Manual $2,700 ($3,500/year), Cellular $3,200 ($3,815/year);
- Hydrometric (Groundwater Level) – Unconfined Aquifer: Manual $10,850 ($3,500/year), Cellular $11,350 ($3,815/year); Bedrock Aquifer: Manual $10,050 ($4,000/year), Cellular $10,550 ($3,815/year)
- Climate – Rain Station (Manual) $13,900 ($4,500/year), All-Season Station: Cellular (or Manual) $29,700 ($4,815/year), Satellite $29,700 ($5,100/year)
    - Snow Survey Transect - $1,600 ($4,500/year)

The summary of estimated costs for new (and reinstated) monitoring stations is shown in Table 3. Based on 2022 cost estimates, the total estimated cost for the strategy is $450,000 with an annual on-going maintenance of $170,000, which is currently based on consulting rates. For each priority phase, the total installation costs (annual on-going maintenance) are listed along with the amount invested on equipment:

- High Priority (< 2 years) = $209,000 ($71,000), equipment $96,000
- Moderate Priority (< 5 years) = $160,000 ($64,000), equipment $47,000
- Low Priority (> 5 years) = $81,000 ($35,000), equipment $11,000

Table 3. Summary of estimated costs for new (and reinstated) hydrometric and climate monitoring stations. Costs are totaled over three phased priorities: high (within 1-2 years), moderate (within 5 years), and low (after 5 years). Data ret. is the type of data retrieval method for the station: manual, cellular or satellite. Lake level and groundwater monitoring were proposed as manual stations, while upgrade to cellular data retrieval would add $500/station and $315/year for annual on-going costs. +Snow indicates the added cost of snow survey transects and on-going monitoring. The estimated costs and on-going annual maintenance costs are rounded to the nearest one thousand.

Priority Phase	Hydrometric				Lake Level				Groundwater Level[1]				Climate Station[3]			
	#	Data Ret.	Est. Cost	On-Going	#	Data Ret.	Est. Cost	On-Going	#	Data Ret.[2]	Est. Cost	On-Going	#	Data Ret.	Est. Cost	On-Going
High (<2 Yr)		Man (3)	44	17		Man (-)	0	0		Man (4)	43	14		Man (1)	14	5
	5	Cell (-)	0	0	-	Cell (-)	0	0	4	Cell (-)	0	0	3	Cell (-)	0	0
		Sat (2)	44	12		Sat (-)	0	0		Sat (-)	0	0		Sat (2)	60	10
Mod. (<5 Yr)		Man (2)	30	11		Man (1)	3	4		Man (7)	73	25		Man (3)	34	14
	3	Cell (1)	19	6	1	Cell (-)	0	0	7	Cell (-)	0	0	3	Cell (-)	0	0
		Sat (-)	0	0		Sat (-)	0	0		Sat (-)	0	0		Sat (-)	0	0
Low (>5 Yr)		Man (3)	44	17		Man (2)	6	7		Man (3)	31	11		Man (-)	0	0
	3	Cell (-)	0	0	2	Cell (-)	0	0	3	Cell (-)	0	0	-	Cell (-)	0	0
		Sat (-)	0	0		Sat (-)	0	0		Sat (-)	0	0		Sat (-)	0	0
High ($K)			88	29			0	0			43	14	3	+Snow	78	28
Mod. ($K)			49	17			3	4			73	25	1	+Snow	35	18
Low ($K)			44	17			6	7			31	11			0	0
Total Est. Cost ($K)			**181**	**63**			**9**	**11**			**147**	**50**			**113**	**46**

[1]Reinstatement of inactive PGOWN wells in unmonitored mapped aquifers could be explored, but potential cost savings is more likely through partnership agreements with FLNRORD.

[2]All stations are set up as manual data retrieval; however, cost estimates reflect the aquifer subtype for drilling and installation of a new well in bedrock versus unconfined aquifers. During the high priority phase there are three unconfined and one bedrock, moderate priority includes one unconfined and two bedrock, and the low priority phase includes one unconfined aquifer.

[3]Potential partnerships with the MoE for satellite stations could provide potential cost savings only if the province operates the climate or hydrometric station. Otherwise, the CVRD would need to apply for a federal license to operate ground stations in Canada that includes an application process and annual fee (pers. comm., Neil Goeller). These stations also require a cloud service account ($4K; Hoskins Scientific).

6 Recommendations and Strategy Development – Phase 4

6.1 Logistics and Agreements

The stations selected for the hydrometric and climate monitoring strategy require field reconnaissance to review conditions and suitability for installation. ParcelMap BC Parcel Fabric, Google Maps and aerial imagery were used to assess potential access constraints (Table 4, Table 5, Table 6, Table 7). Proposed stations in the upper watersheds of Chemainus River and Koksilah River will likely require land access agreements with forestry companies. Proposed stations in residential areas may also require land access agreements if the station is not accessible from a public road or right-of-way. The land access agreement should include the following:

- Location and proposed station;
- Proposed route of access;
- Proposed parking spot;
- Contact details;
- Expected frequency of access (e.g., monthly); and,
- If notification of property owner is required prior to a visit.

The agreements necessary to implement the network on lands managed by others is outlined below:

- Hydrometric (Discharge and Lake Level) –
    - Crown Land: stations will require a Water Sustainability Act (WSA) Section 11 Notification to be submitted at least 45 days before beginning work through FrontCounter BC (*https://portal.nrs.gov.bc.ca/web/client/home*). If the habitat officer has not notified the CVRD within 45 days of FrontCounter BC receiving the notification, then the work must meet the terms and conditions described in Part 3 of the Water Sustainability Regulation (*https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/36_2016*). Work may then proceed with the proposed changes.
    - Private Land: an agreement for access will be required with the landowner. If a hydrometric station is attached to an MoTI bridge, then an agreement/correspondence with MoTI is required. Agreements must be in place prior to installation.
    - All satellite ground stations in Canada require a federal license, which includes an application process and annual fee (personal communication, Neil Goeller).
- Hydrometric (Groundwater) –
    - Crown Land: stations will require a "Community and Institutional Land Lease or License for Crown Land" (Section 51 of the Land Act) through FrontCounter BC. Contact westcoast.landsreferral@gov.bc.ca (250-751-7220) prior to the application to ensure the necessary information is submitted along with the application.
    - Private Land: a WSA Section 9 (Water License) is recommended through FrontCounter BC to ensure the province is aware of this well and if the water is being used (e.g., sampling, pump tests). An agreement with the landowner is required and must be in place prior to installation.
    - If there are potential partnerships with the Ministry of Environment, ensure the well installation and monitoring aligns with the PGOWN standards.

- Climate –
  - Crown Land: stations will require a "Community and Institutional Land Lease or License for Crown Land" (Section 51 of the Land Act) through FrontCounter BC. Contact westcoast.landsreferral@gov.bc.ca (250-751-7220) prior to the application to ensure the necessary information is submitted along with the application.
  - Private Land: an agreement with the landowner is required and must be in place prior to installation.
  - All satellite ground stations in Canada require a federal license, which includes an application process and annual fee (personal communication, Neil Goeller).

For each application submitted through FrontCounter BC, a map showing the location of the proposed monitoring locations, station and equipment details, anticipated installation date(s), and expected monitoring period (1 year, 5 years, greater than 10 years) is required. In addition, we recommend confirming the First Nation consultation process with FLNRORD prior to submitting an application. This process is continuing to evolve as the province implements United Nations Declaration of Rights of Indigenous Peoples (UNDRIP) and Declaration of Rights of Indigenous Peoples Act (DRIPA) and the new Ministry of Lands, Water and Natural Resource Stewardship.

6.1.1 Proposed Land Developments

Proposed developments or rezoning applications that are within Development Permit Area 1 (DPA 1) should be assessed to determine if a restrictive covenant is required. DPA1 are areas that are defined under the provincial Riparian Areas Protection Act (CVRD, 2021). Waterbodies or watercourses that provide fish habitat or are connected to fish habitat require a Riparian Area Regulation (RAR) assessment. Wetlands and ditches will not require restrictive covenants. However, most watercourses such as streams and rivers will require restrictive covenants. The restrictive covenant will allow the riparian area to be accessed by gate or right-of-way. The restrictive covenant will provide access for future monitoring stations. A template for a restrictive covenant is available on: *https://www.env.gov.bc.ca/lower-mainland/ecosystems/restrictive_covenants/index.htm*.

Proposed developments that are within DPA 4, Aquifer Protection Area, may have monitoring requirements associated with the Development Permit. DPA 4 includes all mapped aquifers (CVRD, 2021). The installation of a groundwater observation well will be a requirement, if the proposed development includes a water license application for an aquifer. The CVRD and FLNRORD will assist the developer in the installation and maintenance of the observation well.

The range of requirements the CVRD impose on applicants for development permit areas for protection of the natural environment could expand to include a planned right-of-way for access to a stream or river in a proposed subdivision. Requirements could also include the installation and maintenance of a groundwater observation well for a proposed semi-rural parcel development.

6.1.2 Recommendations

- Selected monitoring sites should have field reconnaissance to review conditions and suitability for installation;
- Initiate discussion with land owners for installation of sites on privately owned land to obtain access permission;
  - develop a standard CVRD land use right-of-way and covenant form for use of properties for hydrometric and climate network under a public amenity process;

- Submit appropriate applications with FrontCounter BC for installation of monitoring sites on crown land to obtain land lease or license;
- Confirm the First Nation consultation process with FLNRORD prior to submitting any applications; and,
- Consider the range of requirements for developers imposed by the CVRD for DPAs for protection of the natural environment for potential expansion to include planned right-of-ways to access watercourses for potential monitoring, or installation and maintenance of a groundwater observation well.

Table 4. Recommended list of new (or reinstated) hydrometric monitoring stations to measure discharge listed with site information regarding land ownership, First Nation territories, access, and potential partners.

Station Name	Longitude	Latitude	Station ID	Operator[1]	Station Status	Land Ownership[2]	First Nation Territories[3]	Access	Potential Partner
Bonsall Creek Near the Mouth	-123.6789	48.87722	08HA073	WSC	Inactive	Private	1, 7, 3, 4, 5	Access by Crofton Rd will likely need to obtain permission from land owner	WSC
Bush Creek above Island Highway	-123.854	49.00528	1AHB033	BC Hydro	Inactive	Private	1, 2, 3, 4, 5	Access from Comox Logging Truck Rd and Cowichan Valley Trail on foot	LFC
Garnett Creek at Cherry Point Beach	-123.557	48.70992		CVRD	New	Private	1, 3, 6, 5	Access at end of Garnett Road at park, located 500 m E of historical BC Hydro gauge (1AHA013). Historical water quality site (E291150).	
Koksilah River at Renefrew Rd	-123.7937	48.62879		CVRD	New	Private	1, 3, 6, 9, 5	Access from Renefrew Rd	
Chemainus River above Chipman Creek	-123.9272	48.84266		CVRD	New	NA	1, 2, 3, 4, 5	Access from MacMillan Bloedel Fs Rd	
Chemainus River above Rheinhart Creek	-124.0789	48.92043		CVRD	New	Private	1, 2, 3, 4, 5	Access from Copper Canyon Main Forest Service Rd	
Tyee Creek above Ladysmith	-123.8531	48.99195		CVRD	New	Private	1, 2, 3, 4, 5	Access from Comox Logging Truck Rd	
Spectacle Creek at Ebadora Lane	-123.5558	48.56909		CVRD	New	Private	1, 3, 6, 9, 5	Access from Ebedora Lane	
Banon Creek upstream of Reservoir	-123.7758	48.91293		CVRD	New	Municipal	1, 2, 3, 4, 5	Access via Road to Reservoir	DNC
Little Nitinat River at Hatchery	-124.6578	48.85803		CVRD	New	NA	11, 12	Access via Nitinat River Hatchery, site located upstream of a DFO climate and water level/water temperature station. Confirm with DFO if existing discharge gauge.	DFO
Shawnigan Creek at Shawnigan-Mill Bay Rd Bridge	-123.5711	48.65755		CVRD	New	NA	1, 3, 6, 9, 5	Access from Shawnigan-Mill Bay Rd	

[1]Operator and potential partner names include Water Survey of Canada (WSC), Ladysmith Fisherman's Club (LFC), District of North Cowichan (DNC), and Department of Fisheries and Oceans (DFO).
[2]Land ownership data were collected from the spatial dataset *BC Parcel Map Fabric*, which only includes active titled parcels and surveyed provincial Crown land parcels. A site designated NA indicates there was no information available for the site location.
[3]First Nations Territories include: 1) Coast Salish, 2) Snuneymuxw, 3) Quw'utsun, 4) Stz'uminus, 5) Hul'qumi'num Treaty Group (represents Cowichan Tribes, Halalt, Lyackson, Ts'uubaa-asatx, and Pene̱lakut), 6) Á,LEṈENEȻ ŁTE (W̱SÁNEĆ), 7) Semiahmoo, 8) Pacheedaht, 9) Te'mexw Treaty Association, 10) Ts'uubaa-asatx, 11) ditidaqiic̓aq disib̓aʔk (Ditidaht), 12) Ditidaht.

Table 5. Recommended list of new (or reinstated) hydrometric monitoring stations to measure lake levels listed with site information regarding land ownership, First Nation Territory, access, and potential partner.

Station Name	Longitude	Latitude	Station ID	Operator[1]	Station Status	Land Ownership[2]	First Nation Territories[3]	Access	Potential Partner
Somenos Lake Near Duncan	-123.7072	48.80361	08HA013	WSC	Inactive	Municipal	1, 10, 3, 6, 5	Access by boat via Drinkwater Rd dock/boat launch	WSC
Crofton Lake	-123.6612	48.8543		CVRD	New	Municipal	1, 7, 10, 3, 6, 4, 5	Access through restricted usage roads- may need permission	DNC
Holyoak Lake	-123.8354	48.89821		CVRD	New	Private	1, 2, 3, 4, 5	Access at South End of Lake	DNC

[1]Operator and potential partner names include Water Survey of Canada (WSC) and District of North Cowichan (DNC).
[2]Land ownership data were collected from the spatial dataset *BC Parcel Map Fabric*, which only includes active titled parcels and surveyed provincial Crown land parcels. A site designated NA indicates there was no information available for the site location.
[3]First Nations Territories include: 1) Coast Salish, 2) Snuneymuxw, 3) Quw'utsun, 4) Stz'uminus, 5) Hul'qumi'num Treaty Group (represents Cowichan Tribes, Halalt, Lyackson, Ts'uubaa-asatx, and Penelakut), 6) Á,LEṈENEȻ ŁTE (W̱SÁNEĆ), 7) Semiahmoo, 8) Pacheedaht, 9) Te'mexw Treaty Association, 10) Ts'uubaa-asatx, 11) ditidaqiic̓aq disib̓aʔk (Ditidaht), 12) Ditidaht.

Table 6. Recommended list of new (or reinstated) hydrometric monitoring stations to measure groundwater levels listed with site information regarding land ownership, First Nation Territory, access, and potential partner.

Station Name	Long.	Latitude	Station ID	Aquifer ID	Operator[1]	Station Status	Land Ownership[2]	First Nation Territories[3]	Access	Potential Partner
Honeymoon Bay Landfill	-124.172	48.8118		189	CVRD	New	Private	11, 10, 3, 6, 9, 5, 12	Access from Gordon River Rd near Landfill	FLNRORD
Youbou Little League Park	-124.198	48.8714		190	CVRD	New	Municipal	1, 11, 10, 3, 6, 5	Access from Sa Seen Os Rd	FLNRORD
Mile 77 Park	-124.127	48.8555		191	CVRD	New	Municipal	1, 11, 10, 3, 6, 5	Access from Creekside Pk	FLNRORD
Herd and Tom Windsor Rd	-123.672	48.8205		175	CVRD	New	Municipal	1, 10, 3, 6, 5	Access from Tom Windsor Rd	FLNRORD
South Shawnigan Lake	-123.629	48.5929		205	CVRD	New	Municipal	1, 3, 6, 9, 5	Access from West Shawnigan Lake Rd	FLNRORD
Coopers Hawk Rise	-123.545	48.6367		208	CVRD	New	NA	1, 3, 6, 9, 5	Access from Coopers Hawk Rise	FLNRORD
Teal Court Cul-de-Sac	-124.121	48.8378		946	CVRD	New	Private	1, 11, 10, 3, 6, 5, 12	Access from Teal Crt- may need permission from owner if outside of Road ROW	FLNRORD
Southern Playfield Park	-124.131	48.8337		948	CVRD	New	Municipal	1,11, 10, 3, 6, 5, 12	Access via Park Access Rd for Southern Playfield Park	FLNRORD
Cowichan River Prov. Park near Boat Launch Parking Lot	-123.893	48.7724		179	CVRD	New	Crown Prov.	1, 10, 3, 6, 5	Access from Boat Launch Parking Lot	FLNRORD
Resource Rd off Riverbottom Rd W	-123.884	48.7779		182	CVRD	New	Private	1, 10, 3, 6, 5	Access from Resource Road that is 850 m from Stoltze Rd- may need permission from forestry company	FLNRORD
Hooper Rd	-123.647	48.6867		201	CVRD	New	NA	1, 3, 6, 9, 5	Access from Hooper Rd	FLNRORD
End of Panorama Ridge Rd	-123.757	48.9253		170	CVRD	New	NA	1, 2, 3, 4, 5	Access from Panorama Ridge Rd	FLNRORD
Fuller Lake Arena South Parking Lot	-123.717	48.9011		171	CVRD	New	Municipal	1, 2, 3, 4, 5	Access from south end of Fuller Lake Area Parking Lot	FLNRORD
Inactive Provincial Observation Well Network (PGOWN) Wells										
256 – Cobble Hill	-123.554	48.665	E206152	203	PGOWN	Inactive	Private	1, 3, 6, 9, 5	Need permission to access from farm owner on Kilmalu Rd	FLNRORD

297 – Cowichan Bay	-123.65	48.754	E206919	188	PGOWN	Inactive	Private	1, 3, 6, 5	Need permission to access from farm owner on Lochmanetz Rd	FLNRORD
380 – Mill Bay	-123.569	48.6447	E305030	203	PGOWN	Inactive	Municipal	1, 3, 6, 9, 5	Likely has land agreement issues	FLNRORD
315 - Ladysmith	-123.772	49.042	E217413	162	PGOWN	Inactive	NA	1, 2, 7, 3, 4, 5	Access from Yellow Point Rd	FLNRORD

[1]Operator and potential partner names include provincial groundwater well network (PGOWN) and Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD).
[2]Land ownership data were collected from the spatial dataset *BC Parcel Map Fabric*, which only includes active titled parcels and surveyed provincial Crown land parcels. A site designated NA indicates there was no information available for the site location.
[3]First Nations Territories include: 1) Coast Salish, 2) Snuneymuxw, 3) Quw'utsun, 4) Stz'uminus, 5) Hul'qumi'num Treaty Group (represents Cowichan Tribes, Halalt, Lyackson, Ts’uubaa-asatx, and Pen̓elakut), 6) Á,LEN̲ENEȻ ŁTE (W̱SÁNEĆ), 7) Semiahmoo, 8) Pacheedaht, 9) Te’mexw Treaty Association, 10) Ts’uubaa-asatx, 11) ditidaqiic̓aq disib̓aʔk (Ditidaht), 12) Ditidaht.

Table 7. Recommended list of new (or reinstated) climate monitoring stations listed with site information regarding land ownership, First Nation Territory, access, and potential partner.

Station Name	Longitude	Latitude	Station ID	Operator[1]	Station Status	Land Ownership[2]	First Nation Territories[3]	Access	Potential Partner
Harris Creek Near Lake Cowichan	-124.2261	48.71833	08HA070	FRBC	Inactive	Private	8	Access from Forest Service Road off Hemmingsen Rd, next to WSC Harris Creek gauge	WSC
Crofton Substation	-123.6539	48.87453	E220217	BC Air	Inactive	NA	1, 7, 3, 6, 4, 5	Access from Crofton Rd at Catalyst Paper & Pulp, at the BC Air Quality station	BC Air
Cowichan Bay at Cherry Point	-123.5567	48.7111	1012010	ECCC	Inactive	Private	1, 3, 6, 5	Access via Cherry Point Nature Park on Garnett Rd. Long-term climate history (88 years).	ECCC
Upper Chemainus	-124.0892	48.95013		CVRD	New	Private	1, 2, 3, 4, 5	Access from Forestry Road on southwest side of Rheinhart Lake	
Koksilah River at Cutblock	-123.8969	48.71283		CVRD	New	Private	1, 3, 6, 9, 5	Access from Forest Service Road off Holt Rd	
Chipman Ck	-123.9052	48.86698		CVRD	New	Crown Prov.	1, 2, 3, 4, 5	Access from MacMillan Bloedel Fs Rd- restricted usage road likely need permission, located 890 m NW from historical FLNRORD – WMB Chipman Ck station	

[1]Operator and potential partner names include Forest Renewal of British Columbia (FRBC), BC Environment – Air Quality Network (BC Air), Environment and Climate Change Canada (ECCC), and Water Survey of Canada (WSC).
[2]Land ownership data were collected from the spatial dataset *BC Parcel Map Fabric*, which only includes active titled parcels and surveyed provincial Crown land parcels. A site designated NA indicates there was no information available for the site location.
[3]First Nations Territories include: 1) Coast Salish, 2) Snuneymuxw, 3) Quw'utsun, 4) Stz'uminus, 5) Hul'qumi'num Treaty Group (represents Cowichan Tribes, Halalt, Lyackson, Ts'uubaa-asatx, and Penelakut), 6) Á,LEṈENEȻ ŁTE (W̱SÁNEĆ), 7) Semiahmoo, 8) Pacheedaht, 9) Te'mexw Treaty Association, 10) Ts'uubaa-asatx, 11) ditidaqiic̓aq disib̓aʔk (Ditidaht), 12) Ditidaht.

6.2 Data Collection

After monitoring stations are installed, the data needs to be collected, quality assessed, and catalogued with metadata information before those data are stored in a database.

6.2.1 Collection

Collection of hydrometric and climate data for recommended equipment includes:

- Hydrometric –
  - Water level and water temperature data (discharge, lake, groundwater) collected with the Hobo MX2001 allows wireless data offload to mobile devices or Windows computers via Bluetooth. With the free HOBOconnect app, it is fast and easy to configure the MX series loggers, view data and manage the collected data. The reference water level can be entered at the start of deployment so pressure data are converted to a water level. Files can be exported as .csv or .xlsx. However, through the HOBOconnect app, data can be automatically uploaded to HOBOLink once a readout is complete and configured to automatically deliver exported data to an FTP location on a selected schedule.
  - Water level and water temperature data collected with the PS8900 (Onset RX3000) or OTT-PLS (Sutron XLink) pressure transducers would require a cable and Windows computer to offload data manually or if the data were not retrieved via telemetry. Data retrieved via telemetry could be managed via HoboLink (Onset RX3000) or LinkComm (Sutron XLink) software. This software can deliver data files to storage databases via FTP sites.
  - For watercourses, water levels are converted to discharge using a water level-discharge relationship (i.e., rating curve). Rating curves would be constructed from a series of manual water level and discharge measurements collected in the field. The rating curve can be developed in a statistical program like R or through other software such as HoboLink or LinkComm, which allow an operator to input water level-discharge tables to output discharge. Rating curves can also be managed in a storage database. For example, WISKI or Aquarius can develop, store and utilize multiple water level-discharge curves and deal with rating curve adjustments. These storage databases can also manage Sontek FlowTracker file formats, other non-standard discharge measurement field forms, or qualitative metadata.
- Climate –
  - Meteorological data collected with the Onset H22 data logger would require a cable and Windows computer to offload data manually as a .csv file, which could then be uploaded to data management software such as R, Excel, WISKI or Aquarius. Similar to above, data retrieved from climate stations with Sutron XLink data loggers could be managed with LinkComm and delivered to storage databases via FTP sites.
  - For snow survey transects, manual measurements of snow depth and snow water equivalent are taken along the same transect often once or twice a month that are collected on a field form, which would need to be manually input into a .csv or .xlsx for further processing in Excel or R.

6.2.2 Data Quality and MetaData

The collected data need to be reviewed to confirm data quality and remove any erroneous data due to sensor/logger malfunction, which involves a skilled technologist that understands how the data were collected and has the experience to interpret if the data need adjustment or should be completely removed. There should be standardized procedures for data validation, correction and evaluation, and data changes should be logged. During data review, software programs such as R or Excel that can organize numbers and data are useful to assess and flag the provisional data for any erroneous records. Alternatively, storage databases such as WISKI or Aquarius have automated quality assurance and quality control activities for real-time data or for imported files collected manually. After review, it is recommended that publishable data be output as .csv files for database storage if using software programs such as R or Excel.

It is very important that information about these data are catalogued. The metadata should include information such as location, elevation, date of installation, type of equipment, field visit notes, maintenance logs, contact information, review status (i.e., provisional, published), and data quality. We recommend following the metadata standards used by the province for hydrometric and climate monitoring data. In addition, the relative quality of the published data should be assessed using standards outlined by the RISC for hydrometric monitoring, while ECCC provides guidance for climate data.

6.2.3 Recommendations

- Hire a skilled technologist that understands data collection, validation, correction, and evaluation;
- Adopt standardized procedures for data validation, correction (e.g., logging changes), and evaluation;
- Adopt standardized procedures for cataloguing metadata and making site metadata publicly available; and,
- Assess hydrometric and climate data quality using the RISC and ECCC standards.

6.3 Data Storage, Warehousing and Deployment

The Phase 2 component of this project provides an overview of the data management strategies recommended for the DWWP (refer to Section 4 or Appendix B). The primary aspect of the data management strategy is the technical architecture of the proposed system, shown in Figure 4. This modular architecture allows for integration of previously existing data alongside new data collection, distribution of data to various systems and internal/external parties, and future development of advanced analytics, visualization, or reporting capabilities to meet the information needs of the Program.

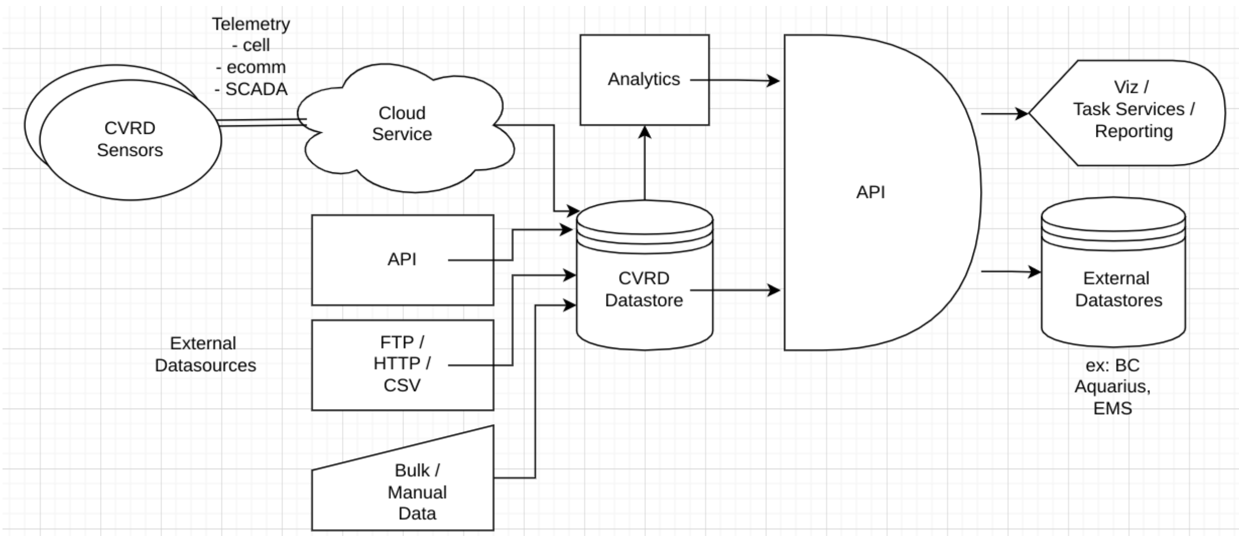

Figure 4. Proposed technology architecture.

6.3.1 Deployment

The technology architecture can be deployed through on-premise computer hardware managed and maintained by the CVRD or service providers, on cloud hosts or platform-as-a-service offerings managed by CVRD or service providers, or through cloud hosts maintained by external consultant organizations. The CVRD must weigh the pros and cons of these options against internal IT policies, requirements, staff resources, and costs. In general, if heavy analytical workloads are contemplated against the system, network latency associated with accessing data from a remote-hosted solution may become frustrating. Similarly, cloud storage costs can be substantial if data volumes expand greatly, such as through the incorporation of very dense data such as gridded weather forecasts - which are not part of the contemplated solution at present, but may be desired in the future in support of operational modeling or the development of advanced flood warning systems. When the system is deployed, in addition to hardware or hosting costs, the CVRD should also anticipate ongoing support and maintenance fees, which are typically in the range of 10-25% of build costs, annually, depending on the type of support required and the desired and ability of the CVRD to monitor and address data related issues in the system.

6.3.2 Data Display

The focus of the hydrometric and climatic monitoring strategy has been on foundational systems, and gap analysis of existing monitoring networks, to support an evolving set of use cases for hydrometric and climatic data in the CVRD. As such, the recommendations within this report focus on considerations around the collection of new and existing data, and centralized storage, management, and distribution of the data. Use cases such as supporting land use planning may require the development of water balance models for the district. The characteristics of these models and specific needs of planning staff for leveraging the information that they contain, has not been defined at this time. These specifics will instruct, in future, the needs for analytics and visual display of information. The proposed technology architecture has been designed to fully support this. Data display may be realized through user defined data presentations conducted in desktop software applications, or delivered through web-based platforms with either customizable chart, map and tabular displays, or pre-configured business area specific visualizations. Environmental analysts with skills in the use of the R programming language and Shiny apps will be able to build visualizations programmatically using the API.

6.3.3 Recommendations

Implementation of the technology architecture should be conducted in phases, the recommendations below provide a 4-step plan, with increasing functionality and capabilities building on prior steps as available data increases, and business cases for connecting data systems into operational or planning practices emerge. These steps are described below:

1. **Technology development**
    a. **Core database and information flows**
        i. **Plan and configure IT infrastructure**
        Determine IT policies and requirements, procure hardware and/or cloud resources
        ii. **Datastore**
        Install database, define data model, configure tables. The data store heavily leverages PostGIS enabled PostgreSQL database.
        iii. **External data sources**
        Configure ETL tools to harvest hydroclimatic real-time data sources via regularly scheduled scripts (15 min to daily). Monitor data acquisition via basic QA/QC checks, import errors and notification of new data available. Bulk import archive data directly into the database.
        iv. **API**
        Define, configure and implement an application programming interface to distribute data from the database.
    b. **Connections to external datastores**
    Work with external BC repositories such as Aquarius or the Climate Related Monitoring Program (CRMP) to determine mechanisms to deliver data to these external datastores.
2. **Set-up CVRD/partner sensors**
    a. **Agreements**
    Various agreements are anticipated to be required in advance of station installation. These may include land access, construction permits, and data sharing agreements with partners, among others. Agreements must also be developed with external partner datastores.
    b. **Hardware**
    Acquire and install hardware, perform field measurements and regular maintenance

c. **Data QA**

   Evaluate and grade data, publish quality assured products

d. **Connection to core database**

   Create connections between sensor data management systems and centralized core database

   i. **Distribution to external datastores**

      Operationalize the data distribution systems

3. **Partner data collection (ongoing)**

   a. **Roles/responsibilities**

      Define agreements related to funding, staffing, data ownership

   b. **Data management plans**

      Define responsibilities for data custodianship, management, distribution, storage, and retrieval

   c. **Data collection**

      Execute and ensure quality of data collection, QA, publish data

   d. **Incorporation into core database**

      Ingestion of data into core database, either via bulk-load or through configuring ongoing data collection via API or other means.

4. **Analytics / Decision-support**

   a. **Modeling / creation of interpreted products**

      Define specific information needs for use cases, collect technical resources (people, data, tools), configure and validate models.

   b. **Analytics**

      Define specific analyses on raw data that would be of use for specific use cases (i.e., frequency / return interval thresholds, rolling sums, inter-annual comparisons)

   c. **Visualization / reporting**

      Connect information needs from use-cases with specific analytical needs, operationalize requisite analyses, design and develop communication tools to deliver information.

   d. **Decision-support tools**

      Where specific functions have significant friction as a result of time or financial resources to conduct lengthy workflows, seek options to automate all or portions of the workflow, through integration of modeling/interpreted products, analytics, visualization and reporting needs into self-serve tools. Closely consider the use cases and associated needs / skills of the target user group(s), being cautious of simulation tools (consider the impacts of a decision vs varying the inputs to a decision). Before technology development is begun, validate user needs through primary research and engagement with the target audience.

7 Summary

Technology plays an important role in environmental management. The core focus of the DWWP is on effectively managing water resources for human and ecosystem use. Technology systems can efficiently support these goals at various stages, with field sensors continuously monitoring conditions across the district, transmitting data to a centralized database producing intelligence for planning and operational needs. Consolidated data from existing monitoring systems provides a foundational base on which new data can be collected and incorporated alongside.

The CVRD had a reasonably good baseline network of existing climate and hydrometric monitoring stations that provide data to assess regional water vulnerability. However, review of the active hydrometric and climate monitoring stations had identified key gaps in the network to evaluate short-term watershed management and drinking water supply forecasting, and future water strategy development and planning at smaller scales. To fill these gaps, additional sites for hydrometric and climate monitoring were selected to increase the number of stations in phased priority to better understand: weather patterns across the watersheds, discharge and water levels within watershed planning areas, and runoff generation across watershed groups. The monitoring network should function to provide specific data to support future development of conceptual models, water balances, hydrological modelling and watershed management plans. Monitoring technology was selected to ensure high-quality data collection with long-term investment as well as the potential to provide real-time data for emergency response.

New data collection efforts, conducted by the CVRD or independently, should have data management plans in place for each new collection effort, documenting roles and responsibilities for project funding, delivery, and data custodianship, including how and with whom the data can be shared. Where possible, such efforts should take an ‘open by default’ approach assuming that data will be made available to all who wish to use it.

By establishing a centralized, open-source database to house existing and newly collected data, the CVRD will be able to ensure that data is readily available for further analysis, can support the creation of additional derived intelligence products, and easily distributed to external data repositories.

As data holdings mature, and opportunities for integrating intelligence into planning and operational programs emerge, in depth primary research of user needs should be performed to clearly understand both the data needs and desired form of delivery, to ensure that the highest and best outcomes are achieved. On an ongoing basis, the CVRD should catalogue and prioritize use cases for hydrometric and climatic monitoring data (and associated derived products), and use this prioritization to ensure that data collection efforts continue to be in alignment with the needs from priority use cases.

8 Closing

MacHydro in collaboration with Foundry Spatial (hereafter Project Team) prepared this document for the account of the CVRD. The material in it reflects the judgment of the Project Team considering the information available to the Project Team at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. The Project Team accepts no responsibility for damages, if any, suffered by any third party because of decisions made or actions based on this document.

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We trust the above satisfies your requirements. Please contact us should you have any questions or comments.

Sincerely,

Amy Goodbrand, Ph.D., P.Geo.
Senior Hydrologist

Rachel Plewes, M.Sc.
Data Analyst/GIS Specialist

Ben Kerr, B.Sc., P.Ag.
Technical Lead

Hailey Eckstrand, B.Sc.
Data Analyst

Reviewed By:

Ryan MacDonald, Ph.D., P.Ag.
Senior Hydrologist

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Appendix A

Phase 1 Memo – Identification of Stakeholders, Technical Team Support and Data Collection

Final Memo – Identification of Stakeholders, Technical Team Support & Data Collection

Phase 1, Development of a Regional Hydrometric and Climate Monitoring Strategy and Workplan for Cowichan Valley Regional District

2022.05.18

Prepared For:

Cowichan Valley Regional District

MacHydro FOUNDRY SPATIAL

Introduction

MacDonald Hydrology Consultants Ltd. (MacHydro) in collaboration with Foundry Spatial (Foundry) were retained by the Cowichan Valley Regional District (CVRD) to develop a *Regional Hydrometric and Climatic Monitoring Strategy and Implementation Workplan* as part the Drinking Water and Watershed Protection program (DWWP; CVRD, 2020). The CVRD requires a strategy that is designed and implemented across the region at regional, watershed, and surface/aquifer scales. The goal is to improve the understanding and management of water in the individual watersheds to assist with short-term watershed management and drinking water supply forecasting, and future water strategy development and planning within the CVRD. The strategy is expected to provide information to drive adaptive management and emergency response and has critical linkages to the climate adaptation program. The development of a monitoring strategy was divided into four phases. This memo summarizes Phase 1 of the development of a regional hydrometric and climatic monitoring strategy, The objectives of Phase 1 include:

- Identify all data collection agencies and potential partners that should be consulted for this project;
- Support a multi-party technical oversight team made up of project partners who will provide input and support to the strategy development at key points;
- Source and review all current and historical hydrometric and climate data from CVRD and other identified partners that includes location, status, availability, data format, and relevance to the project; and,
- Identify any necessary memorandum of understanding (MOU) or data sharing agreements

Methods

Cowichan Valley Regional District

The study area was determined by selecting the 20 Watershed Planning Areas that intersect the CVRD. There were five additional Watershed Planning Areas that were excluded from the study area because they had only small overlaps with the CVRD boundary. In total, this study area is approximately 503,410 hectares (Figure 1), which is larger than the regional boundaries of the CVRD (~350,000 hectares).

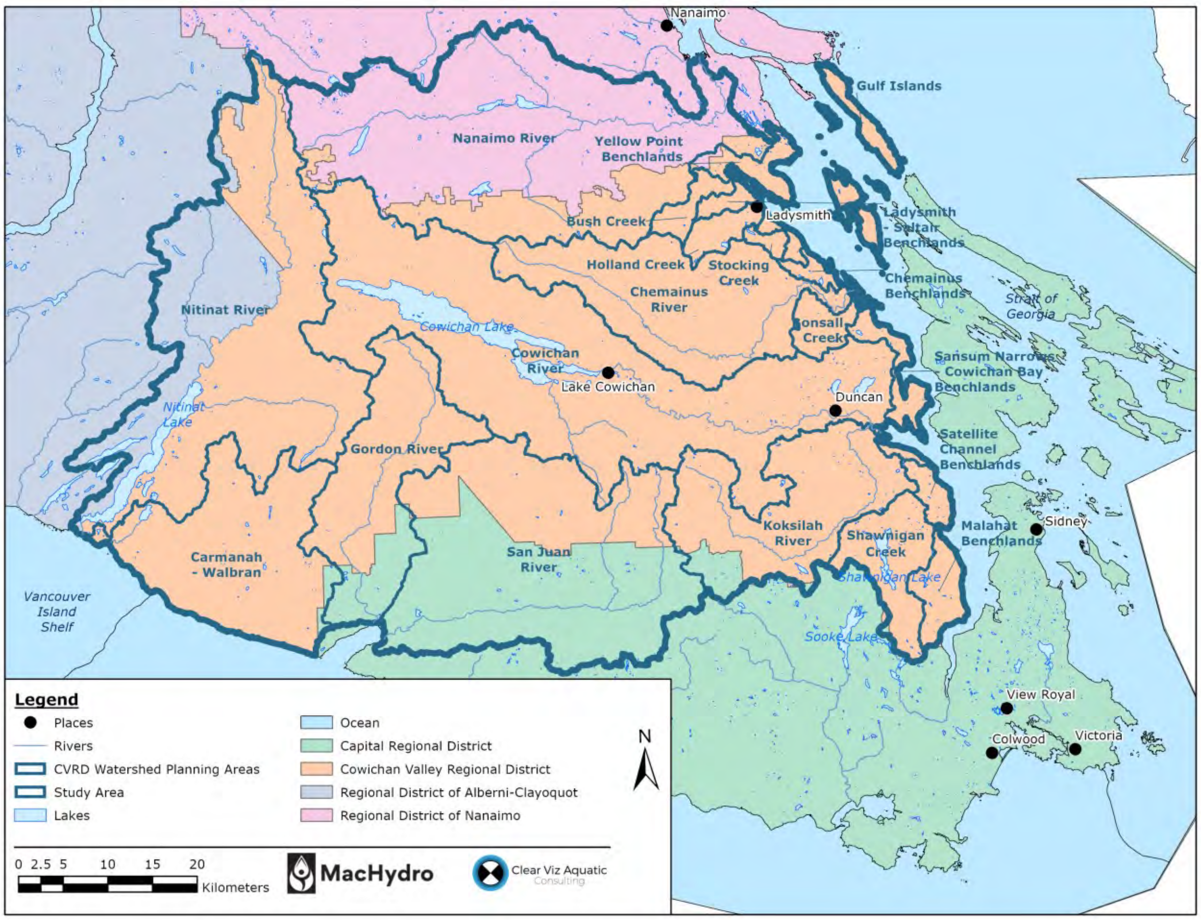


Figure 1. Study area map showing major population centers, Regional Districts, and CVRD Watershed Planning Areas.

Identification of Stakeholders and Technical Team Support

A list of potential stakeholders and data partners were identified by the Project Team and sent to CVRD (Project Manager – Jeff Moore, Environmental Services). The list contained organizations that would be both beneficial to engage (e.g. partnership for purposes of monitoring, data collection, data sharing) or track (e.g. aware of organization's activities, but no formal partnership). From there a list of Technical Advisory Group members were contacted by the CVRD to discuss data sharing and opportunities for data acquisition partnerships. A meeting was held on November 10, 2021 with members of the Technical Advisory Group (Table 1).

Table 1. Identification of stakeholders and technical team support includes a list of potential partners and data collection agencies. Those that are represented in the Technical Advisory Group include the contact's name.

Data Collection Agency/Potential Partner	Track/ Engage	Technical Advisory Group
CVRD Water Management		Brian Dennison, Lisa Daugenet, Jason Molyneaux, Todd Etherington
Mill Bay Improvement	Engage	Sandy Kresse
Cowichan Bay Improvement	Engage	
Municipality of North Cowichan	Engage	Dave Preikshot, Clay Reitsma
City of Duncan	Engage	Brian Murphy
Town of Ladysmith	Engage	Ryan Bouma, Ira Adams
Town of Lake Cowichan	Engage	Dave Parker
FLNRORD – West Coast Region	Engage	Jaroslaw Szczot (Fish & Wildlife Division)
B.C. Provincial Hydrometric Operations	Engage	Neil Goeller
B.C. Water Protection	Engage	Jessica Doyle
B.C. Provincial Climate Network	Engage	Ted Weick
B.C. Provincial Data Systems	Engage	Robert Williams
B.C. Parks	Engage	
B.C. Ministry of Agriculture, Food and Fisheries	Engage	
B.C. Ministry of Transportation and Infrastructure	Engage	
B.C. Timber Sales	Engage	
Islands Trust	Engage	William Shuba
Regional District of Nanaimo (RDN)	Engage	
Capital Regional District	Engage	
Department of Fisheries and Oceans Canada (DFO)	Engage	
Water Survey of Canada	Engage	
Meteorological Service of Canada	Engage	
Penelakut Tribe	Engage	
Halalt First Nation	Engage	
Cowichan Tribes	Engage	Darryl Tunnicliffe
Lake Cowichan First Nation	Engage	
Ditidaht First Nation	Engage	
Pauquachin First Nation	Engage	
Malahat Nation	Engage	
Stz'uminus First Nation	Engage	
Lyackson	Engage	
University of Victoria	Engage	
POLIS Water Sustainability Project	Track	
BC Hydro	Engage	
Mosaic Forest Management	Engage	David Beleznay
Catalyst Pulp & Paper	Engage	
Vancouver Island Trout Hatchery	Engage	
Cowichan River Hatchery	Engage	

Data Collection Agency/Potential Partner	**Track/ Engage**	**Technical Advisory Group**
Marine Harvest Canada	Engage	
Shawnigan Basin Society	Engage	
Shawnigan Research Group	Engage	
Cowichan Lake and River Stewardship Society	Engage	
Cowichan Valley Naturalists Society	Track	
Yellow Point Ecological Society	Track	
Cowichan Community Land Trust	Track	
Koksilah Watershed Working Group	Engage	
Cowichan Watershed Board	Engage	Tom Rutherford
Watersheds BC	Track	
BC Freshwater Legacy	Track	
British Columbia Conservation Foundation (BCCF)	Engage	

Data Access and Compilation

The BC Water Tool (BCWT) and R were used to compile hydrometric, climatic data, and water quality data from various sources. A list of networks who maintain and provide the data gathered for this study and accompanying metadata are provided in Table 2. The BC Water Tool (BCWT) acquired historical data from the Pacific Climate Impacts Consortium (PCIC) Data Portal, as well as publicly available datasets (generally provided as CSV's) from Federal and Provincial open data servers. The BCWT received a data package in 2017 of the DFO and CVRD datasets and as such they are temporally limited as they have not been updated since 2017. An updated status about DFO stations was provided by their website that uploads real-time provisional data, which includes three climate stations (air temperature and rainfall) and water level at Nitinat River, Haslam Creek and San Juan River.

Publicly available spatial datasets were downloaded from Pacific Climate Impacts Consortium (PCIC) Data Portal, the CVRD website, and the BC data catalogue using bcdata R package (Teucher et al. 2019). We requested spatial data from the CVRD for the Preliminary Groundwater Study and the Watershed Risk Analysis study because the data from these studies were not available through the CVRD website. The list of complied spatial datasets are described in Appendix B.

The spatial extents of hydrometric and climatic studies were summarized and presented in a study extents map. The extent of 1 m Digital Elevation Models (DEM) derived from LiDAR was also summarized in a map. The DEM data was provided by CVRD and downloaded through the LidarBC - Open LiDAR Data Portal.

Table 2. Networks and observations available that have been collected for this study.

Network Name	Station Count	Status	Parameters	Period
Climate				
Agricultural and Rural Development Act Network *Retrieved from PCIC*	47	Historical / Inactive	Precipitation Amount Surface Snow Depth Air Temperature	1970-1991
BC ENV - Air Quality Network *Retrieved from PCIC*	2	Historical	Temperature Wind Speed Relative Humidity Wind Direction	1990-2021
BC ENV - Automated Snow Pillow Network	2	Current	Precipitation (Cumulative) Surface Snow Depth Air Temperature Snow Water Equivalent	1995-2021
BC ENV - Manual Snow Survey	4	Historical	Snow Depth Snow Water Equivalent	1959-2016
BC FLNRORD - Wild Fire Management Branch *retrieved from PCIC*	17	Current	Precipitation Amount Air Temperature Wind Direction Relative Humidity Wind Speed Dewpoint	1971-2021
BC MoTI	2	Current	Precipitation Amount Rainfall Amount Snowfall Amount Surface Snow Depth Air Temperature Wind Speed Relative Humidity	1988-2021
Environment Canada	37	Current	Precipitation Amount Rainfall Amount Snowfall Amount Surface Snow Depth Air Temperature	1894-2021
Forest Renewal British Columbia	4	Historical network (no longer active)	Precipitation Amount Temperature	1999-2010
Hydrometric				
BC ENV - Groundwater Observation Well Network	22	Current	Groundwater Level	1954-2021
BC ENV - Real-time Water Data Reporting	16	Current	Flow Water Levels Water Temperature Water Turbidity	2011-2021
BC FLNRORD – Water Rights Database	1373	Current	Water Licence	1902-2020
Cowichan Valley (Regional District)	3	*Unknown*	Water Levels	2015-2017
Department of Fisheries and Oceans	2	*Unknown*	Water Levels	2015-2017
Water Survey of Canada	37	Current	Flow Water Levels	1913-2021

Network Name	Station Count	Status	Parameters	Period
Water Quality				
BC ENV - Environmental Monitoring System	672	Current	Various chemistry parameters	1968-2021
ECCC – National Long-term Water Quality Monitoring Data	1	Current	Various chemistry parameters	2000-2019

Analysis

Data compilation and spatial analysis were performed in R version 4.0.3 (R Core Team, 2020) and ArcGIS Pro 2.8.1 (Environmental Systems Research Institute, 2021). Data from hydrometric, climatic and water quality stations were summarized based on period of record and parameters measured. Weather stations were classified as "Active" if they contained observations in the last year (i.e. since 2020) and "Inactive" if they did not. The stations were further classified based on whether they contained long-term records, determined as greater than 3 (consecutive) years. Hydrometric stations were classified as Active or Discontinued based on their reported status in the Water Survey of Canada's HYDAT database metadata. Groundwater and surface water quality stations that were sampled once were identified.

Maps were created to summarize the distribution of sites throughout the CVRD watershed planning areas. Biogeoclimatic Zones, temperature, and precipitation climatologies and DRASTIC Aquifer Intrinsic Vulnerability were also included in relevant maps to better understand spatial variability in physical characteristics.

Results

Several types of hydrometric and climate datasets have been compiled during this phase of work. Data sources and licensing are provided in Appendix Table A1. All thematic datasets are presented in maps, showing their spatial coverage and/or distribution as well as attributes detailing the length of record (if applicable) and if these stations are currently active or if data collection has been discontinued (Appendix C).

Air Temperature and Precipitation

Climate variables air temperature and precipitation were compiled at point scale for weather stations at hourly and daily resolutions. In addition, long-term (30-year; 1981-2010) spatial outputs of PRISM gridded 800 m monthly air temperature and precipitation datasets were obtained for the study area. Air Temperature is actively collected from 16 locations within the CVRD, primarily in valley bottom locations along the east coast and near Cowichan Lake. Precipitation is actively collected from 12 locations within the CVRD, primarily in valley bottom locations along the east coast and near Cowichan Lake.

Snowpack

Snowpack data (snow water equivalent, mm) is collected as manual snow surveys, which are made at approximately monthly intervals during the winter and spring, and at automated snow pillows, which use sensors to estimate snow water equivalent continuously. In the CVRD, automated snow pillows are active at Jump Creek (since 1995) and Heather Mountain Upper (since 2015). In addition, discontinued snow survey sites were located at Heather Mountain

(1959-2016), Sno-Bird Lake (1966-1999), and Lyford Mountain (1959-1981). All stations are located at higher elevation, mountainous regions where the snowpack is likely to be deeper and persist longer into the spring.

High Resolution LiDAR

High resolution digital elevation models (DEM; 1m spatial resolution) can be useful tools for a variety of applications, including hydroclimatic investigations such as floodplain mapping and modelling. LiDAR DEMs have been derived for the entirety of the Cowichan River watershed, as well as much of the east coast of the CVRD. In addition, LiDAR DEM coverage is available for the lower portions of the Nitinat River, San Juan River, and Gordon River, as well as adjoining coastal areas.

Surface Water

Surface water is monitored for rivers by measuring the streamflow (discharge; m^3/s) and lakes by measuring the water level (m). Discharge is measured primarily in rivers and streams in the eastern side of the CVRD. In total, 17 hydrometric stations actively collect discharge observations, primarily concentrated in a few watersheds; 4 in the Nanaimo River, 5 in the Cowichan River, 4 in the San Juan, 2 in each of the Koksilah River and Chemainus River. Notably, no available hydrometric stations (active or discontinued) are available in the Nitinat or Gordon River watersheds. An active hydrometric station monitors water level at Cowichan Lake.

Groundwater

Groundwater is monitored in wells, measuring the water level (m) in a well. Groundwater is measured at 17 locations within the CVRD. Of these, 3 were added in 2021. All groundwater wells reported here are located along the eastern low-lying areas of the CVRD.

DRASTIC Aquifer Vulnerability mapping is a procedure designed to show areas of greatest potential for ground-water contamination based on hydrogeologic and anthropogenic (human) factors. This mapping has been completed for the east coast of the CVRD as well as much of the Cowichan River watershed, the north end of Nitinat Lake, and around Port Renfrew.

Water Licences

Water licences and approvals allow people to divert, use or store surface water or groundwater, or to make changes in and about a stream. Water licences and approvals are issued for water use purposes supporting agriculture, commerce, domestic household requirements (surface water only), habitat conservation, industry, natural resources development, power production, water storage and water supply. In the CVRD, water licences are largely located along the east coast and in the Cowichan Valley. Most of the licences are clustered close to population centers and in agricultural areas along valley bottoms. Water licences in the CVRD have been issued for both surface water and groundwater sources. The majority (i.e. > 90%) of water licences have been issued for diversions under 5000 m^3/day. There are 14 water licences over 1,000,000 m^3/day. These licences are primarily municipal waterworks (i.e. City of Nanaimo, District of North Cowichan) as well as for agriculture (irrigation) or forestry operations.

Water Quality

Water quality is measured both in surface water and groundwater using periodic sampling of the water of interest and performing lab analysis to identify a wide variety of chemical and physical properties, including, among other variables, nutrient levels, pollutant concentrations, mineral composition, and sedimentation. Surface water quality sampling sites are located across the CVRD, with river sites primarily located along the eastern coast of the study area, and lake sampling sites primarily in larger lakes such as Cowichan Lake and Shawnigan Lake. Groundwater water quality is monitored periodically at 13 locations along the east coast of the CVRD as well as several more one-time samples.

Hydrometric and Climatic Studies

In addition to monitoring data, this phase of work has also identified several studies that have derived datasets with relevance to hydrometric and climatic monitoring. Most notably, the *CVRD Watershed Analysis Final Risk Analysis* (SNC Lavalin, 2019) covers much of the CVRD, notably including the entirety of the Cowichan River, Chemainus River, Koksilah River, and Shawnigan Creek. *Preliminary Groundwater Budgets* (Harris and Usher, 2017) covers Koksilah River and Shawnigan Creek watersheds. Several flood preparedness studies have also been completed in the CVRD, including *Cowichan River Riverbottom Road Area Flood and Erosion Hazard Mapping* (NHC, 2020), *Updated Cowichan-Koksilah River Flood Mapping Project* (NHC, 2021), *Shawnigan Lake Flood Preparedness Monitoring Project* (NHC, 2020), and *Sea Level Rise - Coastal Flood Extent* (NHC, 2019).

Data Sharing Agreements

Follow up with the Technical Advisory Group indicated some future potential memorandums of understanding or data sharing agreements (**Error! Reference source not found.**). This meeting with identified stakeholders helped to direct the scope and focus of the project, particularly by providing information regarding potential data partnerships, existing data, and the needs of data users.

Table 3. Information provided from follow up with potential data partners of the Technical Advisory Group or other identified organizations. The need for memorandums of understanding or data sharing agreements were identified. Only locations of relevant monitoring stations (active, proposed) were collected. No data were collected from the potential data partners in the table.

Potential Data Partner	Comments
Town of Ladysmith	Data from climate station at Public Works, potential climate stations at Holland Lake and Stocking Lake installed no earlier than 2023. Installing climate station, flow monitoring and water level at Holland Lake with potential communication system between reservoir and Public Works. All work is budget dependent.
Municipality of North Cowichan	Data from hydrometric stations on Chemainus River and its tributaries. Water level data available from Somenos Creek and Richards Creek from 2005 – 2020.

Potential Data Partner	Comments
	Data available for water quality at South Quamichan Lake, Elkington Creek, Stanhope Rd Ditch, Stamps Rd Ditch. Data available from water quality sampling (water temperature, dissolved oxygen, pH, conductivity) in Somenos Basin via Somenos Marsh Wildlife Society (ginahoar@somenosmarsh.com)
City of Duncan	Data from hydrometric station at Fish Gut Alley and from groundwater monitoring program at a number of wells in downtown Duncan.
B.C. Ministry of Transportation and Infrastructure	Andrew Anderson (Water Resources) - Data from hydrometric station installed on Dry Bend Creek (tributary to Cowichan River) in October, 2021
B.C. Water Protection	Data from monitoring wells near Cowichan River part of research project will be posted to Aquarius when finalized. Some sites may be suitable for long-term monitoring and would be posted to Aquarius.
B.C. Provincial Climate Network	Province working with ECCC and all data posted to ECCC MSC's DataMart. They expect that all data would be shareable through PCIC, but good to be at the table signing on. Participating networks have stations range from 4 to >200.
B.C. Provincial Hydrometric Operations	Non-digital data of miscellaneous hydrometric measurements in filing cabinets in Nanaimo warehouse. Data reports from old water survey branch in EcoCat.
FLNRORD – West Coast Region	All regional hydrometric and climate data collected by Water Protection, Water Authorizations, Environmental Protection or Fish & Wildlife managed by provincial Aquarius database. Most of these data collected in last 6 to 7 years, but have uploaded some manual station data from historical locations. The system includes third party data from other organization, municipalities, and communities and data sharing agreements and QA/QC protocols are currently being developed.
CVRD Water Management	Jason Molyneaux – CVRD has ~50 water/sewer that could be added to existing SCADA system. Monitoring a few wells to SCADA system, while others are not being logged. He mentioned an unknown third party with lake level monitoring project on Shawnigan Lake. Lisa Daugenet – data from hydrometric station installed at Stocking Creek. Data from two wells near Saltair water treatment facility in process of

Potential Data Partner	Comments
	water license application to provide 1/3 – 1/2 of the water demand.
University of Victoria	Data from the six climate stations within the CVRD from the Vancouver Island School-Based Weather Station Network is publicly available; however, there is a fee charged to prepare data in specific formats for commercial users, which would need to be discussed in more detail. The network has been historically underfunded and maintenance of climate stations has always been done on an as-needed basis.

Summary

The current networks in the CVRD are operated by federal, provincial and local government. This list includes publicly available data and data from communities within the CVRD. No data were collected from potential industry partners (e.g. Mosaic Forest Management). Data were also not collected from any community-monitored stations, which includes the Vancouver Island School-Based Weather Station Network. We did not consider these climate stations (n = 6) or other community-based monitoring stations due to the uncertainty in data quality. Detailed information on data were compiled from the below organizations.

Climate Stations

- Agricultural and Rural Development Act Network (ARDA)
- Environment and Climate Change Canada (ECCC)
- BC Ministry of Environment and Climate Change Strategy (BC ENV) - Air Quality Network
- BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD) - Wildfire Management Branch
- BC Ministry of Transportation and Infrastructure (BC MoTI)
- CVRD
- Municipality of North Cowichan
- Town of Ladysmith

Hydrometric Stations

- Water Survey of Canada (WSC)
- BC ENV – Real-time Water Data Reporting
- BC ENV – Groundwater Observation Well Network (PGOWN)
- CVRD
- Municipality of North Cowichan
- Town of Ladysmith

While most of the datasets compiled during this phase of work are publicly available, this work has also identified several relevant datasets which could be included in the database and help inform gap analysis in Phase 3 following discussion with CVRD and require data sharing agreements. These include:

- *New Normal Cowichan:* The CVRD is currently working on a multi-phased project to take action on climate adaptation. Data from this project, including raster climate layers from Phase 1, and any further subsequent work should be included in the database, following discussions with the CVRD.
  - https://www.cvrd.bc.ca/climate
- *Groundwater outputs for the Koksilah River Watershed:* This desktop study identified stream reaches within the Koksilah watershed where hydraulic connection with underlying aquifers and depletion of streamflow from well pumping can most likely be expected to occur. This study documented Points of Hydraulic Connection with groundwater wells in the watershed and estimated Stream Depletion Factors. Both statistics could be useful additions to informing groundwater resources in the region.
  - Sivak, T. and Wei, M. 2019. Koksilah River Watershed: Preliminary Assessment of Hydraulic Connection. *Water Science Series*, WSS2019-05. Prov. B.C., Victoria B.C. https://a100.gov.bc.ca/pub/acat/documents/r57126/17_1566072779928_6072630385.pdf
- *Vancouver Island Cumulative Effects Framework – Aquatic Ecosystems:* Cumulative effects framework work is on-going on Vancouver Island and many of the datasets generated through this process may be relevant to this project. These could include peak flows, water withdrawals, surface water dams/diversions, or other aquatic/riparian information. The scope of this data request (if any) should be refined in collaboration with CVRD.
  - https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/cumulative-effects-framework
- *Department of Fisheries and Oceans:* Updated information from their website indicates three active climate stations with water level and water temperature monitoring. The data are not currently available as published data up to 2021. Discussions between DFO and CVRD for a data sharing agreement would be needed to include in the database.

Finally, the Project Team will continue work towards further phases of the workplan. This includes Phase 2 which will detail requirements and requests from the technical advisory group and provide recommendations detailing data warehouse structure, software requirements, and communication infrastructure. In addition, the Project Team will continue to work towards providing a Phase 3 memo, which will perform a preliminary assessment of the current hydrometric and climate network and conduct a gap analysis.

Closing

MacHydro in collaboration with Foundry Spatial (hereafter Project Team) prepared this document for the account of the CVRD. The material in it reflects the judgment of the Project Team considering the information available to the Project Team at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. The Project Team accepts no responsibility for damages, if any, suffered by any third party because of decisions made or actions based on this document.

As a mutual protection to the CVRD, the public, and ourselves, all documents are submitted for the confidential information of our client for a specific project. Authorization for any use and/or publication of this document or any data, statements, conclusions or abstracts from or regarding our documents and drawings, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending the Project Team's written approval. A signed and sealed copy of this document is on file at MacHydro. That copy takes precedence over any other copy or reproduction of this document.

We trust the above satisfies your requirements. Please contact us should you have any questions or comments.

Sincerely,

Matthew Chernos, M.Sc., P.Geo.
Hydrologist

Rachel Plewes, M.Sc.
Data Analyst/GIS Specialist

Ben Kerr, B.Sc., P.Ag.
Technical Lead

Hailey Eckstrand, B.Sc.
Data Analyst

Reviewed By:

Ryan MacDonald, Ph.D., P.Ag.
Senior Hydrologist

Appendix A: Data Source Licensing Information

Table A1. Sources, description, and licensing information for networks used in hydrometric and climate data compilation.

Network	Description	Link
Agricultural and Rural Development Act Network	Data from Agricultural and Rural Development Act Network has been acquired from Pacific Climate Impacts Consortium (http://www.pacificclimate.org/data/bc-station-data). PCIC's terms of use are: https://pacificclimate.org/terms-of-use. This data is a copy of an official work that is published by the Government of Canada and the reproduction has not been produced in affiliation with or with the endorsement of the Government of Canada. For more information on the terms and conditions of the data please see: http://www.ec.gc.ca/default.asp?lang=En&n=12345678-1&xsl=mainhomeitem&xml=5830C36B-1773-4E3E-AF8C-B21F54633E0A. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	http://www.ec.gc.ca/default.asp?lang=En&n=12345678-1&xsl=mainhomeitem&xml=5830C36B-1773-4E3E-AF8C-B21F54633E0A
British Columbia Ministry of Environment - Air Quality Network	Data from BC Ministry of Environment and Climate Change Strategy - Air Quality Network has been acquired from Pacific Climate Impacts Consortium (http://www.pacificclimate.org/data/bc-station-data). PCIC's terms of use are: https://pacificclimate.org/terms-of-use. The data contains information licensed under BC Provincial Data disclaimer: http://www2.gov.bc.ca/gov/admin/disclaimer.page. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	https://www2.gov.bc.ca/gov/content/data/open-data/open-government-licence-bc
British Columbia Ministry of Environment - Automated Snow Pillow Network	Data from Automated Snow Pillow Network has been acquired from Ministry of Environment and Climate Change Strategy and DataBC. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	https://www2.gov.bc.ca/gov/content/data/open-data/open-government-licence-bc
British Columbia Ministry of Environment - Environmental Monitoring System	Data from BC Ministry of Environment and Climate Change Strategy Environmental Monitoring System has been acquired from DataBC. https://a100.gov.bc.ca/pub/ems/indexAction.do. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	https://www2.gov.bc.ca/gov/content/data/open-data/open-government-licence-bc
British Columbia Ministry of Environment -	Data from Groundwater Observation Well Network has been acquired from the BC Ministry of Environment and Climate Change Strategy. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas	https://www2.gov.bc.ca/gov/content/data/open-

Network	Description	Link
Groundwater Observation Well Network	Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	data/open-government-licence-bc
British Columbia Ministry of Environment - Manual Snow Survey	Data from BC Ministry of Environment Manual Snow Survey has been acquired from Ministry of Environment and Climate Change Strategy and DataBC. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	https://www2.gov.bc.ca/gov/content/data/open-data/open-government-licence-bc
British Columbia Ministry of Environment - Real-time Water Data Reporting	Data from BC ENV - Real-time Water Data Reporting has been acquired from Ministry of Environment and Climate Change Strategy and DataBC (https://www.env.gov.bc.ca/wsd/data_searches/water/). Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	https://www2.gov.bc.ca/gov/content/data/open-data/open-government-licence-bc
British Columbia Ministry of Environment – Water Rights Databases	Warranty Disclaimer This information is provided as a public service by the Government of British Columbia, Box 9411, Victoria, British Columbia, Canada V8W 9V1. This website and all of the information it contains are provided "as is" without warranty of any kind, whether express or implied. All implied warranties, including, without limitation, implied warranties of merchantability, fitness for a particular purpose, and non-infringement, are hereby expressly disclaimed. Links and references to any other websites are provided for information only and listing shall not be taken as endorsement of any kind. The Government of British Columbia is not responsible for the content or reliability of the linked websites and does not endorse the content, products, services or views expressed within them. Limitation of Liabilities Under no circumstances will the Government of British Columbia be liable to any person or business entity for any direct, indirect, special, incidental, consequential, or other damages based on any use of this website or any other website to which this site is linked, including, without limitation, any lost profits, business interruption, or loss of programs or information, even if the Government of British Columbia has been specifically advised of the possibility of such damages.	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-licences-approvals/water-rights-databases
BC FLNRORD - Wild Fire Management Branch	Data from BC Ministry of Forests, Lands and Natural Resource Operations - Wild Fire Managment Branch has been acquired from Pacific Climate Impacts Consortium (http://www.pacificclimate.org/data/bc-station-data). PCIC's terms of use are: https://pacificclimate.org/terms-of-use. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	https://www2.gov.bc.ca/gov/content/home/copyright
BC MoTI	Data from BC Ministry of Transportation has been acquired from Ministry of Transportation and Infrastructure and Pacific Climate Impacts Consortium (http://www.pacificclimate.org/data/bc-station-data). PCIC's terms of use are: https://pacificclimate.org/terms-of-use. Any reliance you place upon the information contained here is	https://www2.gov.bc.ca/gov/conte

Network	Description	Link
	your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	nt/home/copyright
Cowichan Valley (Regional District)	Data from Cowichan Valley Regional District provided under Memorandum of Understanding with the Province of British Columbia. https://www.cvrd.bc.ca/. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	https://www2.gov.bc.ca/gov/content/data/open-data/open-government-licence-bc
Department of Fisheries and Oceans	Data from Department of Fisheries and Oceans has been acquired from http://www.pacfish.ca/wcviweather/. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations and Rural Development or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	https://www2.gov.bc.ca/gov/content/data/open-data/open-government-licence-bc
ECCC - National Long-term Water Quality Monitoring Data	Data from the National Long-term Water Quality Monitoring Data has been acquired from Environment and Climate Change Canada (http://data.ec.gc.ca/data/substances/monitor/national-long-term-water-quality-monitoring-data/). This data is a copy of an official work that is published by the Government of Canada and the reproduction has not been produced in affiliation with or with the endorsement of the Government of Canada. For more information on the terms and conditions of the data please see: https://open.canada.ca/en/open-government-licence-canada. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	https://open.canada.ca/en/open-government-licence-canada
Environment Canada	Data from Environment Canada has been acquired from The Meteorological Service of Canada and Pacific Climate Impacts Consortium (http://www.pacificclimate.org/data/bc-station-data). PCIC's terms of use are: https://pacificclimate.org/terms-of-use. This data is a copy of an official work that is published by the Government of Canada and the reproduction has not been produced in affiliation with or with the endorsement of the Government of Canada. For more information on the terms and conditions of the data please see: http://www.ec.gc.ca/default.asp?lang=En&n=12345678-1&xsl=mainhomeitem&xml=5830C36B-1773-4E3E-AF8C-B21F54633E0A and http://weather.gc.ca/mainmenu/disclaimer_e.html. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	http://www.ec.gc.ca/default.asp?lang=En&n=12345678-1&xsl=mainhomeitem&xml=5830C36B-1773-4E3E-AF8C-B21F54633E0A
Forest Renewal British Columbia	Data from Forest Renewal BC has been acquired from Pacific Climate Impacts Consortium. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource	https://www2.gov.bc.ca/gov/conte

Network	Description	Link
	Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	nt/home/copyright
Water Survey of Canada	Data from Water Survey of Canada has been acquired from Environment Canada (https://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=9018B5EC-1). This data is a copy of an official work that is published by the Government of Canada and the reproduction has not been produced in affiliation with or with the endorsement of the Government of Canada. For more information on the terms and conditions of the data please see: http://www.ec.gc.ca/default.asp?lang=En&n=12345678-1&xsl=mainhomeitem&xml=5830C36B-1773-4E3E-AF8C-B21F54633E0A. Any reliance you place upon the information contained here is your sole responsibility and strictly at your own risk. In no event will the original data custodian, BC Oil and Gas Commission, Ministry of Forests, Lands and Natural Resource Operations or Foundry Spatial Ltd. be liable for any loss or damage whatsoever, including without limitation, indirect or consequential loss or damage, arising from reliance upon the data or derived information.	http://wateroffice.ec.gc.ca/disclaimer_info_e.html

Appendix B: Spatial Data Compiled and Created

Table B1. List of compiled spatial data in database.

Layer Name	Category	Credits	Report	Access	Coverage
METStations	Climate	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
BEC_Map	Climate	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Forest Analysis and Inventory		Public	Full
bc_ppt_monthly_CAI_timeseries_19500101_20071231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
tasmax_mClimMean_PRISM_historical_19710101-20001231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
tasmax_mClimMean_PRISM_historical_19810101-20101231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
tasmin_aClimMean_PRISM_historical_19710101-20001231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
tasmin_aClimMean_PRISM_historical_19810101-20101231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
tasmin_mClimMean_PRISM_historical_19710101-20001231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
tasmin_mClimMean_PRISM_historical_19810101-20101231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
bc_tmax_monthly_CAI_timeseries_19500101_20071231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
bc_tmin_monthly_CAI_timeseries_19500101_20071231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
pr_aClimMean_PRISM_historical_19710101-20001231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full

Layer Name	Category	Credits	Report	Access	Coverage
pr_aClimMean_PRISM_historical_19810101-20101231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
pr_mClimMean_PRISM_historical_19710101-20001231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
pr_mClimMean_PRISM_historical_19810101-20101231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
tasmax_aClimMean_PRISM_historical_19710101-20001231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
tasmax_aClimMean_PRISM_historical_19810101-20101231.tif	Climate	Pacific Climate Impacts Consortium (PCIC), Victoria, BC, www.pacificclimate.org		Public	Full
Temperature_Sites	Climate	MacDonald Hydrology Consultants Ltd.		Public	Full
Precipitation_Sites	Climate	MacDonald Hydrology Consultants Ltd.		Public	Full
Snow_Sites	Climate	MacDonald Hydrology Consultants Ltd.		Public	Full
SWS_Risk	Groundwater	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
SWS_Haz	Groundwater	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
GWC_Cons	Groundwater	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
GWC_Haz	Groundwater	SNC Lavalin Inc. and Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
GWC_Risk	Groundwater	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
SWS_Cons	Groundwater	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
AvAnnSurp	Groundwater	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
Recharge_30y	Groundwater	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
InflRaster_30y	Groundwater	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
Aquifers	Groundwater	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
ProvMonitoringWells_Select	Groundwater	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial

Layer Name	Category	Credits	Report	Access	Coverage
DRASTIC_Aquifer_Intrinsic_Vulnerability	Groundwater	Ministry of Environment and Climate Change Strategy, Water Protection and Sustainability		Public	Full
Ground_Water_Aquifers	Groundwater	Ministry of Environment and Climate Change Strategy, Water Protection and Sustainability		Public	Full
Lithology_of_Ground_Water_Wells	Groundwater	Ministry of Environment and Climate Change Strategy, Water Protection and Sustainability		Public	Full
Groundwater_Wells	Groundwater	Ministry of Environment and Climate Change Strategy, Water Protection and Sustainability		Public	Full
Water_Rights_Licences___Public	Groundwater	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Water Management		Public	Full
Groundwater_Level_Sites	Groundwater	MacDonald Hydrology Consultants Ltd.		Public	Full
CombinedRisk	Other	SNC Lavalin Inc., Cowichan Valley Regional District.	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
StudyArea_Extended	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
Soils_30y	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
SurficialGeology	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
MINFILE_Locations	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
BedrockGeology_Faults	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
BedrockGeology	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
LandCover_Clip	Other	Agriculture and Agri-Food Canada (AAFC), Annual Crop Inventory 2013	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
Watersheds_Select	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
VegRaster_30y	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
GeoRaster_30y	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
Soils	Other	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial

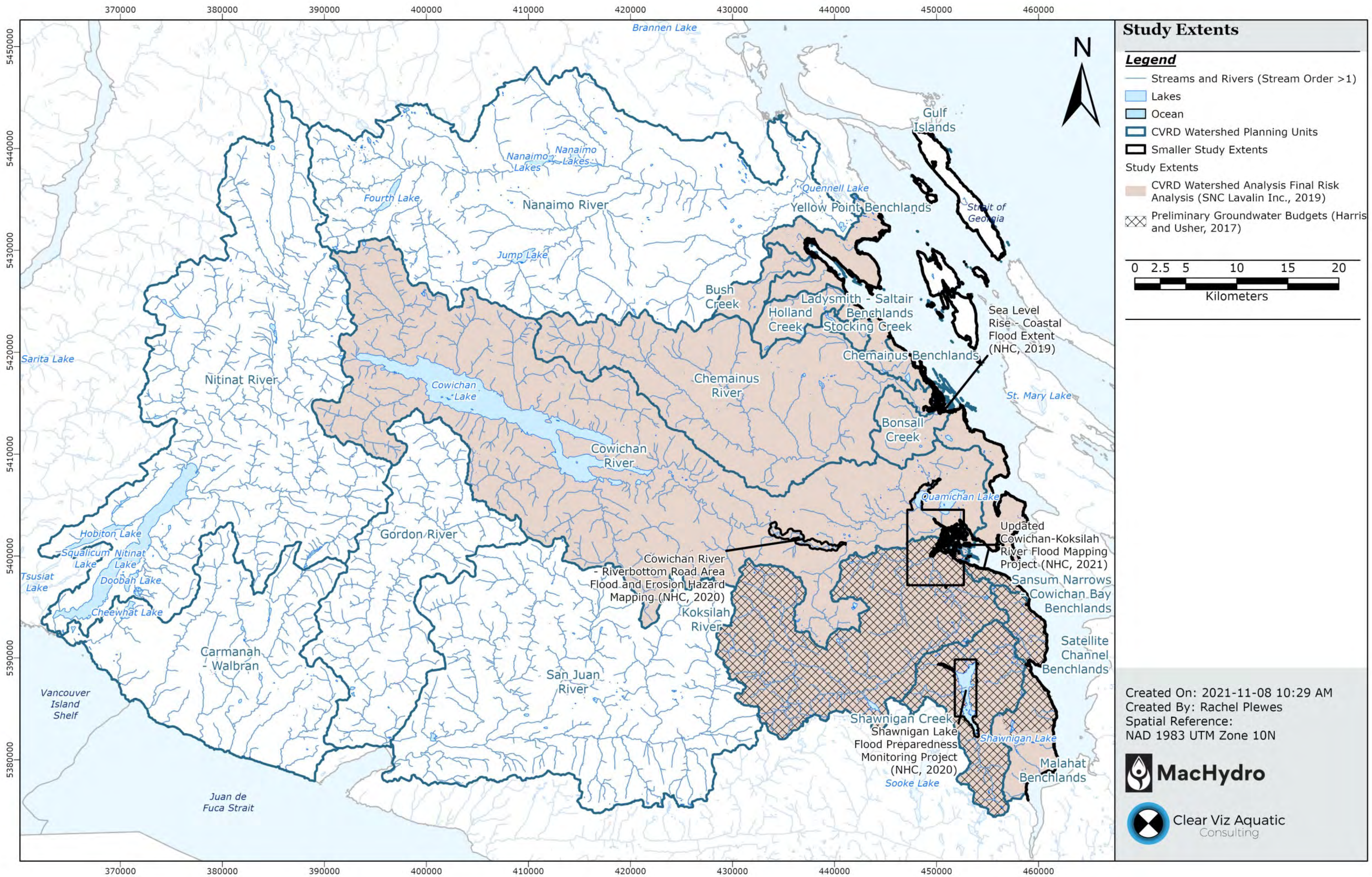
Layer Name	Category	Credits	Report	Access	Coverage
Vegetation_30y	Other	Agriculture and Agri-Food Canada (AAFC), Annual Crop Inventory 2013	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
Environmentally_Sensitive_Areas_Madrone_2018	Other	This mapping project was completed by Madrone Environmental Services Ltd. Madrone's staff involved in the project include Tania Tripp, Harry Williams, Jennifer McEwen, Justin Lange, Anna Jeffries, and Ian Wright. Thank you to the CVRD, especially Jeff Moore and Kate Miller, for making this work possible and providing valuable feedback throughout the project. We are also grateful for the guidance provided by the project Steering Committee during the first phase of the mapping.	Environmentally Sensitive Areas (2018 Madrone)	Public	Full
Hydrometric_Stations_Summary	Other			Public	Full
BC_Dams	Other	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Water Management		Public	Full
Surface_Water_Quality_Sites	Other	MacDonald Hydrology Consultants Ltd.		Public	Full
Groundwater_Quality_Sites	Other	MacDonald Hydrology Consultants Ltd.		Public	Full
Indian_Reserves___Administrative_Boundaries	Other	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
BC_Land_Boundary	Other			Public	Full
Regional_Districts___Legally_Defined_Administrative_Areas_of_BC	Other	Ministry of Municipal Affairs, Governance and Structure		Public	Full
Freshwater_Atlas_Watershed_Groups	Other			Public	Full
BC_Parks_Ecological_Reserves_and_Protected_Areas	Other	Ministry of Environment and Climate Change Strategy, BC Parks - Provincial Services		Public	Full
BC_Major_Cities_Points_1_2000000__Digital_Baseline_Mapping	Other	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
Marine_Ecosections___Coastal_Resource_Information_Management_System_CRIMS	Other	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
Digital_Road_Atlas_DRA___Master_Partially_Attributed_Roads	Other	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
Hydrometric_Surface_Sites	Surface	MacDonald Hydrology Consultants Ltd.		Public	Full

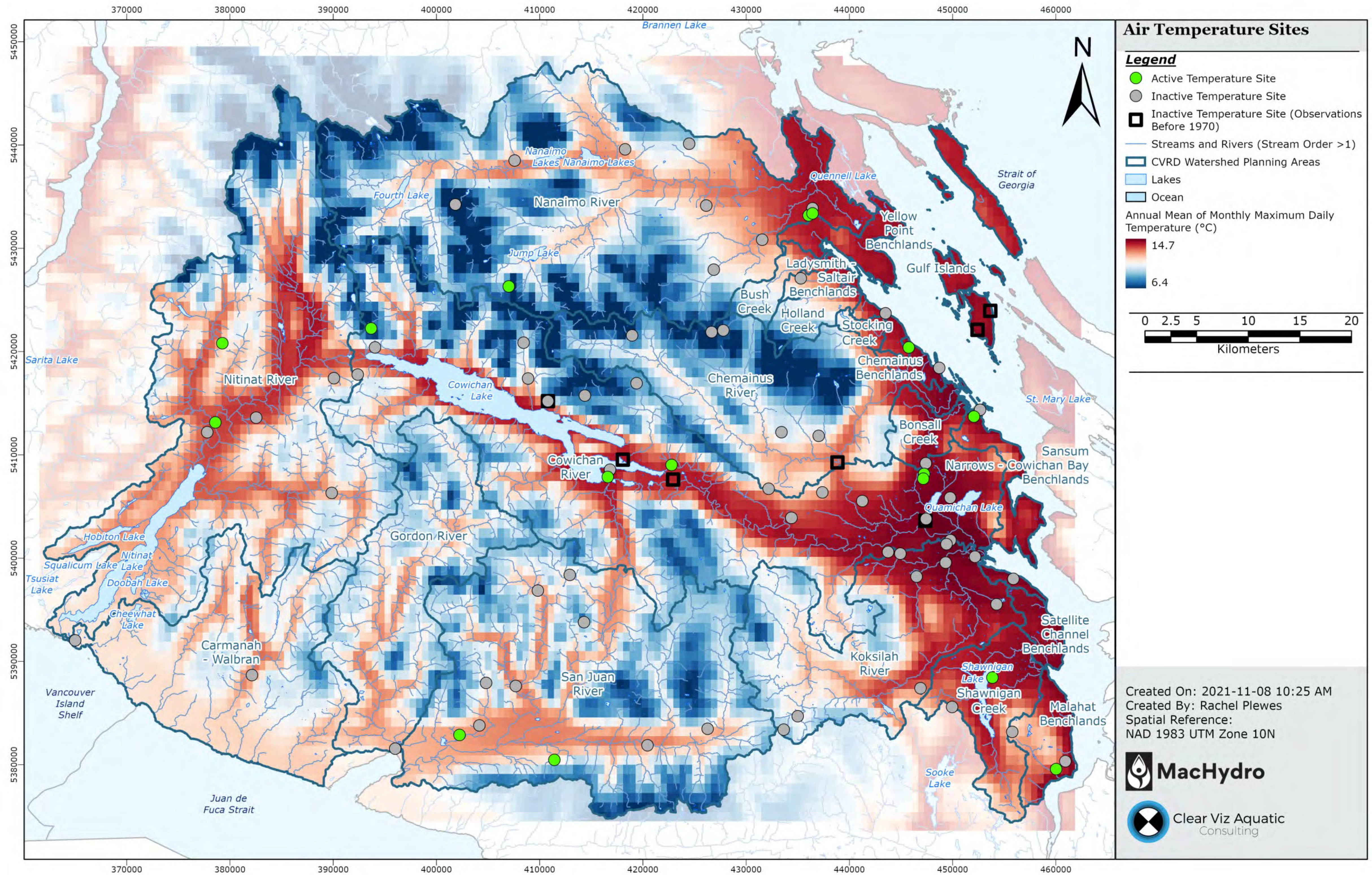
Layer Name	Category	Credits	Report	Access	Coverage
WatershedBoundaries	Surface	CVRD Environment Division	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
SWQRisk	Surface	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
SWQHaz	Surface	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
SWQ_Cons	Surface	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
Flood_Cons	Surface	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
Lakes	Surface	DataBC. Published by the Ministry of Forests, Lands and Natural Resource Operations - GeoBC.	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
Flood_Risk	Surface	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
Wetlands	Surface	DataBC. Published by the Ministry of Forests, Lands and Natural Resource Operations - GeoBC.	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
Streams	Surface	DataBC. Published by the Ministry of Forests, Lands and Natural Resource Operations - GeoBC.	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
Flood_Haz	Surface	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
Runoff_30y	Surface	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
HydrometricStation	Surface	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
Floodplain_2021_Cowichan_Koksilah_Flood_Extents	Surface	Northwest Hydraulic Consultants Ltd.	Updated Cowichan-Koksilah River Flood Mapping Project (2021)	Public	Partial
Floodplain_2021_Cowichan_Koksilah_Flood_Construction_Levels	Surface	Northwest Hydraulic Consultants Ltd.	Updated Cowichan-Koksilah River Flood Mapping Project (2021)	Public	Partial
Floodplain_2020_Cowichan_River_RiverbottomRd_Modern_Valley_Bottom	Surface	Northwest Hydraulic Consultants Ltd.	Cowichan River - Riverbottom Road Area Flood and Erosion Hazard Mapping (2020)	Public	Partial
Floodplain_2020_Cowichan_River_RiverbottomRd_Floodway	Surface	Northwest Hydraulic Consultants Ltd.	Cowichan River - Riverbottom Road Area Flood and Erosion Hazard Mapping (2020)	Public	Partial
Floodplain_2020_Cowichan_River_RiverbottomRd_Flood_Fringe	Surface	Northwest Hydraulic Consultants Ltd.	Cowichan River - Riverbottom Road Area Flood and Erosion Hazard Mapping (2020)	Public	Partial

Layer Name	Category	Credits	Report	Access	Coverage
Floodplain_2020_Cowichan_River_RiverbottomRd_Flood_Construction_Levels	Surface	Northwest Hydraulic Consultants Ltd.	Cowichan River - Riverbottom Road Area Flood and Erosion Hazard Mapping (2020)	Public	Partial
Floodplain_2020_Cowichan_River_RiverbottomRd_Erosion_Hazard_Area	Surface	Northwest Hydraulic Consultants Ltd.	Cowichan River - Riverbottom Road Area Flood and Erosion Hazard Mapping (2020)	Public	Partial
Dam_Assessment_2019_Ecora_Flood_Hazard_Rating	Surface	Ecora Engineering & Resource Group Ltd.	Dam Assessments - Flood Hazard Ratings (2019 Ecora)	Public	Partial
Sea_Level_Rise_2019_NHC_Coastal_Flood_Extent	Surface	Northwest Hydraulic Consultants Ltd. For more information, please contact: Wil Hilsen, P.Geo. Associate Northwest Hydraulic Consultants 405 - 495 Dunsmuir Street, Nanaimo, BC, V9R 6B9 tel. (250) 754-6425 email. whilsen@nhcweb.com	Sea Level Rise - Coastal Flood Extent (2019 NHC)	Public	Partial
Floodplain_2020_Shawnigan_Inundation_Extents	Surface	Northwest Hydraulic Consultants	Shawnigan Lake Flood Preparedness Monitoring Project (2020)	Public	Partial
Floodplain_2020_Shawnigan_Flood_Construction_Levels	Surface	Northwest Hydraulic Consultants	Shawnigan Lake Flood Preparedness Monitoring Project (2020)	Public	Partial
Freshwater_Atlas_Assessment_Watersheds	Surface	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
Freshwater_Atlas_Watershed_Groups	Surface	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
Freshwater_Atlas_Wetlands	Surface	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
Freshwater_Atlas_Islands	Surface	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
Marine_Ecosections_no_islands	Surface	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
Freshwater_Atlas_Stream_Network	Surface	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full

Layer Name	Category	Credits	Report	Access	Coverage
Freshwater_Atlas_Rivers	Surface	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
Freshwater_Atlas_Lakes	Surface	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, GeoBC		Public	Full
CVRD_Selected_Watershed_Planning_Areas	Surface	CVRD Environment Division		Public	Full
SlopeHaz	Topography	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
Slope_Cons	Topography	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
Slope_Risk	Topography	SNC Lavalin Inc., Cowichan Valley Regional District	Watersheds Risk Analysis (2019)	Internal CVRD	Partial
DEM_LEV21	Topography	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
HILLSHADE1	Topography	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
Topo_30y	Topography	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
SlpRaster_30y	Topography	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial
Contours_50m	Topography	SLR Consulting Ltd.	Preliminary Groundwater Budgets (2017)	Internal CVRD	Partial

Appendix C: Maps





Air Temperature Sites
Legend
Active Temperature Site
Inactive Temperature Site
Inactive Temperature Site (Observations Before 1970)
Streams and Rivers (Stream Order >1)
CVRD Watershed Planning Areas
Lakes
Ocean
Annual Mean of Monthly Maximum Daily Temperature (°C)
14.7
6.4
0 2.5 5 10 15 20
Kilometers
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Created By: Rachel Plewes
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NAD 1983 UTM Zone 10N
MacHydro
Clear Viz Aquatic Consulting
N
Brannen Lake
Nanaimo Lakes
Nanaimo Lakes
Nanaimo River
Fourth Lake
Jump Lake
Quennell Lake
Yellow Point Benchlands
Strait of Georgia
Gulf Islands
Ladysmith - Saltair Benchlands
Bush Creek
Holland Creek
Stocking Creek
Chemainus Benchlands
Chemainus River
St. Mary Lake
Bonsall Creek
Sansum Narrows - Cowichan Bay Benchlands
Quamichan Lake
Sarita Lake
Nitinat River
Cowichan Lake
Cowichan River
Gordon River
Hobiton Lake
Nitinat Lake
Squalicum Lake
Tsusiat Lake
Doobah Lake
Cheewhat Lake
Carmanah - Walbran
San Juan River
Koksilah River
Satellite Channel Benchlands
Shawnigan Lake
Shawnigan Creek
Malahat Benchlands
Sooke Lake
Vancouver Island Shelf
Juan de Fuca Strait
370000
380000
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400000
410000
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430000
440000
450000
460000
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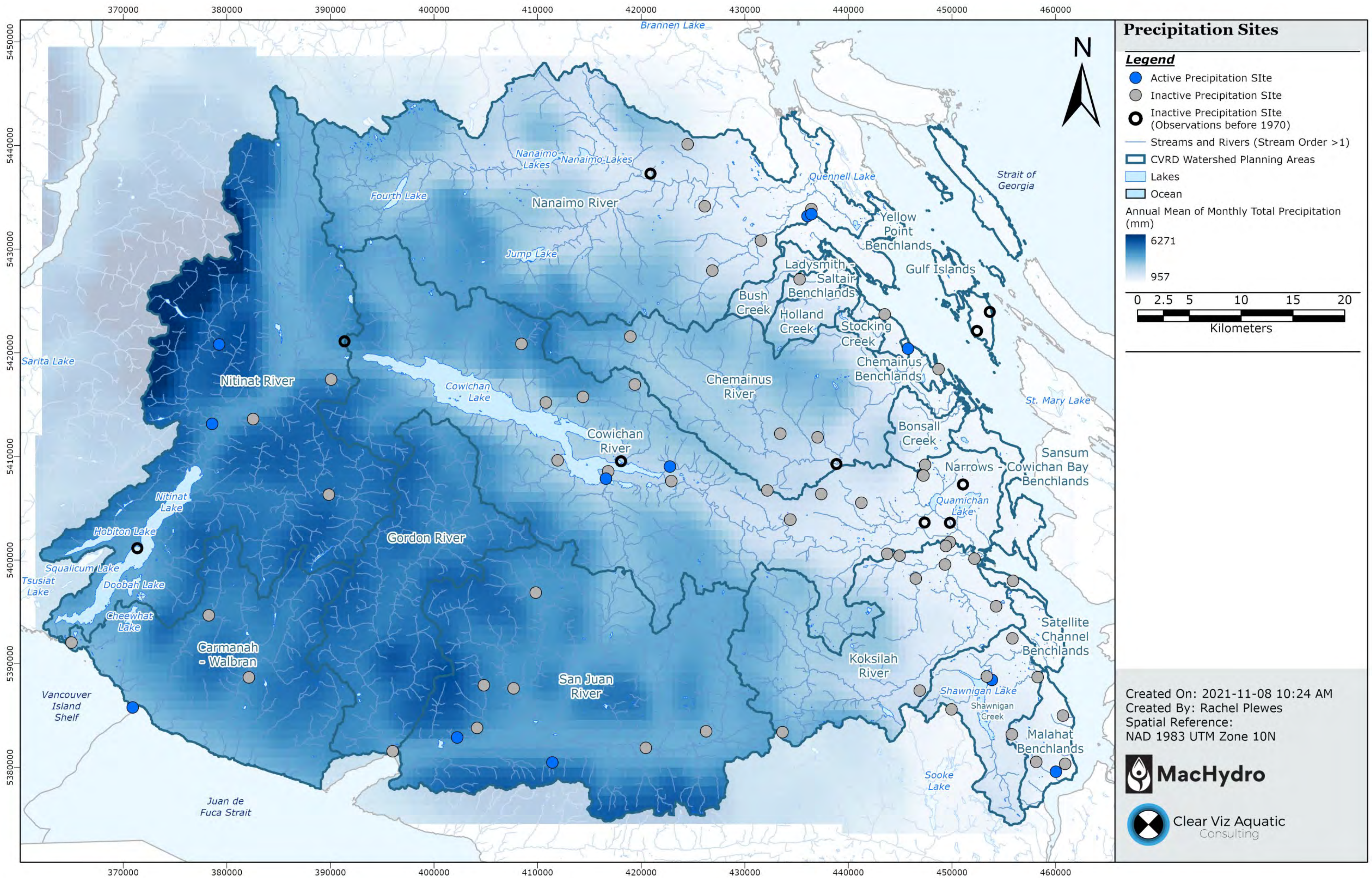
5410000
5400000
5390000
5380000


Precipitation Sites
Legend
Active Precipitation SIte
Inactive Precipitation SIte
Inactive Precipitation SIte (Observations before 1970)
Streams and Rivers (Stream Order >1)
CVRD Watershed Planning Areas
Lakes
Ocean
Annual Mean of Monthly Total Precipitation (mm)
6271
957
0 2.5 5 10 15 20
Kilometers
N
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Created By: Rachel Plewes
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MacHydro
Clear Viz Aquatic Consulting
370000
380000
390000
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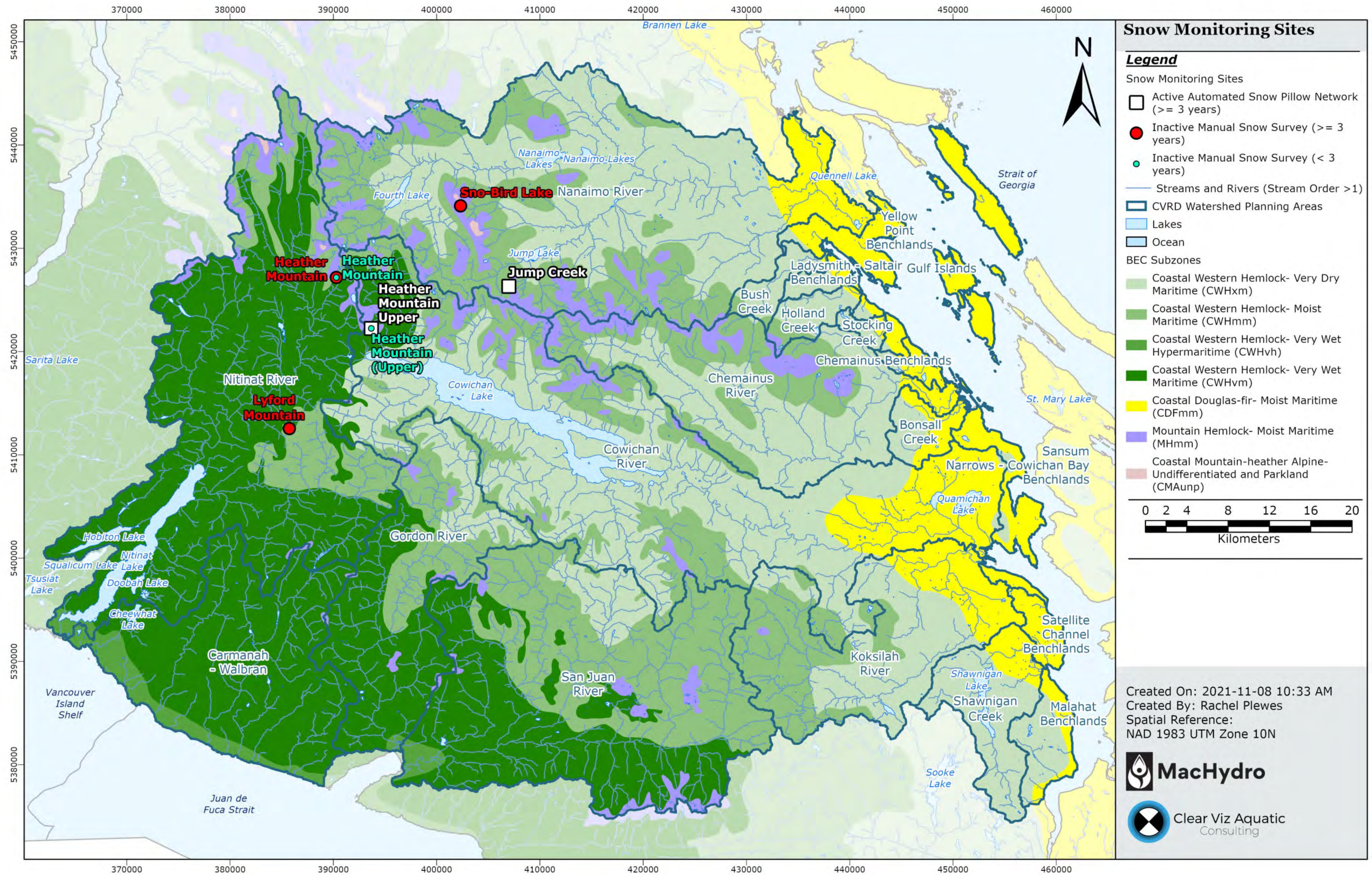
410000
420000
430000
440000
450000
460000
5450000
5440000
5430000
5420000
5410000
5400000
5390000
5380000
Brannen Lake
Nanaimo Lakes
Nanaimo Lakes
Fourth Lake
Nanaimo River
Jump Lake
Quennell Lake
Strait of Georgia
Yellow Point Benchlands
Ladysmith - Saltair Benchlands
Gulf Islands
Bush Creek
Holland Creek
Stocking Creek
Chemainus Benchlands
Chemainus River
Sarita Lake
Nitinat River
Cowichan Lake
Cowichan River
St. Mary Lake
Bonsall Creek
Sansum Narrows - Cowichan Bay Benchlands
Quamichan Lake
Nitinat Lake
Hobiton Lake
Gordon River
Squalicum Lake
Tsusiat Lake
Doobah Lake
Cheewhat Lake
Carmanah - Walbran
Satellite Channel Benchlands
Koksilah River
San Juan River
Shawnigan Lake
Shawnigan Creek
Malahat Benchlands
Vancouver Island Shelf
Sooke Lake
Juan de Fuca Strait



Snow Monitoring Sites
Legend
Snow Monitoring Sites
Active Automated Snow Pillow Network (>= 3 years)
Inactive Manual Snow Survey (>= 3 years)
Inactive Manual Snow Survey (< 3 years)
Streams and Rivers (Stream Order >1)
CVRD Watershed Planning Areas
Lakes
Ocean
BEC Subzones
Coastal Western Hemlock- Very Dry Maritime (CWHxm)
Coastal Western Hemlock- Moist Maritime (CWHmm)
Coastal Western Hemlock- Very Wet Hypermaritime (CWHvh)
Coastal Western Hemlock- Very Wet Maritime (CWHvm)
Coastal Douglas-fir- Moist Maritime (CDFmm)
Mountain Hemlock- Moist Maritime (MHmm)
Coastal Mountain-heather Alpine- Undifferentiated and Parkland (CMAunp)
0 2 4 8 12 16 20
Kilometers
Created On: 2021-11-08 10:33 AM
Created By: Rachel Plewes
Spatial Reference:
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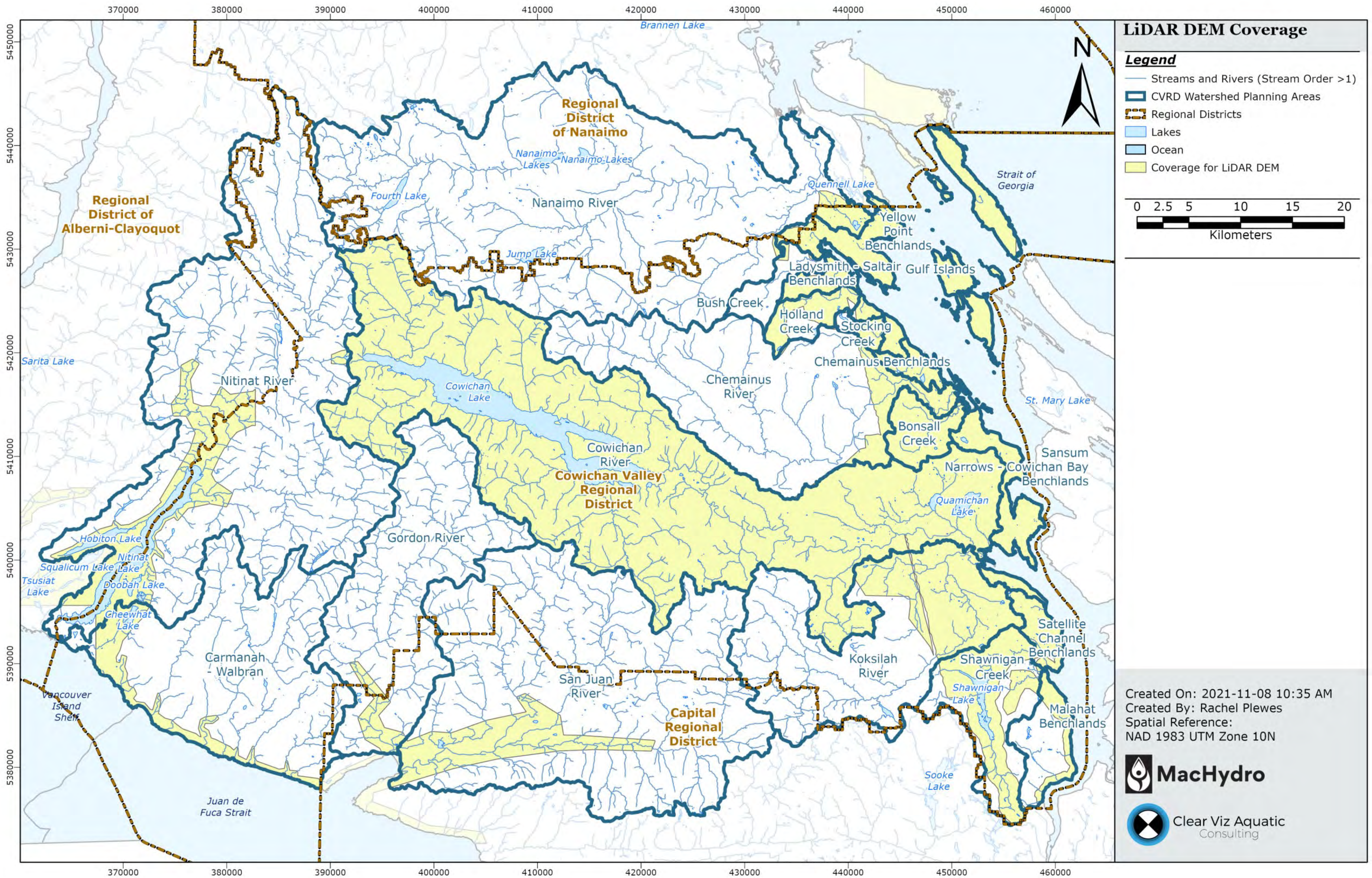
MacHydro
Clear Viz Aquatic Consulting
N
Sno-Bird Lake
Heather Mountain
Heather Mountain
Heather Mountain Upper
Heather Mountain (Upper)
Jump Creek
Lyford Mountain
Nanaimo River
Nitinat River
Gordon River
Carmanah - Walbran
San Juan River
Cowichan River
Chemainus River
Koksilah River
Shawnigan Creek
Bush Creek
Holland Creek
Stocking Creek
Bonsall Creek
Ladysmith - Saltair Benchlands
Yellow Point Benchlands
Gulf Islands
Chemainus Benchlands
Narrows - Cowichan Bay Benchlands
Sansum
Satellite Channel Benchlands
Malahat Benchlands
Strait of Georgia
Juan de Fuca Strait
Vancouver Island Shelf
Brannen Lake
Nanaimo Lakes
Fourth Lake
Jump Lake
Quennell Lake
Cowichan Lake
Sarita Lake
Hobiton Lake
Nitinat Lake
Squalicum Lake
Tsusiat Lake
Doobah Lake
Cheewhat Lake
St. Mary Lake
Quamichan Lake
Shawnigan Lake
Sooke Lake
370000 380000 390000 400000 410000 420000 430000 440000 450000 460000
5450000 5440000 5430000 5420000 5410000 5400000 5390000 5380000



LiDAR DEM Coverage
Legend
Streams and Rivers (Stream Order >1)
CVRD Watershed Planning Areas
Regional Districts
Lakes
Ocean
Coverage for LiDAR DEM
0 2.5 5 10 15 20
Kilometers
N
Created On: 2021-11-08 10:35 AM
Created By: Rachel Plewes
Spatial Reference:
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MacHydro
Clear Viz Aquatic Consulting
Regional District of Nanaimo
Regional District of Alberni-Clayoquot
Cowichan Valley Regional District
Capital Regional District
Nanaimo River
Nitinat River
Cowichan River
Chemainus River
Gordon River
Carmanah - Walbran
San Juan River
Koksilah River
Bush Creek
Holland Creek
Stocking Creek
Bonsall Creek
Shawnigan Creek
Yellow Point Benchlands
Ladysmith - Saltair Benchlands
Gulf Islands
Chemainus Benchlands
Narrows - Cowichan Bay Benchlands
Sansum
Satellite Channel Benchlands
Malahat Benchlands
Brannen Lake
Nanaimo Lakes
Fourth Lake
Jump Lake
Quennell Lake
Strait of Georgia
Sarita Lake
Cowichan Lake
St. Mary Lake
Quamichan Lake
Hobiton Lake
Nitinat Lake
Squalicum Lake
Tsusiat Lake
Doobah Lake
Cheewhat Lake
Shawnigan Lake
Sooke Lake
Vancouver Island Shelf
Juan de Fuca Strait
370000 380000 390000 400000 410000 420000 430000 440000 450000 460000
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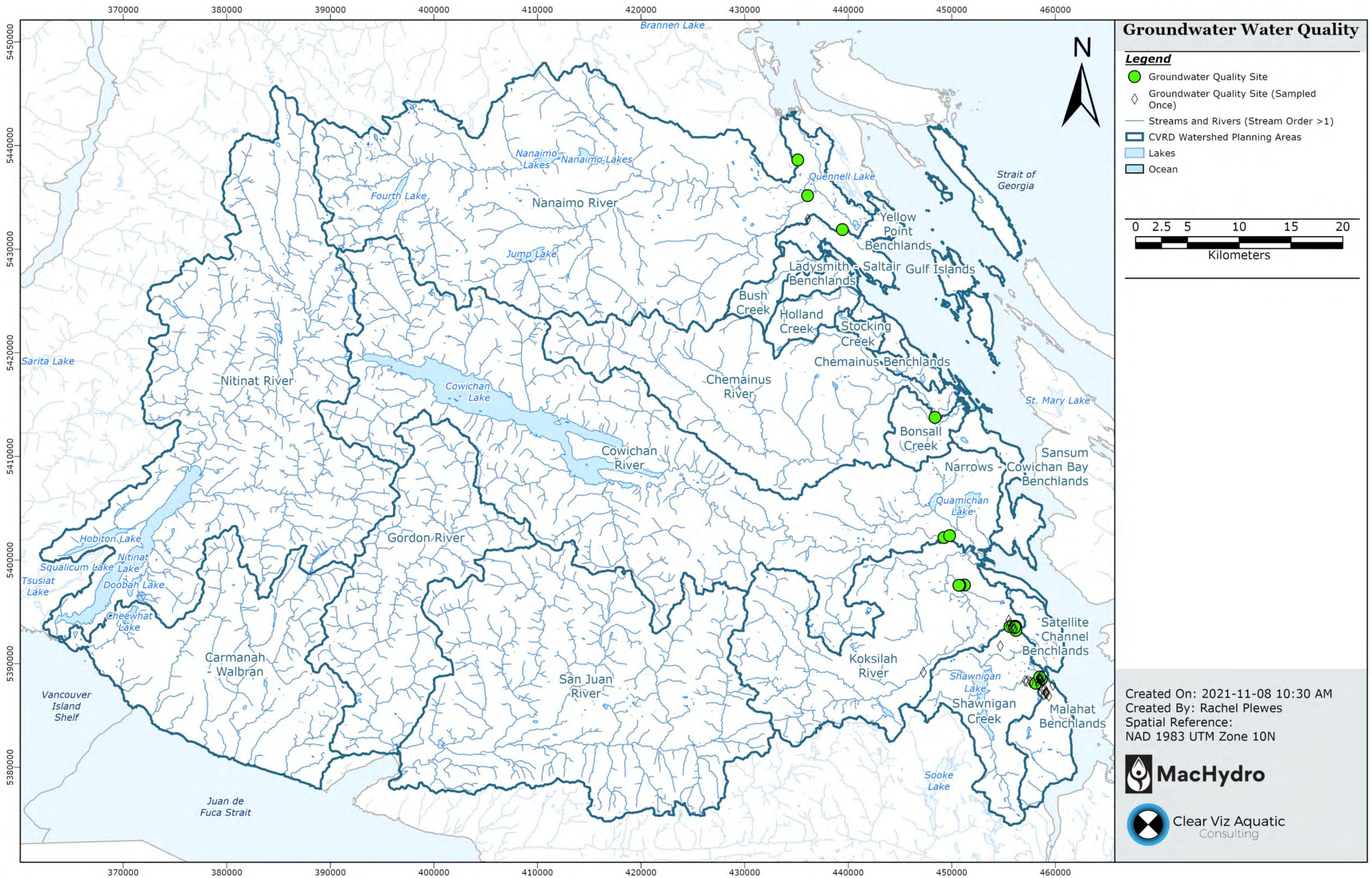

Groundwater Water Quality
Legend
Groundwater Quality Site
Groundwater Quality Site (Sampled Once)
Streams and Rivers (Stream Order >1)
CVRD Watershed Planning Areas
Lakes
Ocean
0 2.5 5 10 15 20
Kilometers
Created On: 2021-11-08 10:30 AM
Created By: Rachel Plewes
Spatial Reference:
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MacHydro
Clear Viz Aquatic Consulting
N
Brannen Lake
Nanaimo Lakes
Nanaimo Lakes
Fourth Lake
Nanaimo River
Jump Lake
Quennell Lake
Yellow Point Benchlands
Ladysmith - Saltair Benchlands
Gulf Islands
Strait of Georgia
Bush Creek
Holland Creek
Stocking Creek
Chemainus Benchlands
Chemainus River
Sarita Lake
Nitinat River
Cowichan Lake
Cowichan River
St. Mary Lake
Bonsall Creek
Narrows - Cowichan Bay Benchlands
Sansum
Quamichan Lake
Gordon River
Hobiton Lake
Nitinat Lake
Squalicum Lake
Tsusiat Lake
Doobah Lake
Cheewhat Lake
Satellite Channel Benchlands
Carmanah - Walbran
San Juan River
Koksilah River
Shawnigan Lake
Shawnigan Creek
Malahat Benchlands
Vancouver Island Shelf
Sooke Lake
Juan de Fuca Strait
370000 380000 390000 400000 410000 420000 430000 440000 450000 460000
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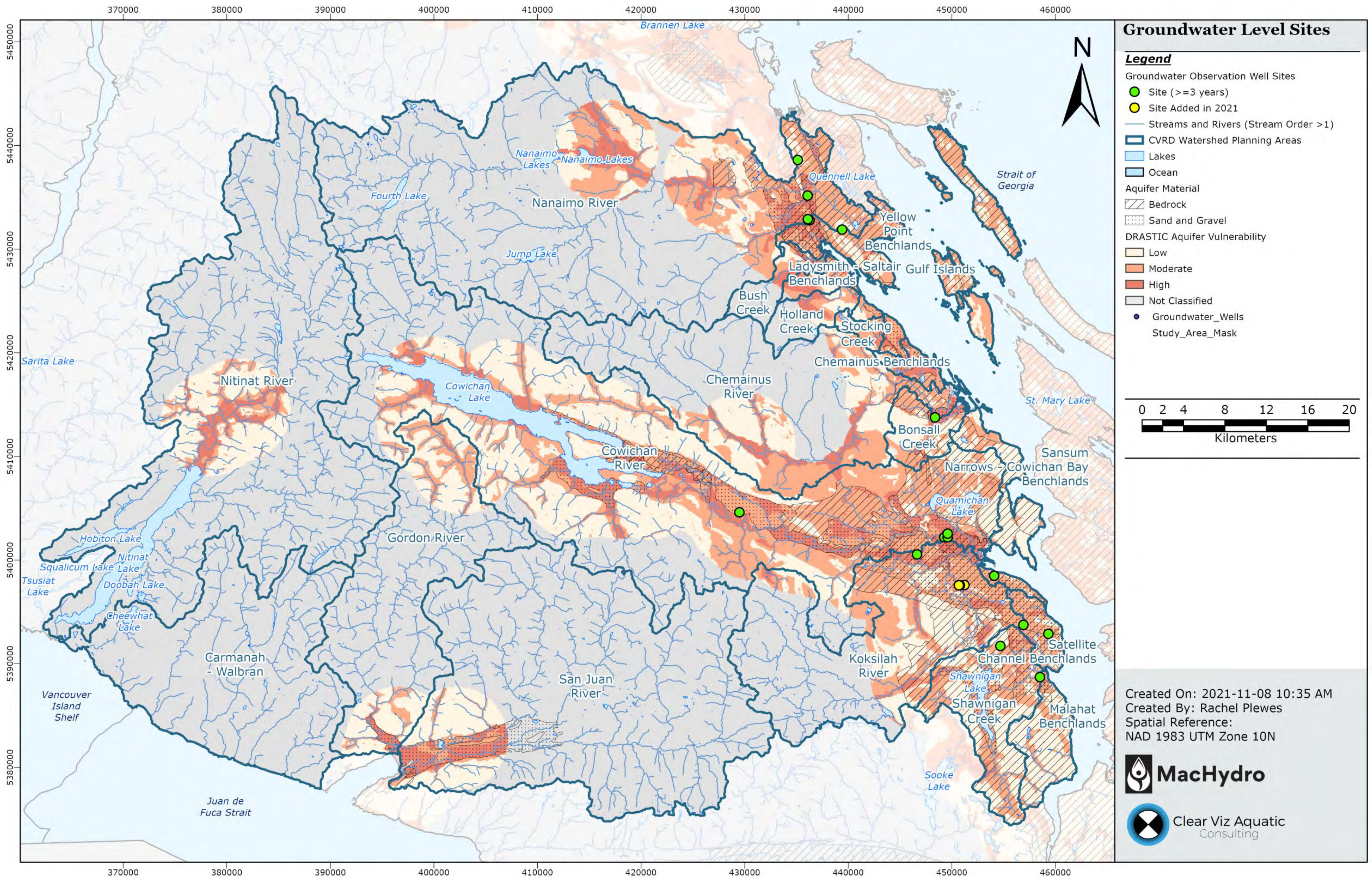

Groundwater Level Sites
Legend
Groundwater Observation Well Sites
Site (>=3 years)
Site Added in 2021
Streams and Rivers (Stream Order >1)
CVRD Watershed Planning Areas
Lakes
Ocean
Aquifer Material
Bedrock
Sand and Gravel
DRASTIC Aquifer Vulnerability
Low
Moderate
High
Not Classified
Groundwater_Wells
Study_Area_Mask
0 2 4 8 12 16 20
Kilometers
Created On: 2021-11-08 10:35 AM
Created By: Rachel Plewes
Spatial Reference:
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MacHydro
Clear Viz Aquatic Consulting
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Brannen Lake
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Nanaimo Lakes
Quennell Lake
Strait of Georgia
Fourth Lake
Nanaimo River
Yellow Point Benchlands
Jump Lake
Ladysmith - Saltair Benchlands
Gulf Islands
Bush Creek
Holland Creek
Stocking Creek
Chemainus Benchlands
Sarita Lake
Nitinat River
Cowichan Lake
Chemainus River
St. Mary Lake
Bonsall Creek
Cowichan River
Sansum Narrows - Cowichan Bay Benchlands
Quamichan Lake
Hobiton Lake
Gordon River
Nitinat Lake
Squalicum Lake
Tsusiat Lake
Doobah Lake
Cheewhat Lake
Satellite Channel Benchlands
Carmanah - Walbran
Koksilah River
San Juan River
Shawnigan Lake
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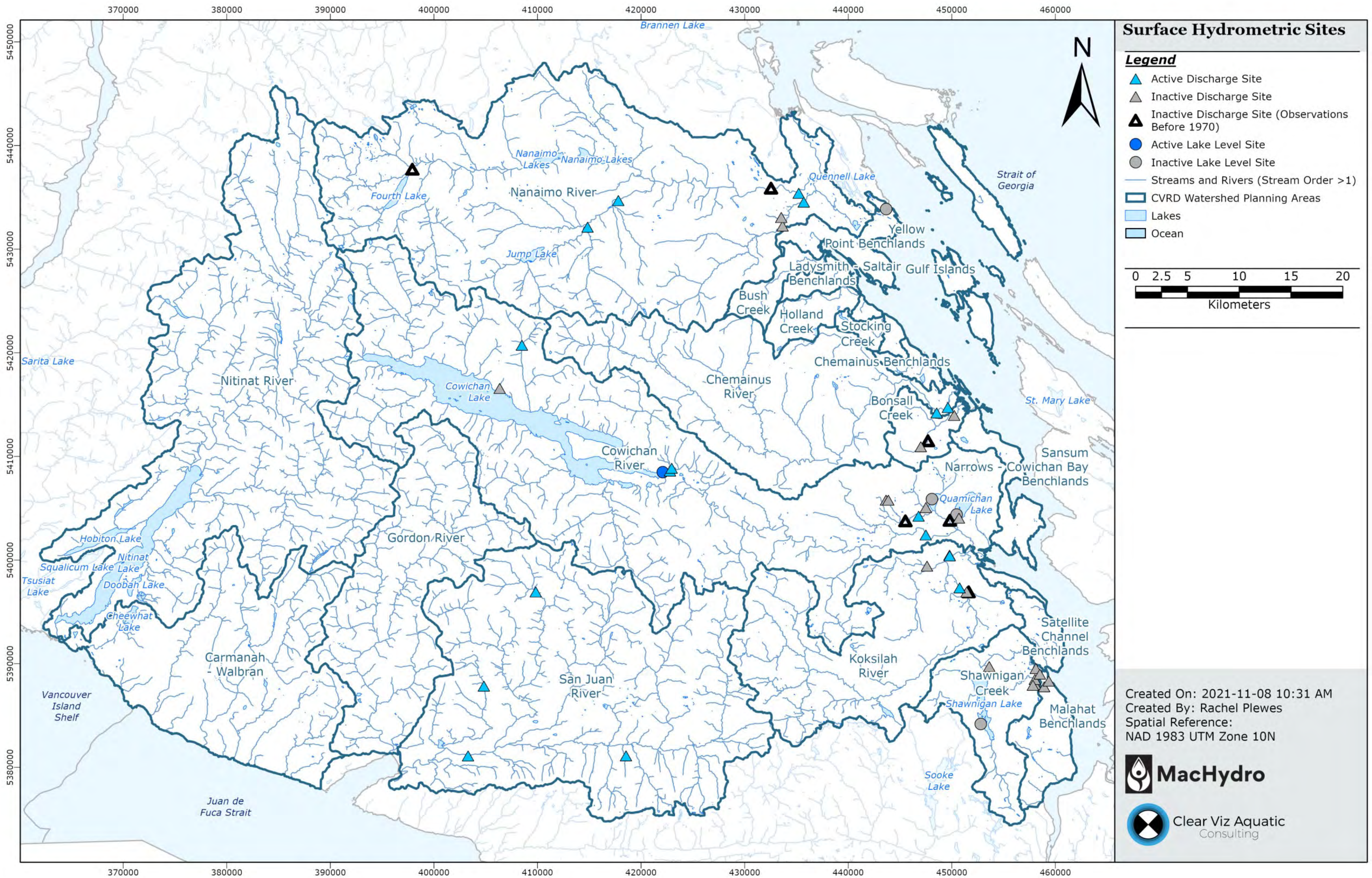
Vancouver Island Shelf
Sooke Lake
Juan de Fuca Strait


Surface Hydrometric Sites
Legend
Active Discharge Site
Inactive Discharge Site
Inactive Discharge Site (Observations Before 1970)
Active Lake Level Site
Inactive Lake Level Site
Streams and Rivers (Stream Order >1)
CVRD Watershed Planning Areas
Lakes
Ocean
0 2.5 5 10 15 20
Kilometers
N
Created On: 2021-11-08 10:31 AM
Created By: Rachel Plewes
Spatial Reference:
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MacHydro
Clear Viz Aquatic Consulting
370000 380000 390000 400000 410000 420000 430000 440000 450000 460000
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Brannen Lake
Nanaimo Lakes
Nanaimo Lakes
Fourth Lake
Nanaimo River
Quennell Lake
Strait of Georgia
Yellow Point Benchlands
Jump Lake
Ladysmith - Saltair Benchlands
Gulf Islands
Bush Creek
Holland Creek
Stocking Creek
Chemainus Benchlands
Sarita Lake
Nitinat River
Cowichan Lake
Chemainus River
Bonsall Creek
St. Mary Lake
Cowichan River
Sansum Narrows
Cowichan Bay Benchlands
Quamichan Lake
Hobiton Lake
Gordon River
Nitinat Lake
Squalicum Lake
Tsusiat Lake
Doobah Lake
Cheewhat Lake
Satellite Channel Benchlands
Carmanah - Walbran
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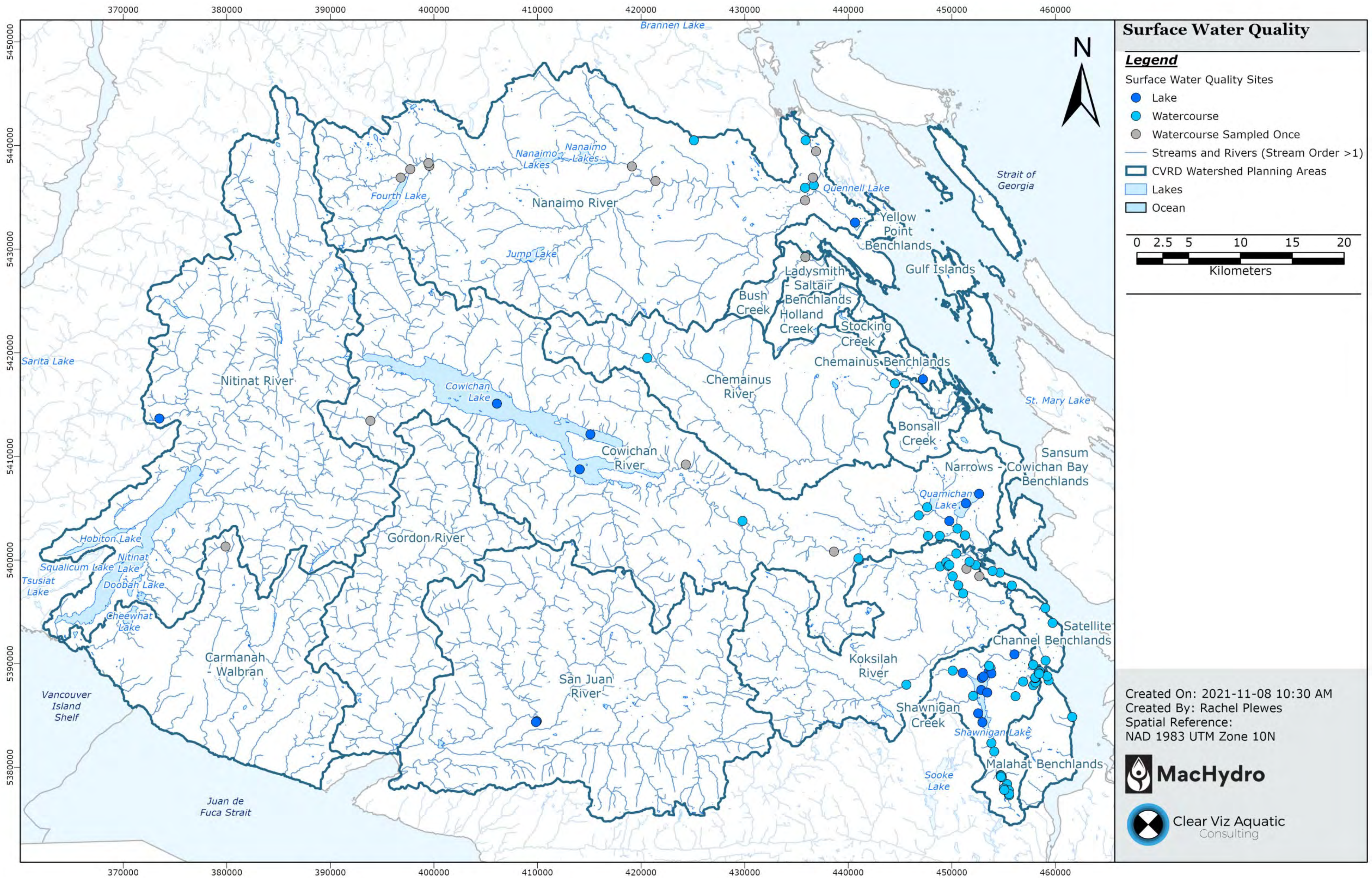
San Juan River
Shawnigan Creek
Shawnigan Lake
Malahat Benchlands
Vancouver Island Shelf
Sooke Lake
Juan de Fuca Strait



Surface Water Quality
Legend
Surface Water Quality Sites
Lake
Watercourse
Watercourse Sampled Once
Streams and Rivers (Stream Order >1)
CVRD Watershed Planning Areas
Lakes
Ocean
0 2.5 5 10 15 20
Kilometers
Created On: 2021-11-08 10:30 AM
Created By: Rachel Plewes
Spatial Reference:
NAD 1983 UTM Zone 10N
MacHydro
Clear Viz Aquatic Consulting
N
Brannen Lake
Nanaimo Lakes
Nanaimo Lakes
Fourth Lake
Nanaimo River
Jump Lake
Quennell Lake
Yellow Point Benchlands
Strait of Georgia
Gulf Islands
Ladysmith - Saltair Benchlands
Bush Creek
Holland Creek
Stocking Creek
Chemainus Benchlands
Chemainus River
St. Mary Lake
Sarita Lake
Nitinat River
Cowichan Lake
Cowichan River
Bonsall Creek
Sansum Narrows - Cowichan Bay Benchlands
Quamichan Lake
Gordon River
Hobiton Lake
Nitinat Lake
Squalicum Lake
Tsusiat Lake
Doobah Lake
Cheewhat Lake
Satellite Channel Benchlands
Carmanah - Walbran
Koksilah River
San Juan River
Vancouver Island Shelf
Shawnigan Creek
Shawnigan Lake
Malahat Benchlands
Sooke Lake
Juan de Fuca Strait
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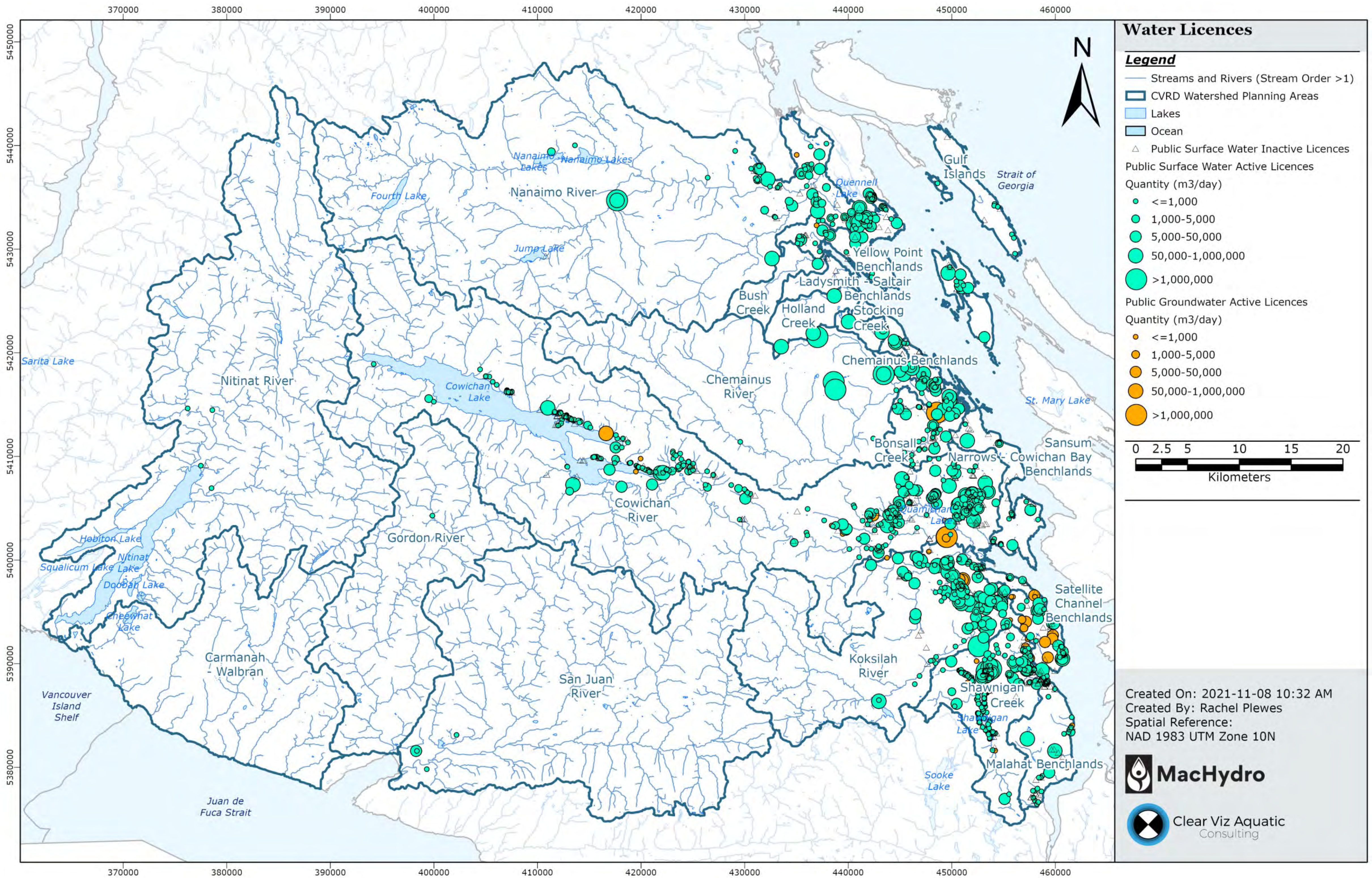

Water Licences
Legend
Streams and Rivers (Stream Order >1)
CVRD Watershed Planning Areas
Lakes
Ocean
Public Surface Water Inactive Licences
Public Surface Water Active Licences
Quantity (m3/day)
<=1,000
1,000-5,000
5,000-50,000
50,000-1,000,000
>1,000,000
Public Groundwater Active Licences
Quantity (m3/day)
<=1,000
1,000-5,000
5,000-50,000
50,000-1,000,000
>1,000,000
0 2.5 5 10 15 20
Kilometers
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Created By: Rachel Plewes
Spatial Reference:
NAD 1983 UTM Zone 10N
MacHydro
Clear Viz Aquatic Consulting
370000 380000 390000 400000 410000 420000 430000 440000 450000 460000
5450000 5440000 5430000 5420000 5410000 5400000 5390000 5380000
Nanaimo River
Nanaimo Lakes
Fourth Lake
Jump Lake
Quennell Lake
Gulf Islands
Strait of Georgia
Yellow Point Benchlands
Ladysmith - Saltair Benchlands
Bush Creek
Holland Creek
Stocking Creek
Chemainus Benchlands
Chemainus River
Sarita Lake
Nitinat River
Cowichan Lake
St. Mary Lake
Sansum Narrows
Cowichan Bay Benchlands
Bonsall Creek
Cowichan River
Quamichan Lake
Gordon River
Hobiton Lake
Nitinat Lake
Squalicum Lake
Doobah Lake
Cheewhat Lake
Satellite Channel Benchlands
Carmanah - Walbran
Koksilah River
San Juan River
Shawnigan Creek
Shawnigan Lake
Vancouver Island Shelf
Malahat Benchlands
Sooke Lake
Juan de Fuca Strait

Appendix B

Phase 2 Memo – Data Management Strategies

Final Memo - Data Management Strategies

Phase 2, Development of a Regional Hydrometric and Climatic Monitoring Strategy and Workplan for Cowichan Valley Regional District

2022.05.18

Prepared For:

Cowichan Valley Regional District

MacHydro FOUNDRY SPATIAL

Executive Summary

The Cowichan Valley Regional District delivers a Drinking Water and Watershed Protection Program to serve the needs of member municipalities and residents of the district. The goals and the objectives of the program are well described as a vision of 'One Water', with a series of areas of focus and associated actions to progress knowledge and awareness of the water resources of the region. Ultimately the objectives of the program are to ensure that sufficient drinking water is available to residents, and that healthy watersheds sustain ecosystems and provide clean and safe environments for recreation.

Core to achieving these objectives are data and knowledge describing the characteristics of water resources in the region. Environmental monitoring data collected from streams, lakes, rivers and aquifers, combined with weather data describing precipitation, air temperature, snow and other variables, have been collected by all levels of government, industry, academia, community groups and other stakeholders, but are scattered across different agencies and systems. Streamlined access to these data for regional and local government staff in the District, can support enhanced awareness and provide data for operational decision making. Integrating data describing different aspects of the water cycle, to produce water balance models creates enhanced knowledge for more complex decisions, but these models and other analytical outputs need clear and simple slices of information which can be easily extracted and used. This will support widespread adoption into planning, public engagement, or other initiatives that benefit from broad participation by stakeholders who may not have the technical expertise, or interest to engage with highly complex scientific information.

Modern data management systems can easily collect, store, and disseminate data, harvesting from other data systems, and/or directly from environmental sensors operated independently. Further distribution of data via APIs and other techniques, including data portals, allows others to easily consume data for further analysis. Authenticated internal staff users can access data directly from these systems, while access control policies can dictate which data is sensitive and only for internal use, and which data is suitable for public distribution. Similarly, knowledge products and systems can be developed in conjunction with data management systems, to support applied use of knowledge, supported by metrics derived from the raw data.

This memo comprises recommendations made by Foundry Spatial, as part of a consulting team led by MacDonald Hydrology Consultants, delivering the *Development of a Regional Hydrometric and Climatic Monitoring Strategy and Implementation Workplan* project for the Cowichan Valley Regional District. Our understanding of the context, options and recommendations are described herein.

Setting

The Cowichan Valley Regional District (CVRD) is located on southern Vancouver Island, and stretches from the west to east coast of the island, north of the Capital Regional District. The CVRD contains several communities, the largest of which is Duncan, located on the Cowichan River near its outlet to Cowichan Bay. Major watersheds in the region are drained by the Cowichan, Chemainus, and Koksilah Rivers, with numerous smaller watersheds interspersed. The larger rivers typically are more diverse in elevation and climate, from low elevation Mediterranean climates in the east to high elevations in the center of the island that receive substantial accumulations of snow and rain on an annual basis. Within the more populated parts of the CVRD region along the eastern side of Vancouver Island, supply and demand pressures vary as a result of the water balance and budget within each water supply area. As a result, during times of drought the risk and impact of shortages are not evenly distributed.

Hydrometric and Climate Monitoring Data

Specific target datasets are described more fully in Memo 1 provided to the CVRD, but the main and common characteristics of these data are that they primarily represent observations collected at points in time, at specific locations on the landscape. These data are often characterized as 'time-series' data but the frequency of collection (from discrete, irregular measurements, to regularly defined intervals such as every 15 minutes or every hour) may vary substantially. Similarly, the time period represented by data collected may differ - historical observations are more widely distributed across the landscape than the coverage provided by monitoring programs or sensors operating presently.

Data exists from a range of sources external to the CVRD organization. These include:

- Member municipalities
- Provincial government agencies
- Federal government agencies
- Academia
- Non-government organizations
- Community groups
- Industry
- Indigenous Communities

The CVRD also collects data independently, typically with the support of environmental or engineering consultants.

As part of the present project, a gap analysis is being conducted amongst the currently available data, to identify and prioritize the location and type of new data recommended to be collected, focusing on hydrometric and climatic monitoring, to understand primarily water-related issues across the district.

Where possible, the CVRD wishes to collaborate with other government agencies in efforts to leverage pre-existing investments in data management systems. The CVRD does not desire to duplicate data management efforts, maintain other organizations data collection and management systems, or support ongoing monitoring conducted by other organizations (aside from situations where the CVRD receives value from data collected by other organizations). It does want to align new investments in data collection with other organizations, to find mutually beneficial outcomes such as collaborative decision-making about the location and parameters to be observed of new efforts. The CVRD also wants to have access to a combined knowledge base of information on historical and current hydrologic and climatic conditions in the district to support operational and planning efforts. This requires access to raw data. Simply accessing the uninterpreted raw data will not fully achieve these goals but will support future efforts to create analytical or interpreted products from the raw data, such as water balance models and water budgets, and then these information products will need to be connected to end users.

In order to effectively (and efficiently) use environmental data, either for interpretation of raw data values or for the creation of interpreted products, friction must be reduced in the data acquisition process. Traditional practices often account for substantial contributions of resources towards manual, repetitive data collection from various sources, a process which must be done continuously to ensure that the latest data is available. Recent advances in computing have seen improved availability of re-usable packages in the R programming language, to facilitate data access and basic analysis, but the requisite skills to use these packages (and meaningfully conduct appropriate analyses) are not widely available in the workplace. They also regularly do not meet the needs of non-scientists who are often looking for interpreted products rather than the results of scientific calculations. In most cases analysis or modeling products result in production of a static report summarizing the effort; often models can only be operated by the modelers who built them. This disconnect limits the utility of the research and insight contained within the work products, but can be overcome with careful planning, and consideration of intended use cases and how data collection, analysis, reporting and communication of intelligence can support the use cases.

Data Collection in the CVRD

For most monitoring initiatives which the CVRD participates in, data collection, processing and QA are conducted by specialized engineering or environmental consultants. The CVRD provides input into the location and parameters to be monitored but then acts as consumers of the data - often the same types of data are collected by other levels of government (at different locations) and the CVRD efforts are directed at filling in gaps of knowledge or otherwise responding to issues within the district. Typically, these efforts are motivated by specific issues that occur in the district. When these issues are of broad interest to the community, in some cases CVRD may have easy access to data from the consultant to inform themselves internally on the issue at hand, but may not be able to easily provide transparent access to the same information to the interested public.

The CVRD is interested in continuing ongoing productive collaborations with government and non-government organizations that achieve mutual benefits such as leveraging funding and aligning new data collection locations and parameters towards mutually beneficial conditions. In these cases, and where the CVRD is in a supporting position and another agency manages the operation and collection of data, the CVRD must be able to easily incorporate these new data into their existing data systems; either by loading measurements collected from a targeted initiative after completion, or perhaps more valuably, connecting to data derived from live sensors on an ongoing basis.

To achieve these goals, the CVRD does not require for their normal activities, a data management system which provides the ability for technicians to perform QA or other data adjustment calculations on raw data collected by sensors. Until such time that the CVRD collects, processes, and manages field data collection programs internally, they can rely on the technology resources of consultants to provide them with appropriately quality assured and quality rated data products. The CVRD needs are primarily to have data close by for rapid retrieval and custom analysis, and for interpreted products based on the data to be readily accessible, which are easily distributed for consumption by the relevant parties (such as internal planning staff, or in selected cases, public users). These distribution methods should be digital, consistently updated, and simple to use to maximize their reach.

Technology Systems

Technology systems play a critical role in helping people collect, store, understand, and communicate information for a range of applications. In the context of hydrometric and climatic monitoring, technology systems can include information systems, broadly defined as those which support the collection, storage, processing, and dissemination of information. Information systems can include data management systems, geographic information systems, modeling systems, or decision support systems (among others) . The important characteristic of each, is the structured and repurposable components which can be used and applied across a broad range of applications.

For example, MODFLOW is a numerical groundwater modeling package useful for performing hydrogeologic evaluations. Within MODFLOW, there are a set of reusable packages to represent components of groundwater systems. These components can be assembled by an expert user, in combination with a range of data sources, and used to report on specific aspects of a groundwater system.

These data sources may include GIS systems that provide the location of streams, aquifers, geology, or other characteristics of the landscape. These data sources may also include data management systems that collect and store time series observations of streamflow or groundwater levels. Often, live connections will not exist between the source systems and modeling packages, as calibration and parameterization of the models requires expert judgment of the modeler.

Once the model is complete, the modeler may produce tabular or graphical summaries of model findings at specific locations. In some cases these results may be connected to decision support systems, to allow for end users to retrieve model derived intelligence for their decision-making purposes.

Data-driven decision-making is a core objective of many organizations, but remains an emerging field in practice, due to the inherent complexities embedded organizationally and technologically with existing systems and practices. It requires clear connections from source data through to the dissemination of interpreted products which often presents challenges where this requires cross-cutting of organizational departments or collaboration with external entities. When these challenges are acknowledged and addressed from the outset, with careful planning the desired outcomes can be achieved.

CVRD Users and Use Cases

The primary internal users of hydrometric and climatic data, and interpreted information products are expected to be found within the planning, utilities, and environmental departments. They may desire to know the status of current conditions within the CVRD, short or long term records of historical measurements, how current conditions fit within expected variability, and seasonal or inter-annual trends in certain characteristics. This information could be used for both operational and long-term planning.

Interpreted products which may be produced from these data could include custom analysis and associated static reports, analytical models and associated reports. Data and/or interpreted products may also contribute to broader products and initiatives such as watershed management plans, or other administrative focused plans produced by local or regional government agencies.

> "A point in every direction is the same as having no point at all." - *Harry Nilsson.*

Use cases are often used in systems development to create narratives that drive the definition of functional requirements of the system to be implemented. These narratives are then used to evaluate the success of the system after it is developed; does it do what it set out to do.

A huge number of potential use cases for applying intelligence derived from hydrometric and climatic monitoring data exist within the CVRD. In collaboration with CVRD staff, a selection of use cases were identified which describe how hydrometric and climatic data or interpreted products could be applied in the region. The two main thematic areas were in support of land use planning, and in support of water utility operations.

Use Case 1: Support Environmental Planners evaluate water supply

- New subdivisions
- Mid-long term community planning

Use Case 2: Track conditions in aquifers and streams/rivers which supply water to utilities

- Current conditions in historical context
- Trends
- Thresholds

Use Case 3: Communicate current environmental conditions (drought / flood)

- ‘How are flows in Shawnigan Creek doing this year?’
- ‘Is the Chemainus River at the 50 year flood level?’

These use cases are not suggested to be the only use cases which exist; a fulsome exploration of use cases for public and/or external government agencies was not conducted as part of this work. Regardless, the CVRD should not aim to address all use cases, as this would expand the complexity of the objective to the degree that the chance of success in addressing any individual use case effectively, would be at risk. The three use cases listed above are believed to be indicative of the types of functions where hydrometric and climatic data and interpreted products could be used, and their implications for system requirements for data management should provide a solid foundation for most other use cases.

System Recommendations

Based on our current understanding of the needs of the CVRD, we recommend development and implementation of an open-source technology system, to collect and store the variety of environmental monitoring data available within the CVRD, support access to this data from other internal systems such as GIS or other desktop applications, and provide the ability to consume the data from this system in public facing or internal web-tools.

Foundry Spatial's Intelligent Watershed Management Suite (IWMS) provides reusable design patterns to achieve these goals, leveraging PostgreSQL and PostGIS enabled databases in conjunction with data acquisition scripts to harvest and ingest data into the database, and API gateways to support integration with other internal systems, serve data to internal CVRD staff and integrate data into public facing websites. The IWMS presently harvests climatic, hydrometric, and other related data from dozens of data sources within the CVRD. These data would become immediately available upon implementation. An example data model used for storing hydrometric and climatic data is shown in Figure 1.

The IWMS was initially developed to support web-based visualization and reporting of environmental monitoring data, and includes web-facing module to support the delivery of analytics derived from monitoring data, as well as decision-support components that perform functions including water supply and demand analysis, water use reporting, surface water and groundwater interactions, and equivalent clearcut area, amongst others. These functional components have been developed to address specific use cases in western Canada and California, and show the flexibility in which the system can be further extended. More information can be found on Foundry Spatial's website (https://foundryspatial.com/) and example implementations can be found on the BC Water Tool website (https://www.bcwatertool.ca/).

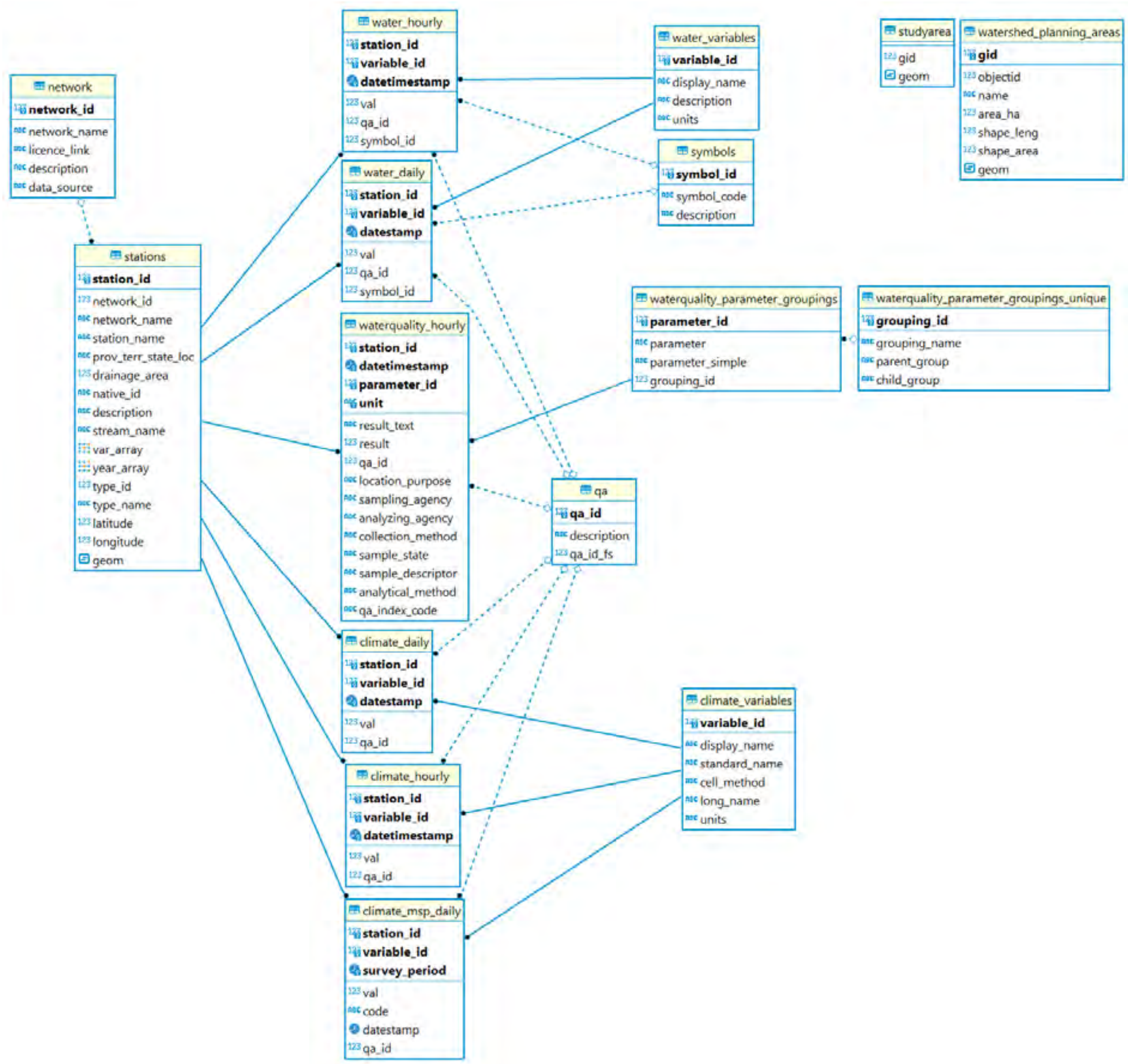

Figure 1. Entity-Relationship Diagram showing database tables for hydrometric and climatic data

Historical data can be bulk uploaded directly into the database, and data upload gateways can be deployed to support ongoing incorporation of project related monitoring data that may become available. New data acquisition scripts can be deployed to harvest data from third-party systems actively collecting real-time data, being delivered through Aquarius web-portals or other distribution methods.

For data owned by the CVRD (for example, collected by consultants on CVRD behalf), data can be delivered through the system to public repositories as desired. This could include data flows into the real-time water data Aquarius repository maintained by the BC Ministry of Environment (for hydrometric, groundwater level, and snow data) or into the cooperative Climate Related Monitoring Program (if formal participation in the collaborative was of interest to CVRD). If so desired, the CVRD could also provision their own data portal if required.

A proposed technical architecture for the system is shown in Figure 2. Centralizing data into the datastore, and provisioning API access to the data, will provide the foundation for the overall technology strategy, supporting the introduction of analytics, and customized visualization, task, or reporting services to address demands for business intelligence from the system.

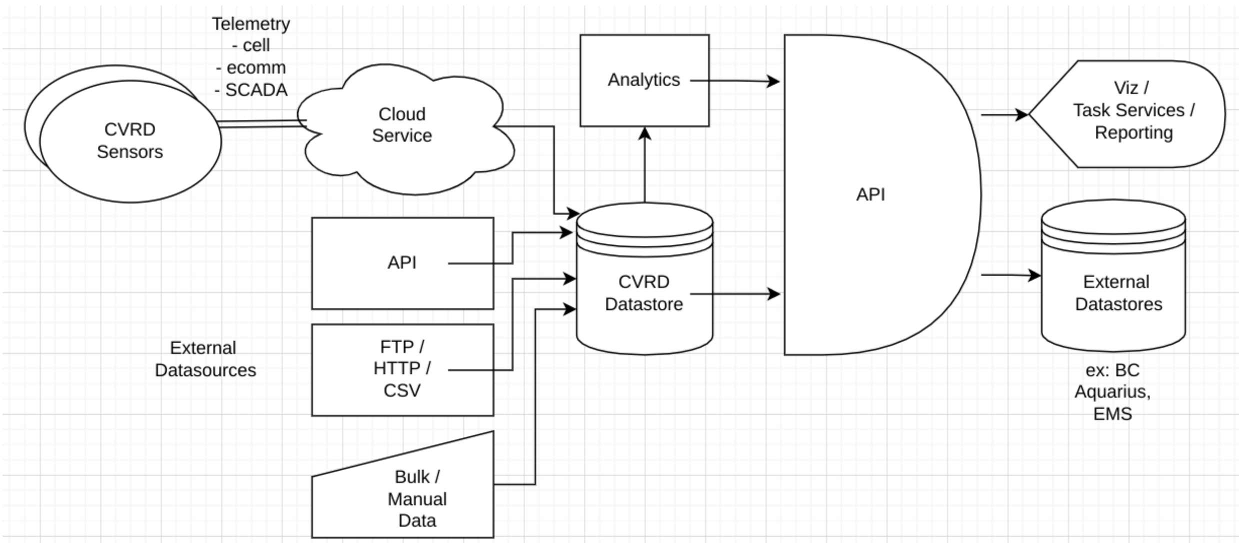

Figure 2. Data warehouse concept

Additional systems were considered in the evaluation. Water data management systems, such as those offered by Aquatic Informatics or Kisters, for example, provide extensive capabilities for technicians and technical staff managing monitoring networks, and working directly with the raw data. These systems are not well designed for supporting derivative products, or extracting insight from combined streams of data and interpreted products. Given the breadth and strength of features provided by these systems, they are more complex to use and this limits their attractiveness to users who are not power users of the systems. Given that the main use cases identified by the CVRD require extending data or analytical products to non-technical users, they are not well suited for these purposes. An example of a public facing gateway to hydrometric and climatic data from Aquarius is the BC Real-Time Water Data Tool (https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/real-time-water-data-reporting).

Multi-purpose environmental data management systems also exist in the marketplace, such as Equis by Earthsoft. Equis is an attractive product in that it provides the ability to store a wide range of disparate data related to environmental projects. It can effectively store and analyze geotechnical, air, water, and biophysical datasets. It provides linkages to other systems such as GIS. It is designed to support regular, complex workflows such as data analysis for environmental reporting. In this sense, it can be characterized as a multi-objective tool. This broad offering of features and applications is attractive in that it can serve many purposes and address potential future requirements that may arise within the Environmental Program at the CVRD. This potential flexibility must be measured against ease of use considerations, however, and it was not clear how the breadth of features provided by Equis would help achieve the defined use cases. Furthermore, the Equis software package is primarily designed for desktop analysis of data contained within the system, supporting interaction with web and external systems through extenders. Further information on Equis is available on the Earthsoft website (https://earthsoft.com/).

Knowledge management software packages are also available, to provide a centralized repository for a variety of types of data. An example of this kind of software is CKAN. This software is offered under an open-source license, and can be implemented, customized and extended to meet the needs of an organization. It does not provide any subject-matter specific functional expertise, in the sense of being able to analyze hydrologic or climatic data, but does provide a wide range of capabilities in the storing, search and retrieval of data and information products. It can contain data (or analytical products) in a variety of formats, and can distribute these data effectively with access control policies in place. It does not have strong capabilities in either analyzing or integrating data, however, and would be better suited for implementation in the CVRD if providing a data portal for external users to acquire data was the main objective. An example of a CKAN implementation is the BC Data Catalogue (https://catalogue.data.gov.bc.ca/).

Data License

Consideration should be given to data licensing for data which the CVRD collects either independently, or in partnership with other groups. A range of licenses are available for evaluation by CVRD technical and administrative staff, and we are not presuming at this time that an open-by-default policy would be suitable, but would strongly encourage an open data license be applied to all monitoring data collected by the CVRD, that does not have considerations related to protection of personal data. This recommendation is made on the basis of maximizing return on investment of taxpayer resources allocated to data collection by removing limitations and/or friction in use of the data by all interested parties.

Summary

The CVRD is in a unique position, geopolitically. As a regional government, by nature its jurisdiction crosses multiple boundaries of local government, and in unincorporated areas serves similar roles as local government. It includes watersheds and aquifers within and crossing local government boundaries. The Province of BC and Government of Canada both have interest in climatic and hydrometric conditions and associated data within the CVRD, but their mandates do not generally extend into residential land use planning and other local matters in the same manner as the CVRD.

This unique position requires the CVRD to engage with multiple interested parties to fulfill their mandate. With a geographic interest enveloping local government jurisdictions, and with a stronger focus on the impacts of conditions and trends in hydroclimatic systems (as compared to provincial and federal governments) on local ecosystems, domestic demands, and commercial uses of water, the CVRD can act as a central hub for water and climate monitoring in the region. Local understanding of the issues on the ground, and potential future issues and pressures on water in the region enable the CVRD to find and fill knowledge gaps, through a collaborative approach with other government agencies as well as non-governmental entities in academia, private industry, and the community at large.

This memo has summarized the current state of water-related data management in the Cowichan Valley Regional District, and presents recommendations and considerations for effectively creating a foundation for enhanced use of water data for decision-making in the future. The guiding principles reflected in these recommendations are that the system be:

- **Inter-operable**

  - With other internal systems at CVRD
  - With external systems at partner agencies
- **Extendable**
  - To incorporate new monitoring data types, locations, partners, and use cases
  - To connect the system with new systems in the future
- **Performant**
  - Meets the information needs of end users
  - Delivers results rapidly
- **Reliable**
  - Continues to be updated
  - Provides trustworthy data
- **Simple to use**
  - Users easily receive data in a format that is easy to work with
  - Developers are able to adapt and extend the system with ease

By keeping these principles in mind, and by maintaining an open and collaborative approach with other parties interested in better understanding hydroclimatic conditions across the CVRD, the CVRD can ensure that water-related concerns of residents and ecosystems within the CVRD are addressed going forward. Ultimately, the success of the Drinking Water and Watershed Program will not be determined by the presence of any data management system. The success of the data management system implemented will be defined through measurable outcomes on the ground for residents and ecosystems in the region, that are supported by information products and other intelligence derived from the system.

Closing

Foundry Spatial, as part of a consulting team led by MacDonald Hydrology Consultants (hereafter Project Team) prepared this document for the account of the CVRD. The material in it reflects the judgment of the Project Team considering the information available to the Project Team at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. The Project Team accepts no responsibility for damages, if any, suffered by any third party because of decisions made or actions based on this document.

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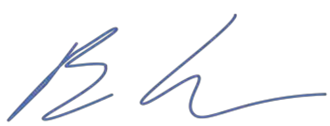
We trust the above satisfies your requirements. Please contact us should you have any questions or comments.

Sincerely,



Ben Kerr, B.Sc., P.Ag.
Technical Lead

Hailey Eckstrand, B.Sc.
Data Analyst

Reviewed By:

Ryan MacDonald, Ph.D., P.Ag.
Senior Hydrologist

Appendix C

Phase 3 Memo – Preliminary Assessment and Gap Analysis

Final Memo – Preliminary Assessment and Gap Analysis

Phase 3, Development of a Regional Hydrometric and Climate Monitoring Strategy and Workplan for Cowichan Valley Regional District

2022.05.18

Prepared For:

Cowichan Valley Regional District

MacHydro FOUNDRY SPATIAL

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Figures

Tables

1 Introduction

MacDonald Hydrology Consultants Ltd. (MacHydro) in collaboration with Foundry Spatial (Foundry) were retained by the Cowichan Valley Regional District (CVRD) to develop a *Regional Hydrometric and Climatic Monitoring Strategy and Implementation Workplan* as part the Drinking Water and Watershed Protection program (DWWP; CVRD, 2020). The CVRD requires a strategy that is designed and implemented across the region at regional, watershed, and surface/aquifer scales. The goal is to improve the understanding and management of water in the individual watersheds to assist with short-term watershed management and drinking water supply forecasting, and future water strategy development and planning within the CVRD. The strategy is expected to provide information to drive adaptive management and emergency response and has critical linkages to the climate adaptation program. The development of a monitoring strategy was divided into four phases. This memo summarizes Phase 3 of the development of a regional hydrometric and climatic monitoring strategy – preliminary assessment and gap analysis. The objectives of Phase 3 include:

- Review of the available hydrometric and climate stations currently operating in the CVRD and undertake a gap analysis to identify strategic locations for investments in additional and relevant infrastructure;
- Develop a framework to assess the need for additional monitoring locations to meet the overall strategy;
- Recommend a ranked list of sites for the hydrometric and climate monitoring network using the framework;
- Develop an implementation plan for the network that includes a budget for installation of new sites and reinstatement of inactive sites as well as on-going maintenance of monitoring sites; and,
- Provide recommendations for proxy data collection for interim data while the monitoring network is being built.

2 Methods

2.1 Cowichan Valley Regional District

The study area was determined by selecting 20 Watershed Planning Areas (WPAs) that intersect the CVRD. There were five additional WPAs that were excluded from the study area because they had only small overlaps with the CVRD boundary. In total, this study area is approximately 503,410 hectares (Figure 1), which is larger than the regional boundaries of the CVRD (~350,000 hectares).

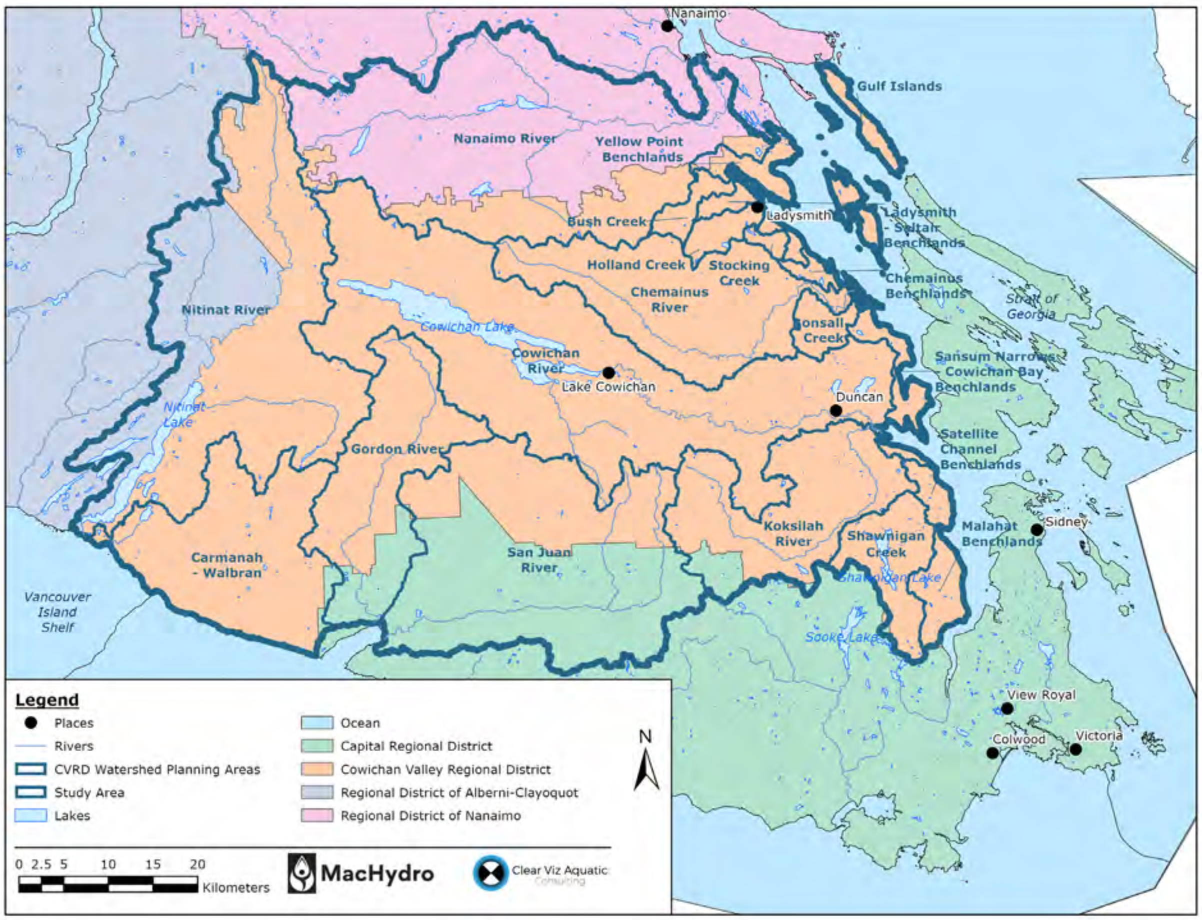

Figure 1. Study area map showing major population centers, Regional Districts, and CVRD Watershed Planning Areas.

The climate is characterized by warm, dry summers and mild, rainy winters, and infrequent air temperatures below freezing. Mean annual precipitation and air temperature varies within the region, varying by elevation and proximity to the ocean. For example, mean annual precipitation is 1248 mm at Shawnigan Lake (159 m.a.s.l.) with 6% falling as snow, while mean annual precipitation is 3546 mm at Heather Mountain (1,190 m.a.s.l.) with 45% falling as snow. Most of the precipitation in the study area falls between October and March. The frequent and dominant hydrologic process that contributes to surface and subsurface runoff generation is generally snowmelt above 800 m.a.s.l., rain-on-snow between 300 and 800 m.a.sl. and rainfall below 300 m.a.s.l. (Figure 2). For example, high flows are typically generated by rain-on-snow or heavy fall rainfall in the Koksilah River watershed (Pike et al., 2017; Hatfield, 2021), whereas it is predominantly rainfall in the Satellite Channel Benchlands, Gulf Islands and Chemainus Benchlands. Runoff in the headwaters of the Nanaimo, Chemainus and Cowichan River watersheds is generated by snowmelt.

The Coastal Western Hemlock (CWH) is the dominant biogeoclimatic zone in the study area. Coastal Douglas-fir spans the east coast region including the Gulf Islands. The Mountain Hemlock and Coastal Mountain-heather Alpine are located at higher elevations.

The landforms and soils have been influenced by glaciation. Surficial deposits are commonly found below 160 m.a.s.l. (SNC Lavalin, 2019), but bedrock is exposed or covered by only a thin layer of glacial till above 160 m.a.s.l. Bedrock in the region is made up of volcanic, intrusive, and sedimentary. There are 57 mapped aquifers within the study area composed of sand/gravel or bedrock. Of the 57 aquifers, only 53 are located entirely within the regional boundaries of the CVRD.

The major west-flowing river systems draining the CVRD include the San Juan River, Gordon River, Carmanah-Walbran, and Nitinat River (Figure 3). The major east-flowing river systems include the Cowichan River, Koksilah River, Somenos Creek, Chemainus River, and Bonsall Creek that drain into the Strait of Georgia. Outside of the major watersheds, the benchlands make up much of the east coast and drain into the ocean. The most populated places are on the east coast (the benchlands) or on the shores of large lakes. Forestry, agriculture, and tourism are major drivers of the economy. The upper portions of the Cowichan River, Chemainus River and Koksilah River are primarily resource lands (Figure 3).

Urban and suburban communities draw their water from centralized municipal water systems that extract their water from groundwater or surface sources; however, most residents rely on groundwater for their drinking water source. The major municipal surface water sources for CVRD residents are sourced from the WPAs of Chemainus River, Holland Creek, Stocking Creek, Cowichan River, Shawnigan Creek, and Sansum Narrows - Cowichan Bay Benchlands (Figure 3). Individual utilities are also operated by improvement districts or private water utilities. There are also over 4,500 private water wells in the region (CVRD, 2020).

Community watersheds are delineated for some of the major municipal surface water sources. A community watershed is all or part of the upslope contributing area for a point of diversion licensed to a waterworks provider (Forest Practices Board, 2014). Designated community watersheds are protected under the Forest & Range Practices Act (FRPA). Within the study area, there are ten designated community watersheds (Figure 4). The Holland, Stocking Lake, Banon, and Shawnigan community watersheds are municipal water sources for CVRD residents. Youbou Creek no longer provides municipal water sources for CVRD residents. The remaining five designated community watersheds were not considered in the gap analysis as they do not provide licensed waterworks to a CVRD water system. These include South Nanaimo community watershed (City of Nanaimo), Denham and Ram community watersheds (domestic licensees), Malachan community watershed (emergency backup for Ditidaht First Nation), and the Malahat community watershed (Malahat First Nation).

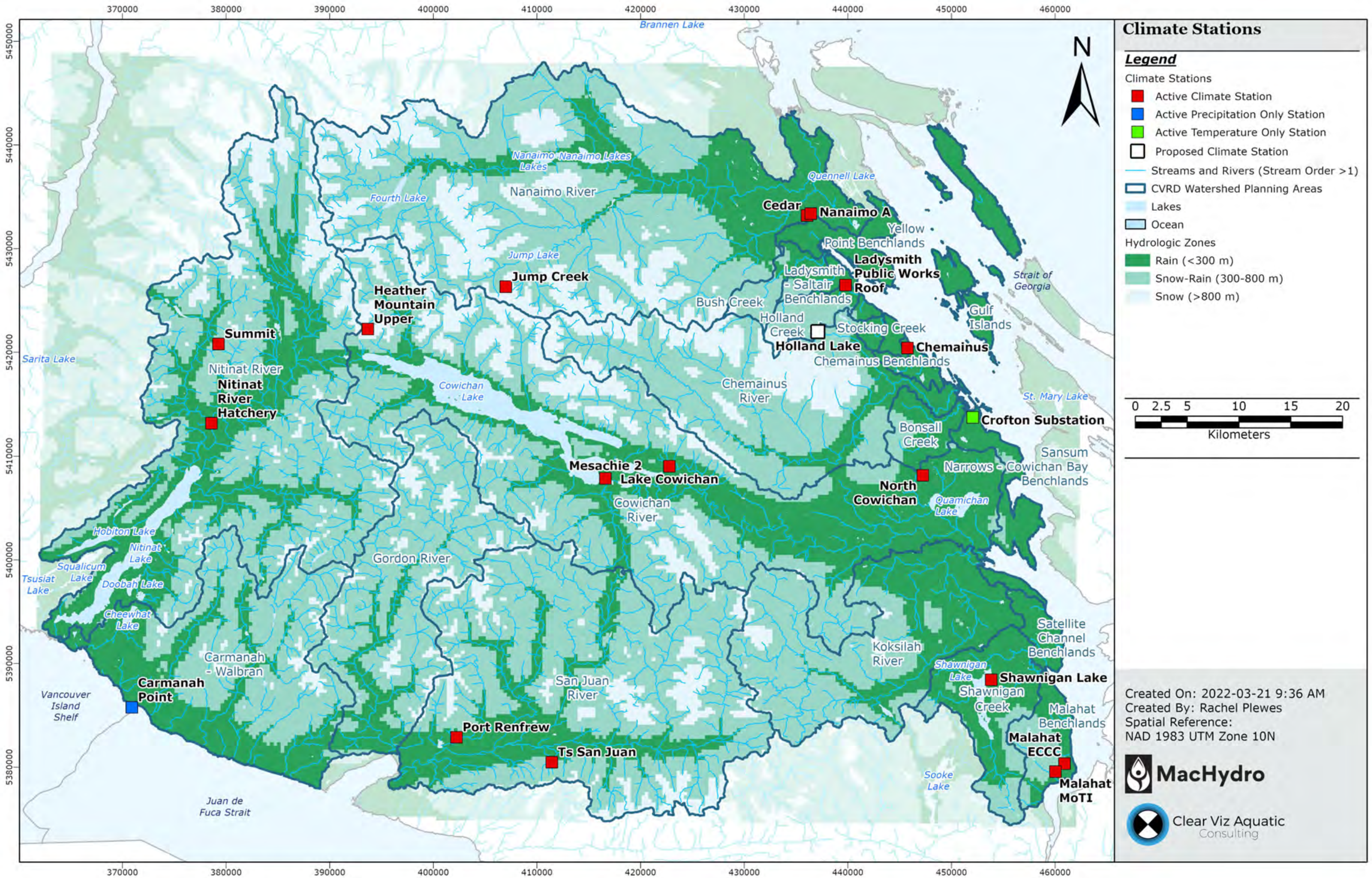

Figure 2: Map of active climate stations within Hydrologic Zones - the dominant hydrologic process that contributes to surface or subsurface runoff generation: snowmelt (>800 m.a.s.l.), rain-on-snow (300 – 800 m.a.s.l.), or rain (<300 m.a.s.l.).

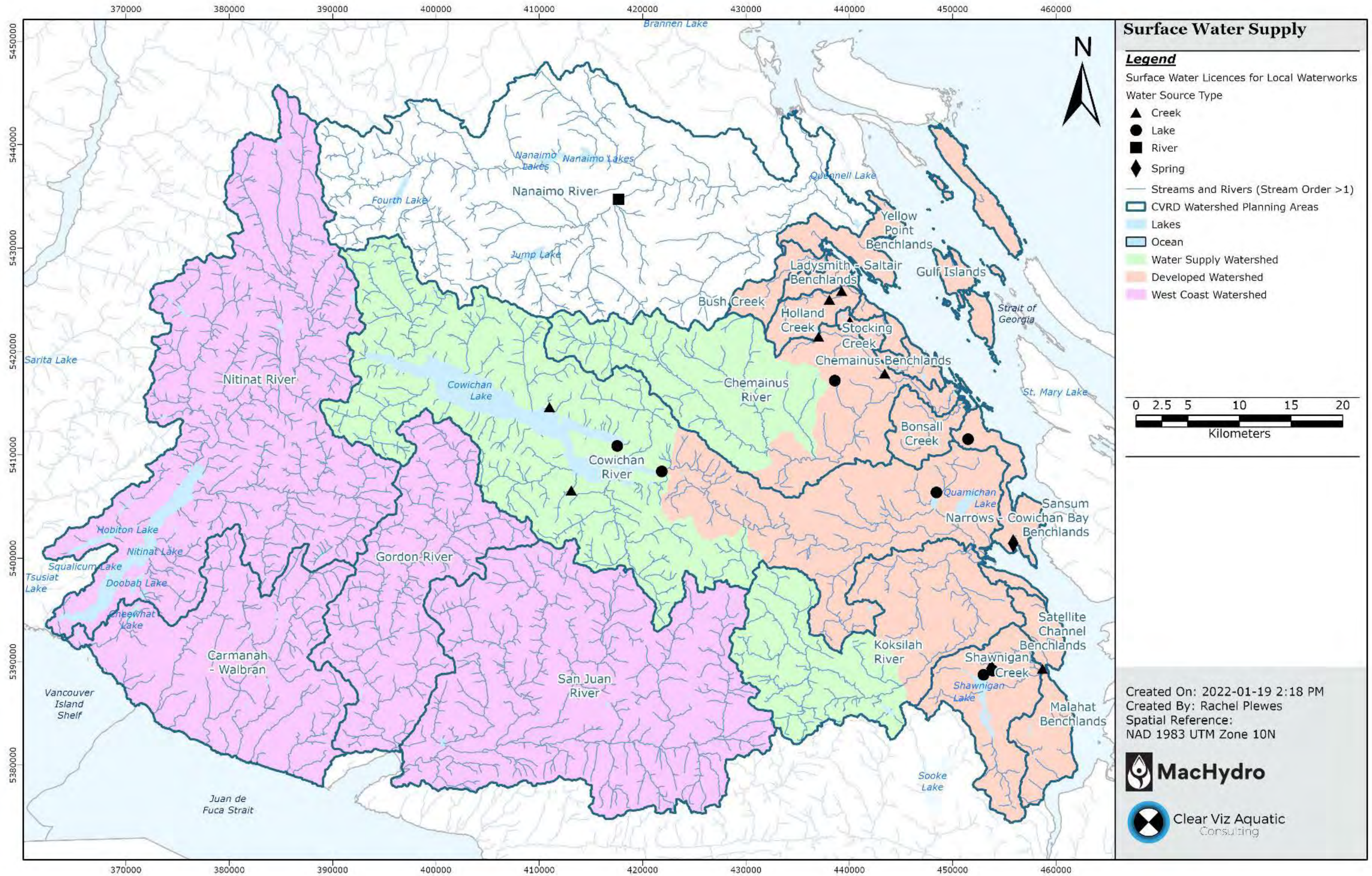

Figure 3: Map of municipal surface water supply. Watersheds categorized by surface water supply were defined by the CVRD (2017).

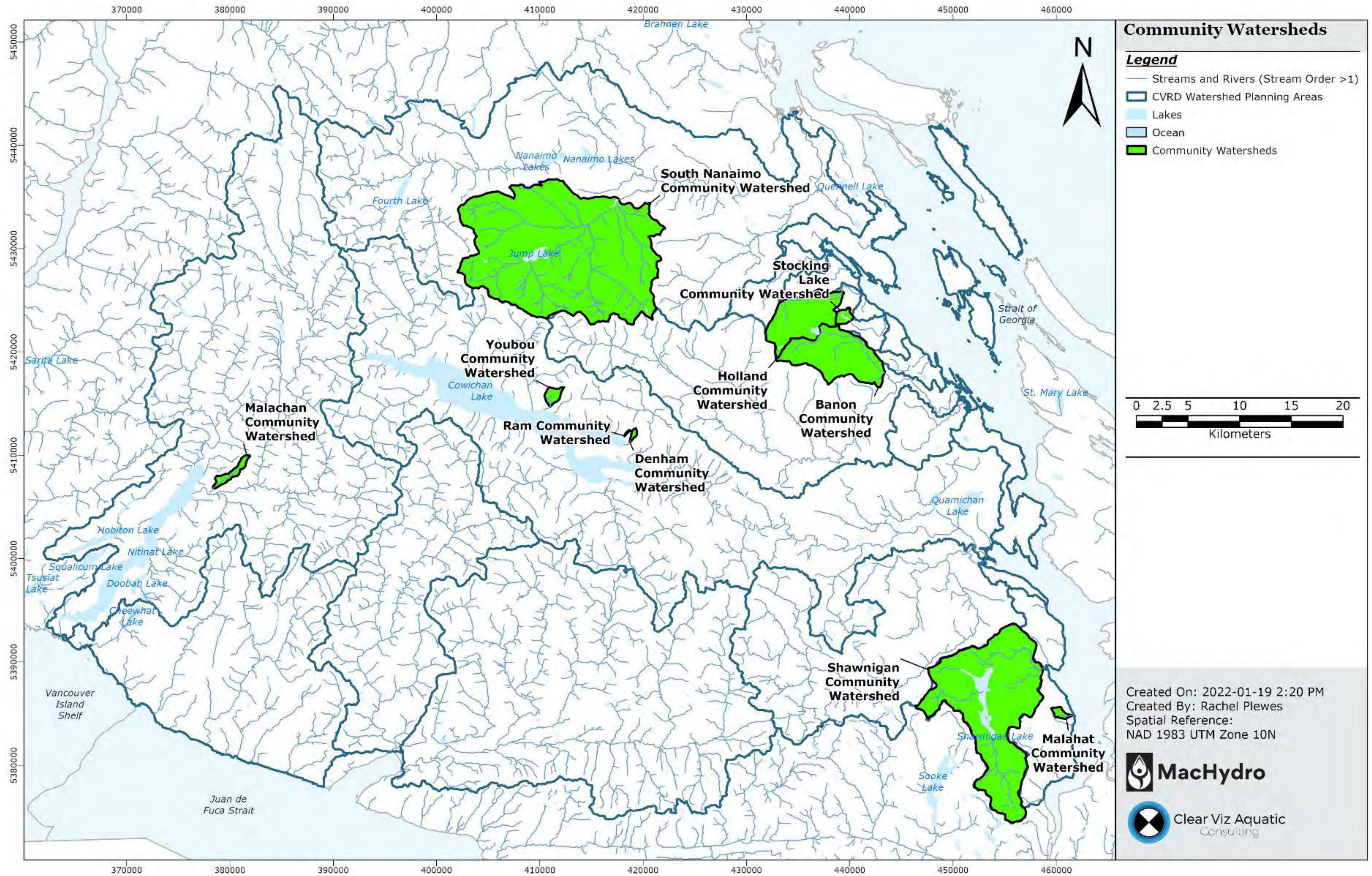

Figure 4: Map of designated community watersheds.

2.2 Existing Hydrometric and Climate Monitoring Networks

The current networks in the CVRD used in the gap analysis are operated by federal, provincial and local government. No networks from industry were available at the time of gap analysis. We also did not include any community-monitored stations, which includes the Vancouver Island School-Based Weather Station Network. We did not consider these climate stations (n = 6) or other community-based monitoring stations due to the uncertainty in data quality and assurance. Active and inactive stations were compiled from the below organizations to guide site selection of monitoring locations.

Climate Stations

- Agricultural and Rural Development Act Network (ARDA)
- Environment and Climate Change Canada (ECCC)
- BC Ministry of Environment and Climate Change Strategy (BC ENV) - Air Quality Network
- BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD) - Wildfire Management Branch
- BC Ministry of Transportation and Infrastructure (BC MoTI)
- CVRD
- Municipality of North Cowichan
- Town of Ladysmith

Hydrometric Stations

- Water Survey of Canada (WSC)
- BC ENV – Real-time Water Data Reporting
- BC ENV – Groundwater Observation Well Network (PGOWN)
- CVRD
- Municipality of North Cowichan
- Town of Ladysmith

2.3 Data Analysis

2.3.1 Watershed Grouping

The provincial freshwater atlas assessment watersheds for the study area were grouped using clustering analysis. The analysis was used to identify groups that have similar runoff response so that monitoring results from one watershed in a group can be extrapolated to other watersheds within that same group. Grouping the watersheds is based on an understanding of runoff generation that is interpreted from physical watershed characteristics. A Watershed Group is assumed to have similar flow regimes and responses to a changing climate and/or land use change.

Runoff generation in a watershed is affected by climate, surficial and bedrock geology (e.g. Goodbrand et al., 2022; Spencer et al., 2021), topography, soils, the percentage of lakes and wetlands, vegetation type and cover, and land use. Variables used to describe the physical watershed characteristics of each assessment watershed are in Table 1. There was information on soil type in the study area, but insufficient data on soil depths. Therefore, a soil variable was not included in the clustering analysis.

Affinity Propagation (AP) clustering was used to group the assessment watersheds. AP clustering is an exemplar-based clustering method that makes no assumptions about the distribution of data (Bodenhofer et al. 2022). The clustering algorithm searches for the most suitable exemplars. Exemplars are selected based on maximizing the similarity between a group of similar watersheds. After exemplars are selected, clusters are formed around each exemplar.

Table 1: Explanatory variables used in AP cluster analysis to create watershed groups.

Attribute Group	Explanatory Variable	Source/Comments
Hydrology	Wetland percentage	Environmental Sensitivity Analysis Mapping
	Lakes percentage	FreshWater Atlas
	Drainage density	FreshWater Atlas
Land Cover/Use	Percent Agricultural	Zoning Classes of Agricultural
	Percent Developed	Zoning Classes of Residential, Industrial, Commercial, Transportation, Utility, Mixed=
	Percent Forested	
Topography/Position	Mean slope	25 m CDED
	Mean elevation	25 m CDED
	Stream order	FreshWater Atlas
Geology	Percent Intrusive	
	Percent Sedimentary	
	Percent Volcanic	
Climate	Annual Mean of Monthly Maximum Daily Temperature	PCIC PRISM 1981-2010
	Annual Mean of Monthly Total Precipitation (mm)	PCIC PRISM 1981-2010

2.3.2 Assessment Framework

A framework was developed to compare potential sites against a set of criteria to prioritize potential monitoring locations for additional hydrometric and climate monitoring sites. These criteria reflect the goals of the DWWP strategy (CVRD, 2020) and should function to provide specific data to support future development of conceptual models, water balance calculations, relative stress assessments, hydrological modelling, and the development of Integrated Watershed Management Plans. Therefore, the framework prioritized monitoring locations to ensure the network strategically collects data to evaluate both watershed planning and water use (Watershed Planning Areas), and water balances (Watershed Groups).

Watershed risk analyses conducted by SNC Lavalin (2019) for the east-ward flowing WPAs were used to prioritize site selection of climate and hydrometric monitoring stations. The risk rating was a combination of the likelihood or probability of occurrence of an undesired event (hazard) and the consequences of that event occurring [Risk = Hazard (or likelihood) x Consequence]. Risk was quantified for riverine and coastal flooding, surface water supply and groundwater contamination. Flooding included hazards such as streams (riverine), flood depths or floodplain mapping (riverine), inundation (coastal), coastal flood sensitivity, while consequences included permanent land use zoning. Surface water supply include the hazards around aquifer type and potential connection to streams, agricultural water demand, sensitive streams or protected rivers, aquifer demand (i.e., the level of groundwater use at the time of aquifer mapping) and aquifer productivity (i.e., aquifer's ability to transmit and yield groundwater), while the consequence was water license points of diversion. Groundwater contamination hazards included DRASTIC vulnerability (i.e., aquifer's relative intrinsic vulnerability to impacts from human activities on land surface), land use zoning, federal and provincial contaminated site inventory, the area extent of municipal sewage systems, and the consequences were aquifer demand and municipal water supply wells.

To prioritize site selection for climate and hydrometric (surface water) monitoring, we used SNC Lavalin's (2019) reported prioritized future assessment of WPAs for riverine and coastal flooding and surface water supply that included an assessment of projected population estimates (rate of change from 2006 to 2036) (Figure 5).

To prioritize site selection of groundwater monitoring, it was important to evaluate risk related to both groundwater supply (aquifer demand/productivity, connection to streams, etc) and quality (land use zoning, extent of sewage systems, development on land surface, etc), because groundwater contamination will limit water supply. Therefore, the median risk rating of surface water supply (Figure 5), groundwater contamination and projected population were equally-weighted for each mapped aquifer within the CVRD to produce an "aquifer rating". Not all aquifers within the study area were rated, because some of the data needed for rating did not exist outside the CVRD boundary. Risk ratings for the Gulf Islands within the study area (Penelakut, Thetis, Hudson, Dayman, Scott, Ruxton, Valdes, Reid, Pylades) were estimated using the methodology in the SNC Lavalin (2019) report as they were not included in the original risk assessment.

The following sections outline the criteria to prioritize site selection of monitoring stations:

Hydrometric (Stream Discharge)

- Was there currently a hydrometric station installed within an east-ward flowing WPA or within the representative watershed of each Watershed Group?
- Does a municipal, improvement district or community watershed divert surface water from the stream as a drinking water source?
- Was the watercourse used as a primary, supplemental, or backup drinking water source?
- What was the riverine/coastal flooding and surface water supply risk rating for the WPA?
- Was there an active climate station near the watershed that would be representative of precipitation and air temperature?
- Does the recommended hydrometric network cover a range of watershed scales?
- Does the recommended site within the representative watershed of each Watershed Group drain a large lake or wetland complex (store runoff) that would not represent discharge in another ungauged watershed?
- Was there a discontinued hydrometric gauge within the WPA or within the representative watershed of each Watershed Group?
- Was there an active water quality monitoring site?

Hydrometric (Lake Level)

- Does a municipal or improvement district or community watershed divert surface water from the lake as a drinking water source?
- Was the lake used as a primary, supplemental, or backup drinking water source?
- Was there a discontinued water level monitoring station within the lake?

Hydrometric (Groundwater Level)

- What was the equally-weighted median risk rating between surface water supply, groundwater contamination, and projected population (rate of change 2006 to 2036) for the mapped aquifer (i.e., aquifer rating; SNC, 2019)?
- Was there an active continuous groundwater monitoring well in each aquifer subtype by aquifer rating?
- Does the mapped aquifer have high population and/or development pressure or a high density of groundwater wells relative to others?
- Was there an inactive PGOWN well that could be re-activated to expand the groundwater monitoring network to collect data from more aquifers?

Climate

- Does the current climate station network capture the most frequent or dominant hydrologic process that will contribute to surface and subsurface runoff generation across the region: snowmelt (>800 m.a.s.l.), rain-on-snow (300 – 800 m.a.s.l.), or rain (<300 m.a.s.l.) (Figure 6)?
- Does the current climate station network provide sufficient coverage to characterize the variation in climatic conditions within the WPAs?
- Was there a climate station within a representative watershed of each Watershed Group?
- Was there an active climate station near the hydrometric gauges that would be representative of precipitation and air temperature?
- Was there a discontinued climate station with a long-term data record that could be re-activated?
- Does the proposed site location have road access and relatively easy site preparation (i.e., within a forest clearing, top of roof)?

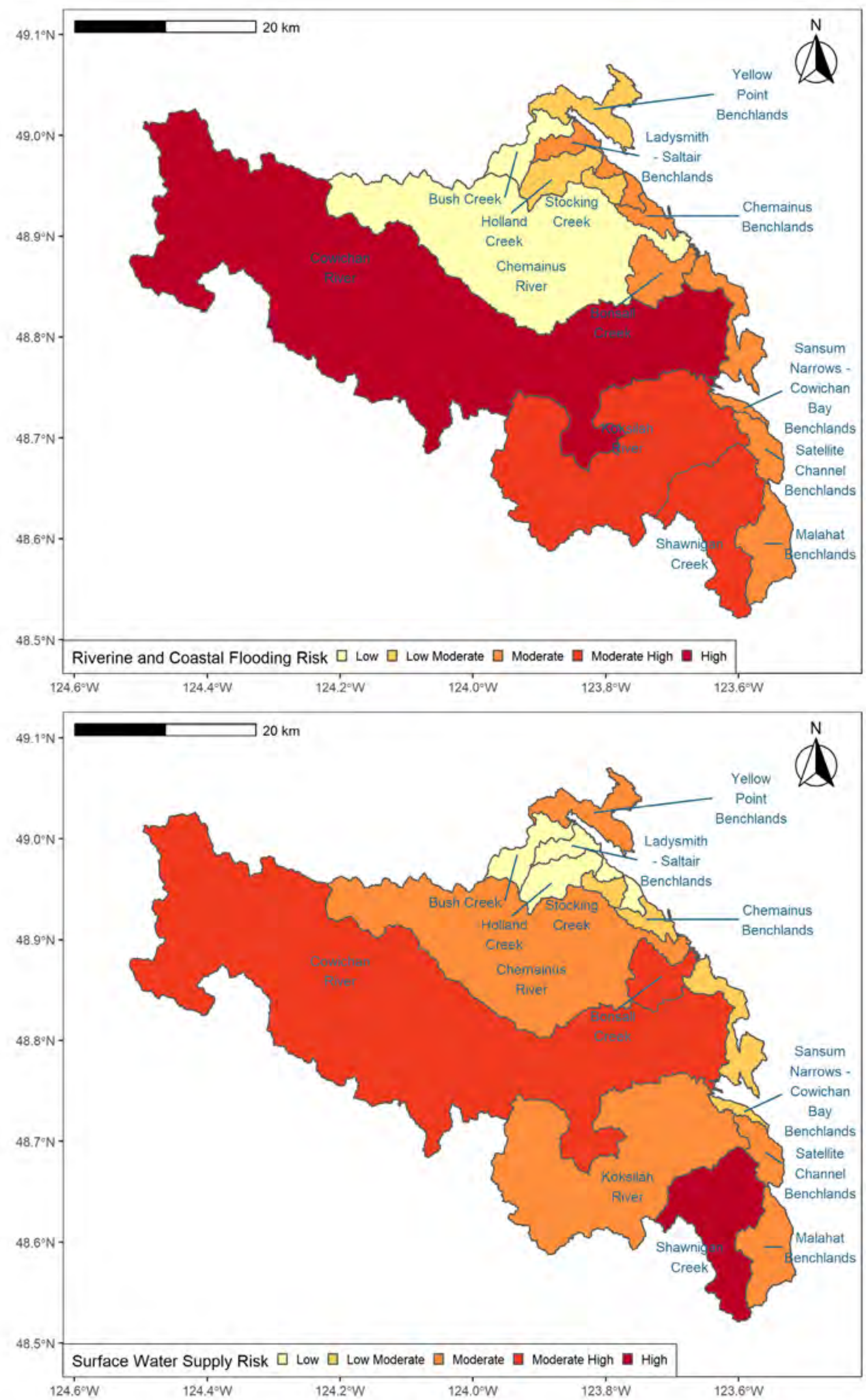

Figure 5: Prioritizations for risks of riverine and coastal flooding and surface water supply risk from SNC Lavalin (2019), where high represents a high priority for future assessment and low represents a low priority for future assessment. Note that this assessment was completed prior to two more recent flooding events in the Chemainus watershed and may not adequately consider the flooding impact on roads that link south Vancouver Island to the rest of the island.

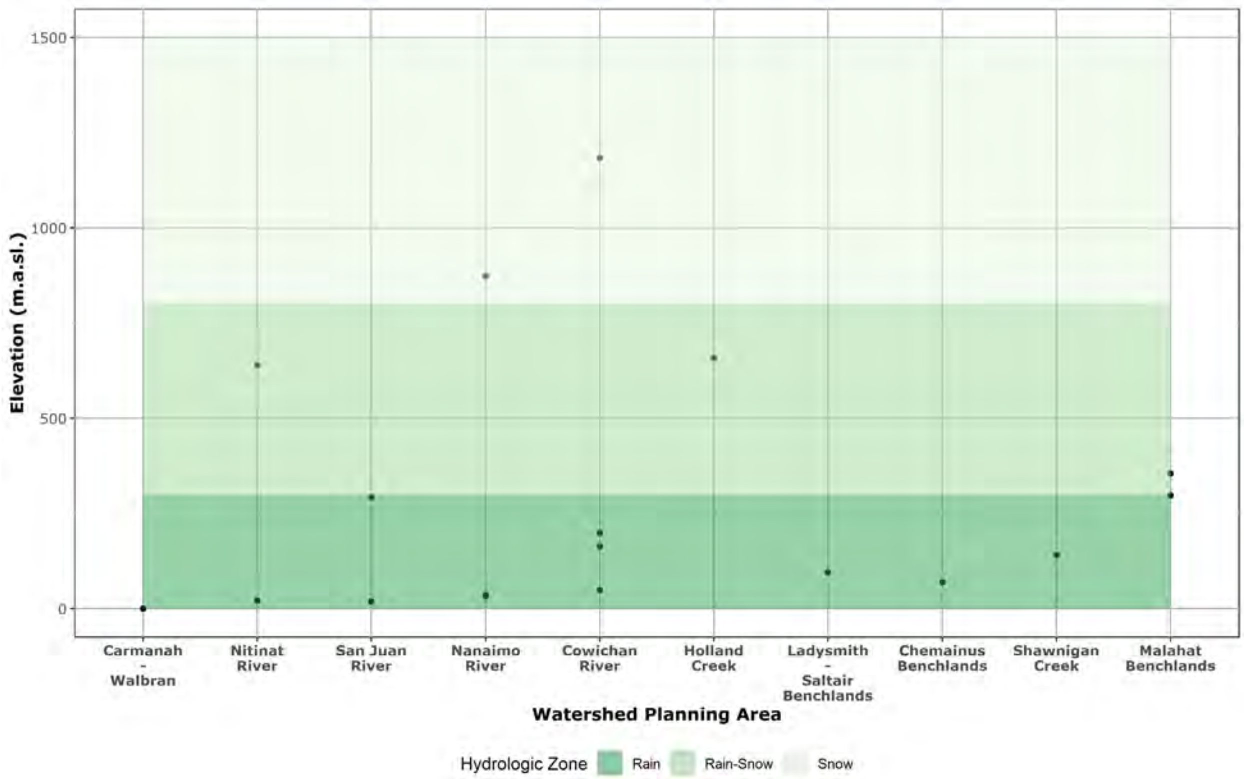

Figure 6: Active precipitation gauges by Watershed Planning Area and dominant hydrologic process that contributes to surface or subsurface runoff generation: snowmelt (>800 m.a.s.l.), rain-on-snow (300 – 800 m.a.s.l.), or rain (<300 m.a.s.l.) (Hydrologic Zone). There are ten WPAs with no active precipitation gauges.

3 Watershed Grouping

The AP clustering analysis resulted in seven watershed groups. Climate and elevation variables provided the best separation between watershed groups. Watersheds in Groups 1 to 3 were located within the east-ward flowing WPAs, whereas watersheds in Groups 5 to 7 were in the west-ward flowing WPAs (Figure 7). Group 4 watersheds are in the headwaters of both east-ward and west-ward flowing watershed planning areas.

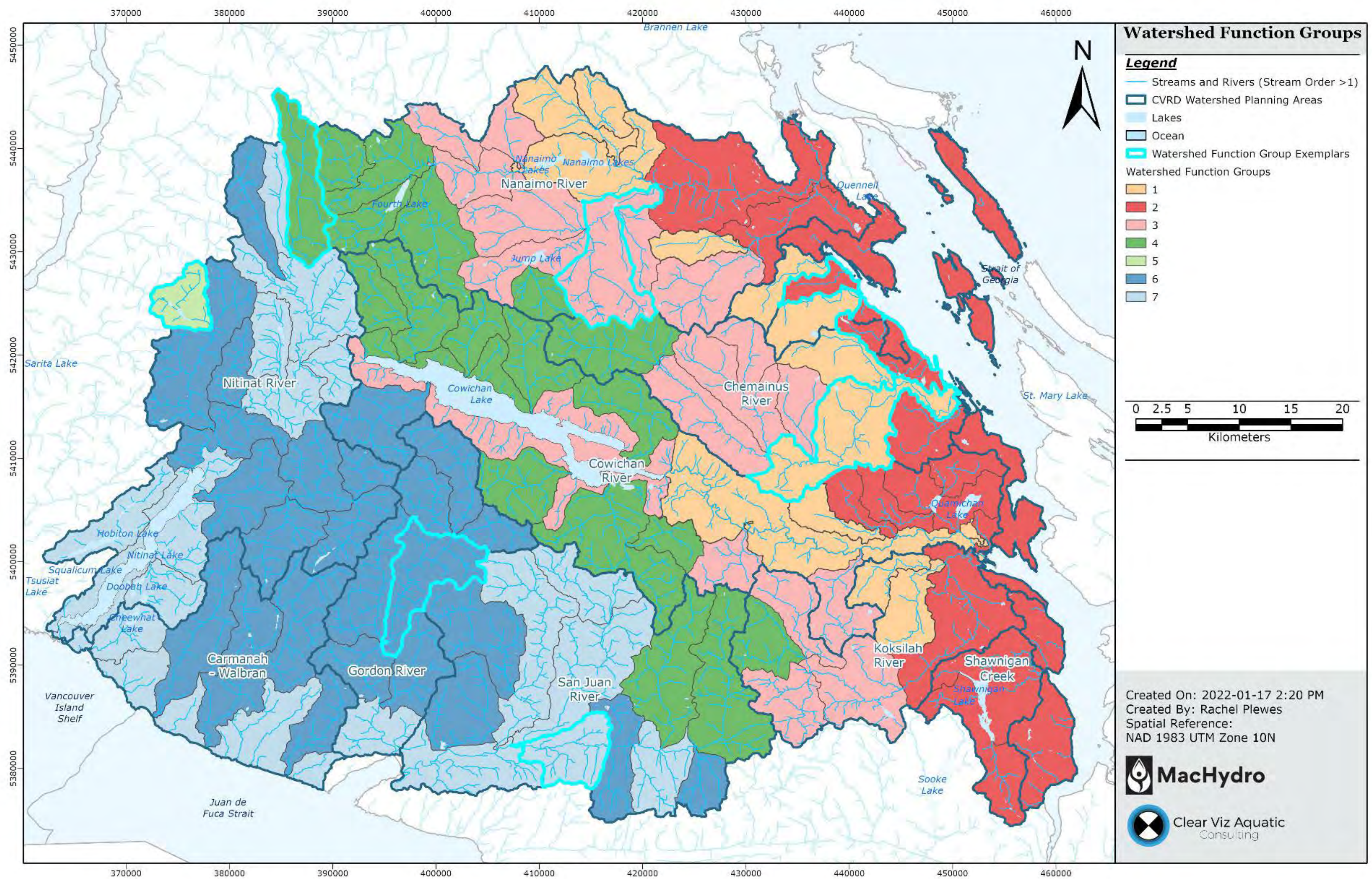

Figure 7: Map of Watershed Function Groups with exemplar watersheds identified.

Group 1 and 2 watersheds have the driest and warmest climates associated with their lower elevations (Figure 8). There was a higher percentage of sedimentary rock in the watersheds of Groups 1 and 2 (Figure 9). Group 2 watersheds have the warmest annual air temperatures and receive the least annual precipitation compared to all other watershed groups. Many of the watersheds in Group 2 are coastal watersheds that drain directly into the Strait of Georgia (Figure 7). Group 2 watersheds occur in flatter areas that are favourable for development and agriculture. As a result, most Group 2 watersheds have higher percentages of agricultural and developed land (Figure 10). However, Group 1 watersheds that are within the lower Koksilah and Cowichan River watersheds also have higher percentages of agricultural or developed land. The higher mean elevations of Group 1 watersheds result in cooler mean monthly air temperatures compared to Group 2.

Watersheds within Groups 3 and 4 are higher elevation watersheds with cooler air temperatures and moderate levels of precipitation (Figure 8). Group 4 watersheds receive more annual precipitation than Group 3 watersheds. These Group 4 watersheds are in the headwaters of the San Juan River, Koksilah River, Nanaimo River, Chemainus River, and Cowichan River WPAs (Figure 7). A small watershed in the northwestern part of the Nitinat River is the only watershed included in watershed Group 5 (Figure 7). This watershed was not grouped with any other watersheds because of its very high mean annual total precipitation value of 4870 mm (Figure 8).

Groups 6 and 7 watersheds have the wettest climates compared to all other Watershed Groups (Figure 8). Most of the watersheds in Group 7 are lower in elevation and receive less annual precipitation than Group 6. The mean slope of Group 7 watersheds is more variable compared to Group 6 (Figure 9). Some of the coastal watersheds within Group 7 have gently sloping land.

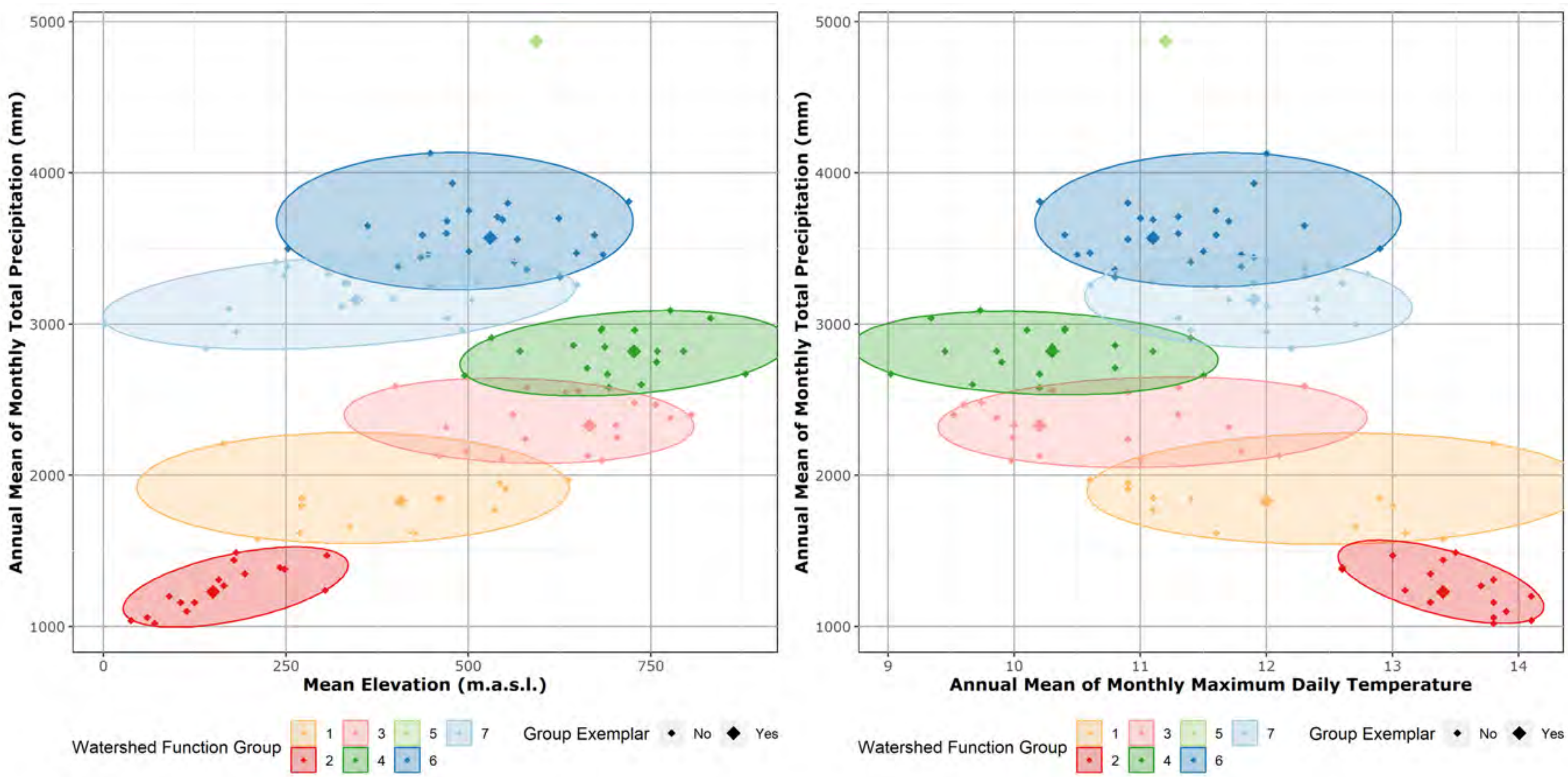

Figure 8: AP Cluster analysis results for assessment watersheds with annual precipitation, air temperature and mean elevation variables.

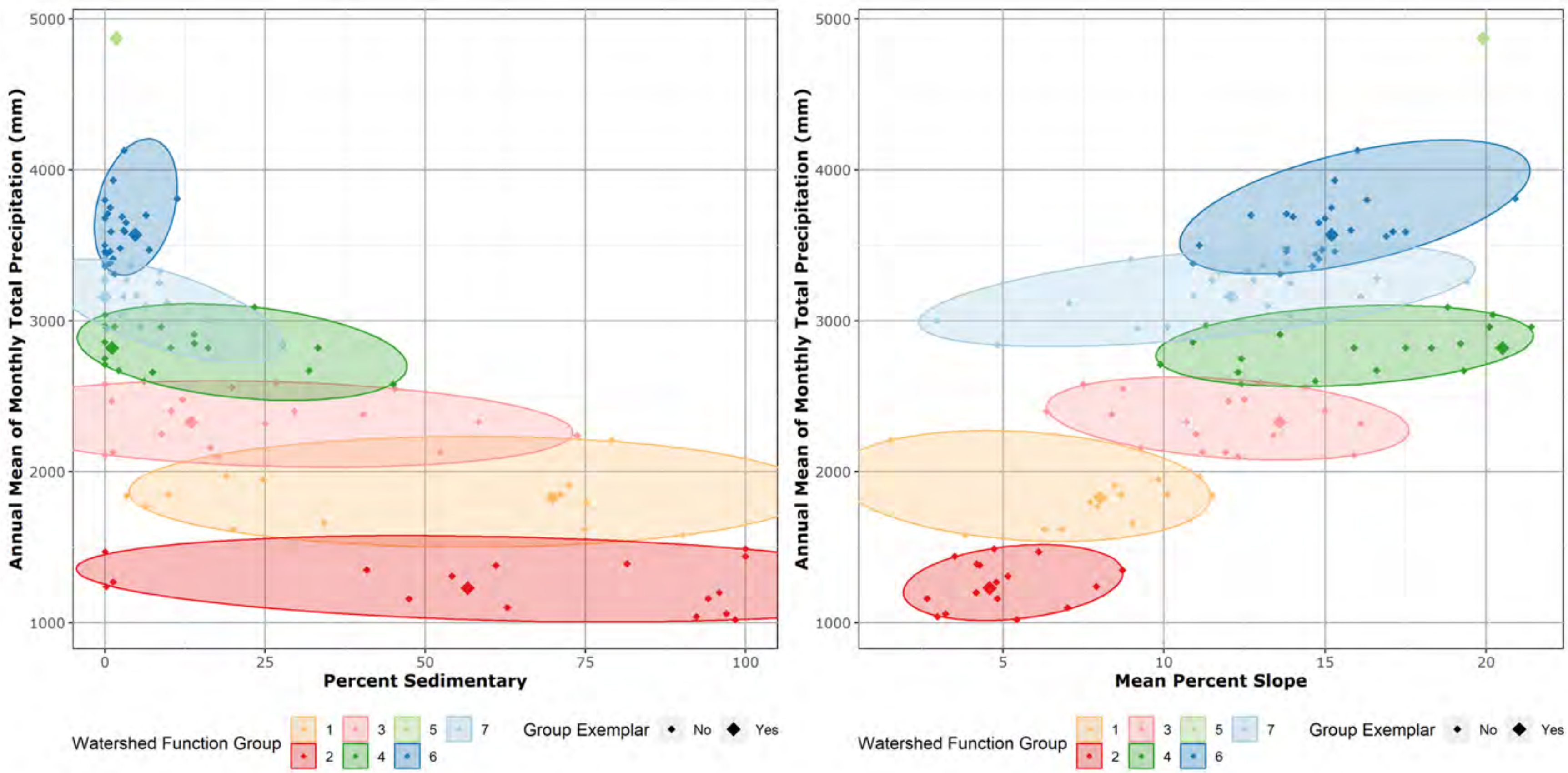

Figure 9: AP Cluster analysis results for assessment watersheds with annual precipitation, bedrock composition and mean watershed slope variables.

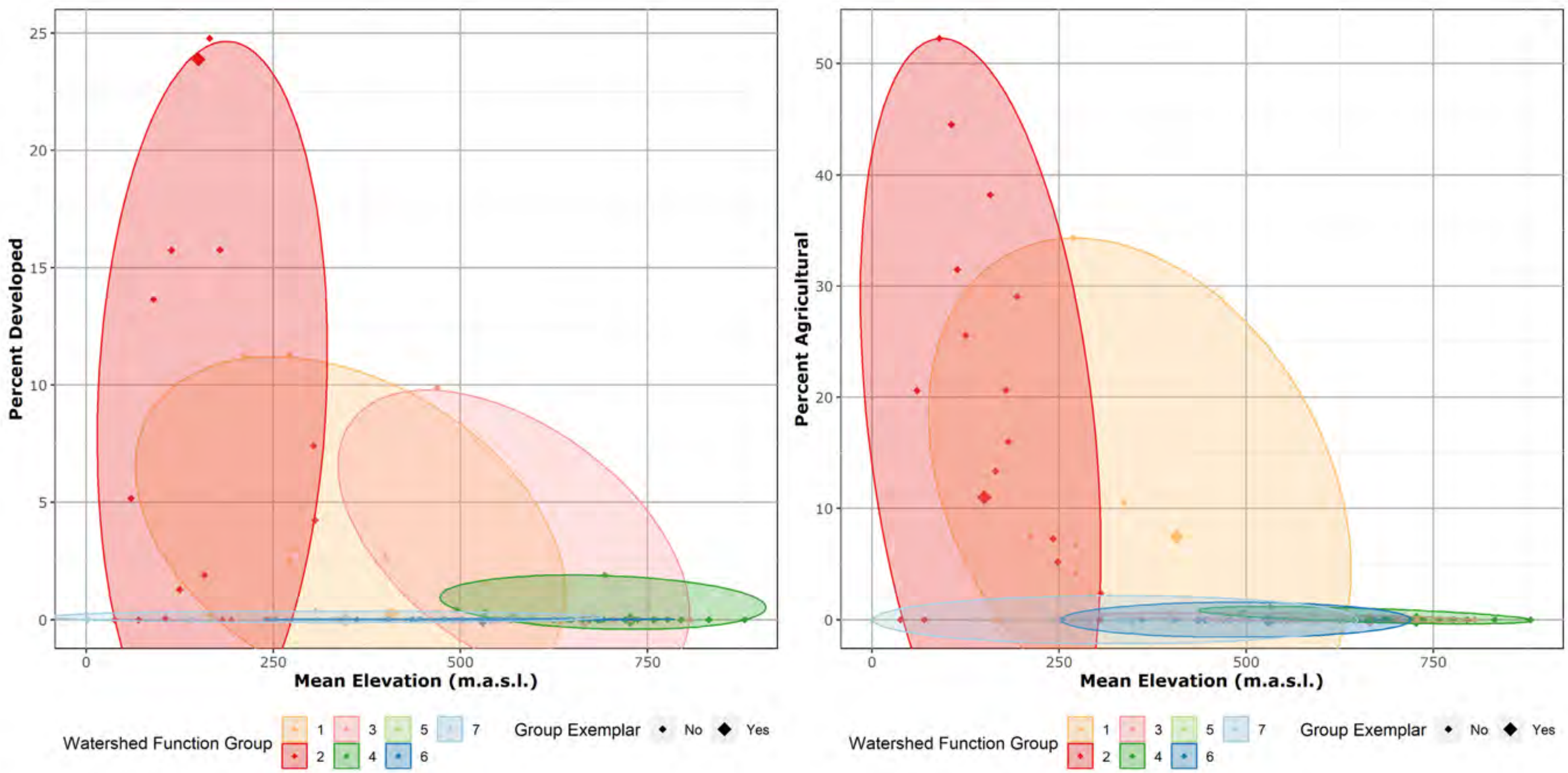

Figure 10: AP Cluster analysis results for assessment watersheds with percent developed and agricultural land and mean elevation.

4 Gap Analysis

4.1 Hydrometric (Discharge and Lake Level)

There are 23 active hydrometric stations that monitor discharge (Table 2; Figure 11). There are two proposed hydrometric gauges: one at Holland Lake (Town of Ladysmith; personal communications, Ira Adams) and one on Gordon River (DFO; personal communications, Neil Goeller). Active hydrometric stations are most abundant in the larger east-ward flowing WPAs. Water Survey of Canada primarily gauges the large rivers (Cowichan, Koksilah, Chemainus, St Juan, Nanaimo, South Nanaimo), with gauges on a few smaller creeks (Bings, Jump, Garbage, Harris, Renfrew, and Cottonwood). There are ten east-ward flowing watershed planning areas that do have active hydrometric stations (Table 2). There are no active hydrometric stations within the six Benchlands WPAs. For the four west-ward flowing WPAs, only the San Jaun River watershed has active hydrometric gauges (Table 2).

Hydrometric stations are most abundant in the east-ward flowing, lower elevation Watershed Groups (Table 2; Figure 11), which include Groups 1 and 2. Group 2 watersheds have six hydrometric stations that provide discharge data for the lower elevations of Cowichan River, Nanaimo River, Stocking Creek and Kolksilah River watersheds (Table 2). There are two active hydrometric stations along the Lower Koksilah River and one station along the Lower Nanaimo River (Figure 11). The Bings Creek and Haslam Creek stations provide discharge information for key tributaries of the Cowichan and Nanaimo Rivers. The newly installed Stocking Creek hydrometric station provides discharge data for Stocking Creek downstream of Stocking Lake.

Group 1 watersheds include nine active hydrometric stations that are in the Chemainus and Cowichan River watershed planning areas. There are five active hydrometric stations that are located along the Lower Chemainus River. The Lower Cowichan River watershed has two active hydrometric stations located within Group 1 watersheds. Two active hydrometric stations on the Cowichan River and Oliver Creek hydrometric stations are located near Cowichan Lake.

The higher elevation watersheds of Groups 3 and 4 only contain three active hydrometric stations. There are two active hydrometric stations in Group 3 watersheds that provide discharge data for Jump Creek and the South Nanaimo River. Cottonwood Creek Headwaters station is the only active hydrometric station within Group 4. Cottonwood Creek flows into Cowichan Lake. The headwaters of Chemainus and Koksilah Rivers include watersheds from Groups 3 and 4 (Figure 7). There are no active hydrometric stations within Groups 3 and 4 for the Chemainus River and Koksilah River watersheds.

The four active hydrometric stations in Groups 6 and 7 watersheds are all located with the San Juan River watershed. Group 6 watersheds contain the Renefrew and Garbage Creek hydrometric stations. The Harris Creek and San Juan River Near Port Renefrew stations are found within Group 7 watersheds. There are no active hydrometric stations along the Gordon River, Nitinat River, or Walbran Creek. However, there is a potential hydrometric station proposed for Gordon River by DFO.

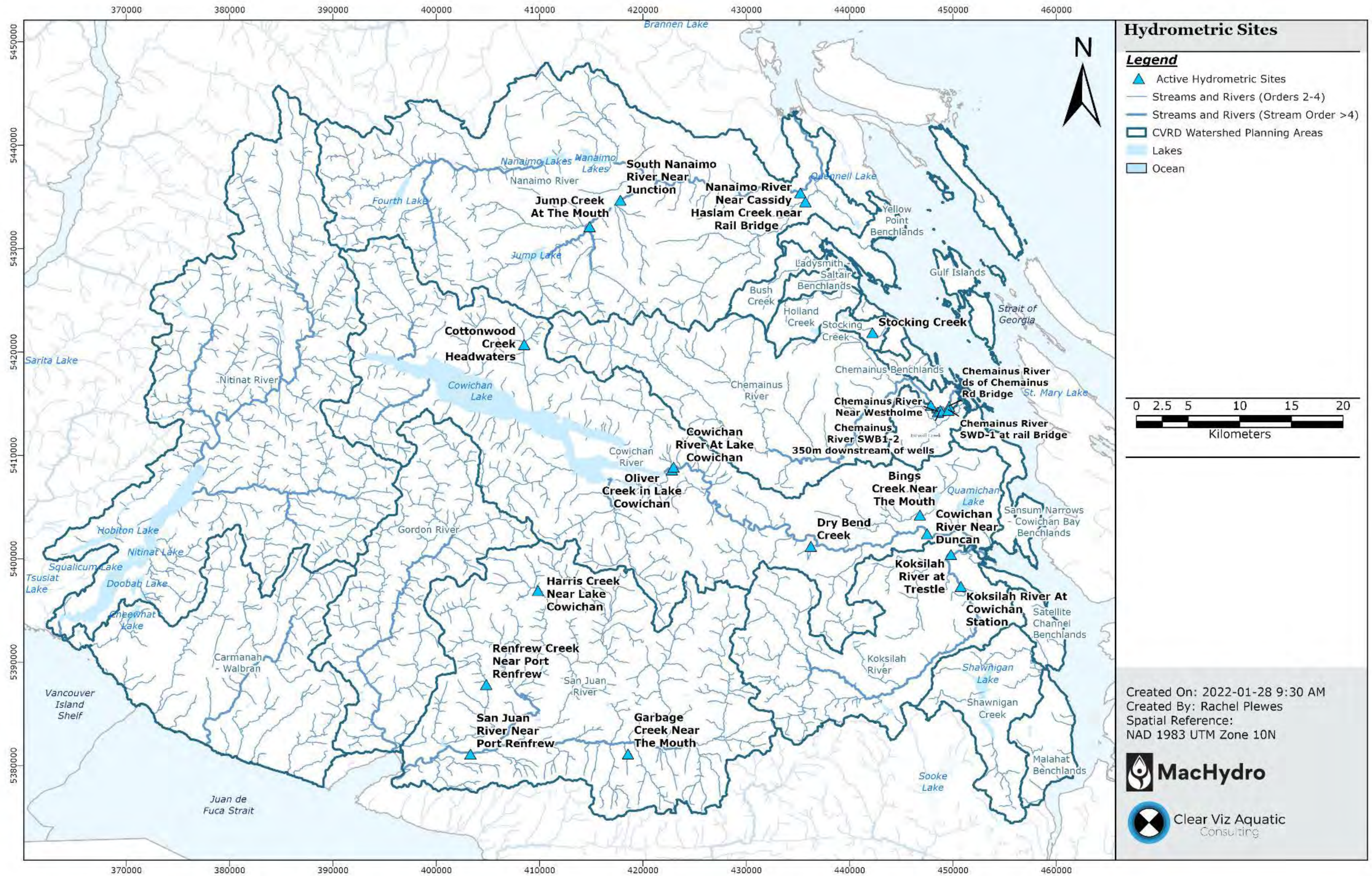

Figure 11: Active hydrometric sites within CVRD watershed planning areas.

Table 2: Active hydrometric stations that measure stream discharge in the study area

Station Name	Station Operator[1]	Record Length (years)	Station Type	Watershed Planning Area	Watershed Group
Cowichan River At Lake Cowichan	WSC	109	Real-time	Cowichan River	1
Cowichan River Near Duncan	WSC	62	Real-time	Cowichan River	1
Oliver Creek in Lake Cowichan	BC Hydro	2	Manual	Cowichan River	1
Dry Bend Creek	BC MoTI	1	Manual	Cowichan River	1
Chemainus River Near Westholme	WSC	107	Real-time	Chemainus River	1
Chemainus River ds of Chemainus Rd Bridge	BC Hydro	3	Real-time	Chemainus River	1
Chemainus River SWA-1 1.2 km upstream of wells	North Cowichan	6	Manual	Chemainus River	1
Chemainus River SWB1-2 350m downstream of wells	North Cowichan	6	Manual	Chemainus River	1
Chemainus River SWD-1 at rail Bridge	North Cowichan	6	Manual	Chemainus River	1
Koksilah River At Cowichan Station	WSC	107	Real-time	Koksilah River	2
Koksilah River at Trestle	BC Hydro	3	Real-time	Koksilah River	2
Bings Creek Near The Mouth	WSC	60	Real-time	Cowichan River	2
Nanaimo River Near Cassidy	WSC	56	Real-time	Nanaimo River	2
Haslam Creek near Rail Bridge	DFO	4	Real-time	Nanaimo River	2
Stocking Creek	Palmer (CVRD)	1	Real-time	Stocking Creek	2
Cowichan Lake Near Lake Cowichan	WSC	109	Real-time	Cowichan River	3
Jump Creek At The Mouth	WSC	51	Real-time	Nanaimo River	3
South Nanaimo River Near Junction	WSC	24	Real-time	Nanaimo River	3
Cottonwood Creek Headwaters	WSC	23	Real-time	Cowichan River	4
Garbage Creek Near The Mouth	WSC	25	Real-time	San Juan River	6

Station Name	Station Operator[1]	Record Length (years)	Station Type	Watershed Planning Area	Watershed Group
Renfrew Creek Near Port Renfrew	WSC	25	Real-time	San Juan River	6
San Juan River Near Port Renfrew	WSC	62	Real-time	San Juan River	7
Harris Creek Near Lake Cowichan	WSC	25	Real-time	San Juan River	7

[1]Station operator indicates the organization responsible for the station, which includes Water Survey of Canada (WSC), Municipality of North Cowichan, Town of Ladysmith, Ministry of Transportation and Infrastructure (MoTI).

There are five designated community watersheds that provide sources of water for the CVRD or its municipal water systems (Table 3). Three of the five community watersheds have active or proposed hydrometric stations. The Town of Ladysmith has proposed a Holland Lake station within the Holland Community Watershed. CVRD installed a hydrometric station on Stocking Creek in 2021 downstream of the Stocking Lake Community Watershed. The location of the Stocking Creek station was selected because of its proximity to groundwater wells that may be used as a future municipal water source for the Saltair water system (Hemmera, 2021). In the Shawnigan Community Watershed, Shawnigan Lake levels are monitored weekly by CVRD staff. The Banon Community Watershed does not contain a hydrometric station and is used as a supplemental water source for the Chemainus Water System.

Table 3: Designated community watersheds that supply water to CVRD and municipal water systems with respective hydrometric monitoring stations.

Community Watershed	Source Name	Water Use	Water System	Station Name	Station Status	Measurement
Holland Community Watershed	Holland Creek/ Holland Lake	Primary	Diamond & Ladysmith Water System	Holland Lake	Proposed	Primary Water Level
Banon Community Watershed	Banon Creek	Supplemental (June 15th to Oct 15th	Chemainus Water System			
Stocking Lake Community Watershed	Stocking Creek/ Stocking Lake	Primary	Diamond, Ladysmith Water System & Saltair	Stocking Creek	Active	Discharge
Shawnigan Community Watershed	Shawnigan Creek	Primary/Backup	Shawnigan Lake North & Private	Staff Gauge (weekly levels)	Active	Primary Water Level

Municipal surface water sources that are not within a designated community watershed are listed in Table 4. The lakes and rivers used as primary water sources by municipal and regional water systems within the Cowichan River watershed have active hydrometric stations. However, Genoa Spring does not have an active hydrometric station. Genoa Bay is the primary water source for Genoa Bay residents.

The surface water sources used as an emergency backup or to supplement primary sources are not currently monitored.

Table 4: Water sources licensed for local waterworks in the CVRD with respective hydrometric monitoring stations.

Source Name	Water Use	Water System	Station Status	Station Name
Cowichan Lake	Primary	Lake Cowichan Water System	Active	Cowichan Lake Near Lake Cowichan
Cowichan River	Primary	Crofton Water System	Active	Cowichan River Near Duncan
Crofton Lake	Backup	Crofton Water System		
Holyoak Lake	Supplemental (June 15th to Oct 15th	Chemainus Water System		
Somenos Lake	Backup			
Ashburnham Creek	Backup	Honeymoon Bay		
Genoa Spring	Primary	Genoa Bay		

4.2 Hydrometric (Groundwater Levels)

There were 51 mapped aquifers assessed within the CVRD (Figure 12). The provincial groundwater observation well network (PGOWN) monitors 18 of 51 aquifers (Table 5). There is one unmapped aquifer near the Stocking Creek hydrometric station that is monitored by the CVRD and is a potential water source for the Saltair water system. Aquifers 161 and 162 provide a water source to the Regional District of Nanaimo (RDN). Aquifer 189 provides water for the Mesachie Lake and Youbou water systems. Aquifers 185, 946, and 203 are municipal water sources for CVRD residents.

The aquifers with the highest surface water supply rating are around Cowichan Lake followed by the unconfined sand and gravel aquifers located along the populated east coast around Duncan, Chemainus, Cowichan Bay as well as west of the Koksilah River (Table 5). The aquifers with a higher groundwater contamination rating are unconfined aquifers located at Duncan, Chemainus, Mill Bay and Cobble Hill, around Cowichan Lake, and the Gulf Islands (South Thetis, Reid, Thetis, Ruxton). Projected population pressure was rated highest for aquifers located around Shawnigan Lake/Cobble Hill/Mill Bay, Duncan/Sahtlam, and Cowichan Lake. Overall, the highest aquifer rating occurred in three unconfined sand and gravel aquifers: North Lake Cowichan (Aquifer 191), Youbou (Aquifer 190) and Duncan (Aquifer 186). There are no active monitoring wells in Aquifer 191 or 190, while Aquifer 186 has two active groundwater monitoring wells (Table 5). When aquifers are grouped by subtype and aquifer rating, the majority of aquifer types have active continuous monitoring wells (Table 6); however, aquifer subtypes with a moderate rating that include fractured crystalline or sedimentary bedrock and unconfined sand and gravel – late glacial outwash have a small number of monitoring wells relative to the number of mapped aquifers compared to other subtypes. Aquifer subtypes that are not currently monitored include unconfined sand and gravel – deltaic and fractured crystalline bedrock. One fractured crystalline bedrock located around Shawnigan Lake (Aquifer 203) has the highest number of groundwater wells compared to all other mapped aquifers in the CVRD (Table 5).

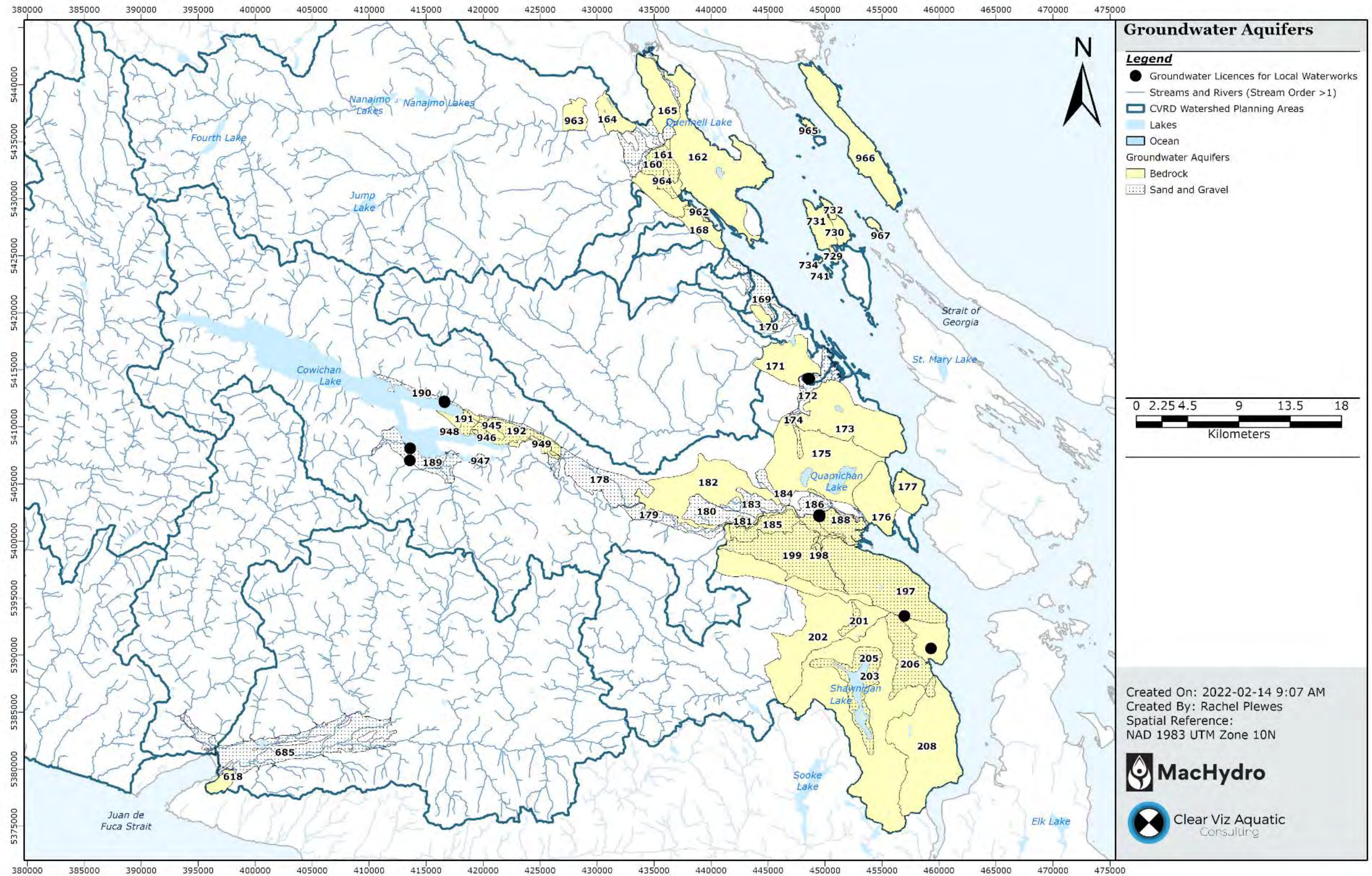

Figure 12: Map of mapped aquifers with municipal water licences.

Table 5: List of mapped aquifers within the boundary of the CVRD with surface water supply (SWS) rating, groundwater contamination (GWC) rating, and projected population (Pop) rating (SNC Lavalin, 2019). These three criteria were equally ranked to determine an aquifer rating.

Aquifer ID	Location	Subtype[1]	SWS Rating	GWC Rating	Pop Rating	Aquifer Rating	Water System	Assumed Drinking Water Wells[2]	Total Groundwater Wells	Total Well Density (well/km^2)	No. Continuous Monitoring Wells
186	Duncan	Stream	Moderate	Moderate High	High	High	North Cowichan	107	165	9.6	2
191	North Lake Cowichan	Deltaic	High	Low Moderate	High	High	-	42	45	13.3	0
190	Youbou	Deltaic	High	Low Moderate	High	High	-	15	16	5.8	0
197	Cowichan Bay, Cowichan Station, Hillbank, Cherry Point	Glacial	Moderate	Low Moderate	Moderate	Moderate	-	758	928	19.2	5
178	Skutz Falls, Lake Cowichan, Paldi	Glacial	Low Moderate	Low	High	Moderate	-	14	18	1.0	2
198	Cowichan Bay, Cowichan Station, Hillbank, and Fairbridge	FSB	Moderate	Low Moderate	Moderate	Moderate	-	265	299	2.9	2
206	Mill Bay and Cobble Hill	Outwash	Low Moderate	Moderate	High	Moderate	-	196	228	14.0	1
172	Chemainus and Crofton	Stream	Moderate	Moderate High	Low	Moderate	North Cowichan	41	53	7.2	1
199	West of Koksilah River, includes Fairbridge	Glacial	Moderate	Low	Moderate	Moderate	-	87	96	3.5	1
181	West Duncan	FSB	Low	Moderate	High	Moderate	-	27	30	23.7	0
180	Sahtlam	Glacial	Low	Moderate	High	Moderate	-	96	110	13.1	0

Aquifer ID	Location	Subtype[1]	SWS Rating	GWC Rating	Pop Rating	Aquifer Rating	Water System	Assumed Drinking Water Wells[2]	Total Groundwater Wells	Total Well Density (well/km²)	No. Continuous Monitoring Wells
948	West shore of Marble Bay, Cowichan Lake	Glacial	Low Moderate	Moderate	High	Moderate	-	4	4	12.4	0
203	Shawnigan Lake / Cobble Hill	FCB	Low Moderate	Low Moderate	High	Moderate	Shawnigan Imp. Dist.	1,179	1,243	10.2	0
949	East shore of Mesachie Lake	Stream	Moderate	Low Moderate	High	Moderate	-	25	25	8.5	0
185	Deerholm, South Duncan	Glacial	Moderate	Moderate	High	Moderate	North Cowichan	64	66	8.0	0
947	East shore of Mesachie Lake	Glacial	Low	Low	High	Moderate	-	7	7	6.0	0
183	West Duncan	Glacial	Moderate	Low Moderate	High	Moderate	-	30	34	5.4	0
946	North-eastern shore of Cowichan Lake	FCB	Low Moderate	Low Moderate	High	Moderate	-	16	18	4.8	0
175	North Duncan	FSB	Low Moderate	Low Moderate	High	Moderate	-	169	180	4.2	0
205	Shawnigan Lake area	Outwash	Low Moderate	Low Moderate	High	Moderate	-	49	55	4.2	0
189	Honeymoon Bay & Mesachie Lake	Deltaic	Moderate	Moderate	High	Moderate	CVRD	38	42	4.0	0
192	North Lake Cowichan	Glacial	Low Moderate	Low	High	Moderate	CVRD Private	27	32	3.6	0
182	Paldi - Sahtlam	FSB	Low Moderate	Low Moderate	High	Moderate	-	77	81	2.6	0
945	North-eastern shore of Cowichan Lake	FSB	Low Moderate	Low Moderate	High	Moderate	-	17	19	1.2	0
188	Duncan	Glacial	Low	Low	High	Moderate	North Cowichan	4	9	1.1	0
179	Sahtlam	Stream	Low	Low Moderate	High	Moderate	-	5	5	0.7	0

Aquifer ID	Location	Subtype[1]	SWS Rating	GWC Rating	Pop Rating	Aquifer Rating	Water System	Assumed Drinking Water Wells[2]	Total Groundwater Wells	Total Well Density (well/km^2)	No. Continuous Monitoring Wells
184	West Duncan	Outwash	Moderate	Moderate	High	Moderate	-	1	1	0.4	0
962	Ladysmith, BC	Outwash	Low Moderate	Low Moderate	Moderate	Moderate	-	10	11	18.8	0
170	Panorama Ridge, Chemainus	FCB	Low	Low Moderate	Moderate	Moderate	-	36	36	18.7	0
201	West slope of Cobble Hill	Outwash	Low Moderate	Low Moderate	Moderate	Moderate	-	23	26	13.4	0
208	East and south slope of Malahat Ridge	FCB	Low	Low Moderate	Moderate	Moderate	-	260	284	6.1	0
174	North Duncan	Glacial	Low	Moderate	Moderate	Moderate	-	8	8	5.4	0
176	East Duncan - Maple Bay	FSB	Low Moderate	Low	Moderate	Moderate	-	40	40	2.6	0
168	Ladysmith	FSB	Low Moderate	Low Moderate	Moderate	Moderate	-	13	15	2.2	0
169	Saltair, South Ladysmith	Glacial	Low Moderate	Low Moderate	Moderate	Moderate	-	13	21	2.1	0
173	Maple Mountain, Crofton - Maple Bay	FCB	Low Moderate	Low	Moderate	Moderate	-	52	52	1.5	0
202	Shawnigan Lake / Cobble Hill	FCB	Low	Low	Moderate	Low	CVRD Private	194	205	5.2	1
161	Cassidy	Stream	Moderate	Low Moderate	Low	Low		169	206	7.1	2
162	Cedar, Yellow Point, N. Oyster (Ladysmith)	FSB	Low	Low Moderate	Low	Low	-	1,123	1,215	24.8	1
729	South Thetis Island	FSB	Low Moderate	Moderate	Low	Low	-	47	51	87.8	0
732	Thetis Island	FSB	Low Moderate	Moderate	Low	Low	-	43	52	42.0	0

Aquifer ID	Location	Subtype[1]	SWS Rating	GWC Rating	Pop Rating	Aquifer Rating	Water System	Assumed Drinking Water Wells[2]	Total Groundwater Wells	Total Well Density (well/km^2)	No. Continuous Monitoring Wells
741	Hudson Island	FSB	Low Moderate	Low Moderate	Low	Low	-	2	2	34.5	0
734	Dayman Island	FSB	Low Moderate	Low Moderate	Low	Low	-	3	3	33.5	0
730	South East Thetis Island	FSB	Low	Low Moderate	Low	Low	-	44	47	17.9	0
967	Reid Island	FSB	Low Moderate	Moderate	Low	Low	-	12	12	13.2	0
965	Ruxton Island	FSB	Low Moderate	Moderate	Low	Low	-	7	9	10.1	0
731	Thetis Island	FSB	Low Moderate	Low Moderate	Low	Low	-	61	66	10.0	0
964	Cassidy Nanaimo Airport	FSB	Low Moderate	Low Moderate	Low	Low	-	57	64	3.7	0
171	Mount Sicker, Crofton - Chemainus	FSB	Low Moderate	Low	Low	Low	-	29	31	2.1	0
966	Valdes Island	FSB	Low Moderate	Low	Low	Low	-	3	5	0.2	0
177	East Duncan - Maple Bay	FSB	Low	Low	Moderate	Low	-	42	42	5.5	0

[1]Aquifer subtypes include fractured crystalline bedrock (FCB), Fractured Sedimentary Bedrock (FSB), Unconfined Sand and Gravel – Deltaic (Deltaic), Unconfined Sand and Gravel – Late Glacial Outwash (Outwash), Unconfined Sand and Gravel Aquifer – Medium Stream System (Stream), Confined Sand and Gravel – Glacial (Glacial).

[2]Potential drinking water wells included groundwater wells that have an intended water use classified as "private domestic", "water supply system", or "unknown well use". Inspection of "unknown well use" wells were typically located within developed residential area and were assumed to have an intended water use as a potential drinking water source. Number of wells reflect those that were correlated with the specific aquifer and not the number of wells within the mapped aquifer footprint.

Table 6: Mapped aquifer types within the CVRD grouped by aquifer rating with the number of active continuous groundwater monitoring wells operated by the CVRD or the PGOWN network.

Aquifer Types in CVRD	Aquifer Rating	No. Mapped Aquifers	No. Continuous Monitoring Wells
Fractured crystalline bedrock	Moderate	5	0
Fractured crystalline bedrock	Low	1	1
Fractured sedimentary bedrock	Moderate	7	2
Fractured sedimentary bedrock	Low	13	1
Unconfined sand and gravel - deltaic	High	2	0
Unconfined sand and gravel - deltaic	Moderate	1	0
Unconfined sand and gravel – late glacial outwash	Moderate	5	1
Unconfined sand and gravel – medium stream system	High	1	2
Unconfined sand and gravel – medium stream system	Moderate	3	1
Unconfined sand and gravel – medium stream system	Low	1	2
Confined sand and gravel - glacial	Moderate	12	8

4.3 Climate

There is good coverage of climate stations below 300 m.a.s.l along the eastern coastline, except for the area between Duncan and Shawnigan Lake along the coastal benchlands (Figure 2). Low elevation areas that extend inland to Cowichan Lake are limited to the stations at Lake Cowichan, North Cowichan and Shawnigan Lake. There are no active climate stations between 300 – 800 m.a.s.l. in the east-ward flowing watersheds, which makes up much of the elevation gradient for the Chemainus and Koksilah watersheds. Above 800 m.a.s.l., there are active snow pillows at Heather Mountain and Jump Creek (and Mt. Arrowsmith about 15 km north of Nanaimo River headwaters and outside of the study area; Table 7). There are fewer climate stations within the westward-flowing watersheds (Watershed Groups 6 and 7); however, there is coverage in the region with the greatest precipitation in the study area (Summit and Nitinat River Hatchery stations). Other stations are at lower elevation likely due to access or within the San Juan watershed.

All Watershed Groups contain at least one active or proposed climate station. However, climate stations are concentrated in Group 2, which is the warmest and driest Watershed Group (Figure 14). Group 1 only contains the proposed climate station at Holland Lake (657 m.a.s.l.) by the Town of Ladysmith.

Station operators of the 18 active climate stations vary across the study area (Table 7). There are currently six stations operated through a co-operative community network with data publicly available though ECCC. These stations should be continually tracked to ensure that operation continues into the future and may need to be replaced by a CVRD operator.

There are no active manual snow survey transects within the study area. There were historical snow surveys done at Lyford Mountain, Heather Mountain and Jump Creek. However, both Heather Mountain and Jump Creek are now active snow pillow sites. There were also historical snow surveys near the CVRD boundary at Labour Day Lake and Sno-bird Lake.

Table 7: Active climate stations within the study area and the station operator. Climate stations monitor both precipitation and air temperature.

Station Name	Station Operator[1]	Elevation (m.a.s.l.)	Record Length (years)	Station Type	Watershed Group
Chemainus	CCN	70	90	Climate	2
Ladysmith Public Works Roof	Town of Ladysmith	95	8	Climate	2
Cedar	BC FLNRORD - WMB	36	33	Climate	2
Nanaimo A	NAV Canada	32	68	Climate	2
Malahat	ECCC	355	40	Climate	2
Malahat	BC MoTI	298	9	Climate	2
Shawnigan Lake	CCN	141	111	Climate	2
North Cowichan[2]	CCN	49	41	Precipitation Only	2
North Cowichan[2]	ECCC	49	10	Temperature Only	2
Crofton Substation	Catalyst Paper & Pulp	40	6	Temperature Only	2
Mesachie 2	BC FLNRORD - WMB	164	16	Climate	3
Lake Cowichan	CCN	199	62	Climate	3
Jump Creek	BC ENV - Snow Pillow	873	27	Climate	3
Heather Mountain Upper	BC ENV - Snow Pillow	1,183	7	Climate	4
Nitinat River Hatchery	CCN	21	41	Climate	6
Summit	BC FLNRORD - WMB	638	31	Climate	6
Port Renfrew	CCN	19	46	Climate	6
Ts San Juan	BC FLNRORD - WMB	293	16	Climate	7
Carmanah Point	Canadian Coast Guard	0	50	Precipitation Only	7

[1]Station operators include a Co-operative Climate Network (CCN), Environment and Climate Change Canada – Meteorological Service of Canada (ECCC), BC FLNRORD – Wildfire Management Branch (WMB), BC Ministry of Transportation and Infrastructure (MoTI), and Department of Fisheries and Oceans (DFO).
[2]The North Cowichan stations are located in proximity to each other, but have two different operators.

5 Site Selection

The selection of sites includes a relative priority of implementation of monitoring stations in three phases: 1) High Priority (within 1 – 2 years); 2) Moderate Priority (within 5 years); and, 3) Low Priority (after 5 years). Priority has been based on the criteria outlined in the framework. There was a focus with the high priority sites to fill gaps in the baseline monitoring network, monitor municipal/community watershed drinking water sources, and collect data on high vulnerability aquifers that have greater risk of groundwater contamination and surface and groundwater sources that are important for drinking water supply.

5.1 Hydrometric Stations (Discharge and Lake Level)

There were five high priority stream gauging sites selected within the Shawnigan Creek, Bonsall Creek, Chemainus River, and Koksilah River WPAs using a combination of manual and real-time data retrieval (Table 8). The potential hydrometric stations for Shawnigan Creek and Bonsall Creek are located at inactive Water Survey of Canada stations. The potential Chemainus and Koksilah River stations are at new sites in the middle and upper reaches (Figure 13). Koksilah River at Renefrew Rd and Chemainus River above Chipman Creek are in Group 3 watersheds. Chemainus River above Rheinhart Creek is within a Group 4 watershed (Figure 14). The installation of hydrometric stations along Chemainus River would provide an opportunity to look at streamflow regimes at a range of watershed scales without the added complexity of large storage reservoirs (e.g., Cowichan Lake).

There were three moderate priority sites selected within the Malahat Benchlands, Satellite Channel Benchlands, and Chemainus River (Table 8). Two of the sites are within the Satellite Channel Benchland and only one would be a priority to install a steam gauging cross section because they both drain similar land cover and have a historical water quality monitoring location: Unnamed Stream at Kilmalu Rd and Garnett Creek near Cobble Hill (Figure 13). These streams are relatively small and may be affected by land development; therefore, site selection in the Satellite Channel Benchland should be based on field reconnaissance. In addition, there were three sites selected as low priority, because the purpose of monitoring is to evaluate the water balance of WPAs or a watershed group (Table 8).

Sites selected for monitoring of lake level include Holyoak Lake, Somenos Lake (reinstatement), and Crofton Lake (Table 9). These sites act as a supplemental or backup drinking water source. The Town of Ladysmith has proposed installation of lake level monitoring in Holland Lake because it is used as a primary drinking water source for the Diamond & Ladysmith Water System.

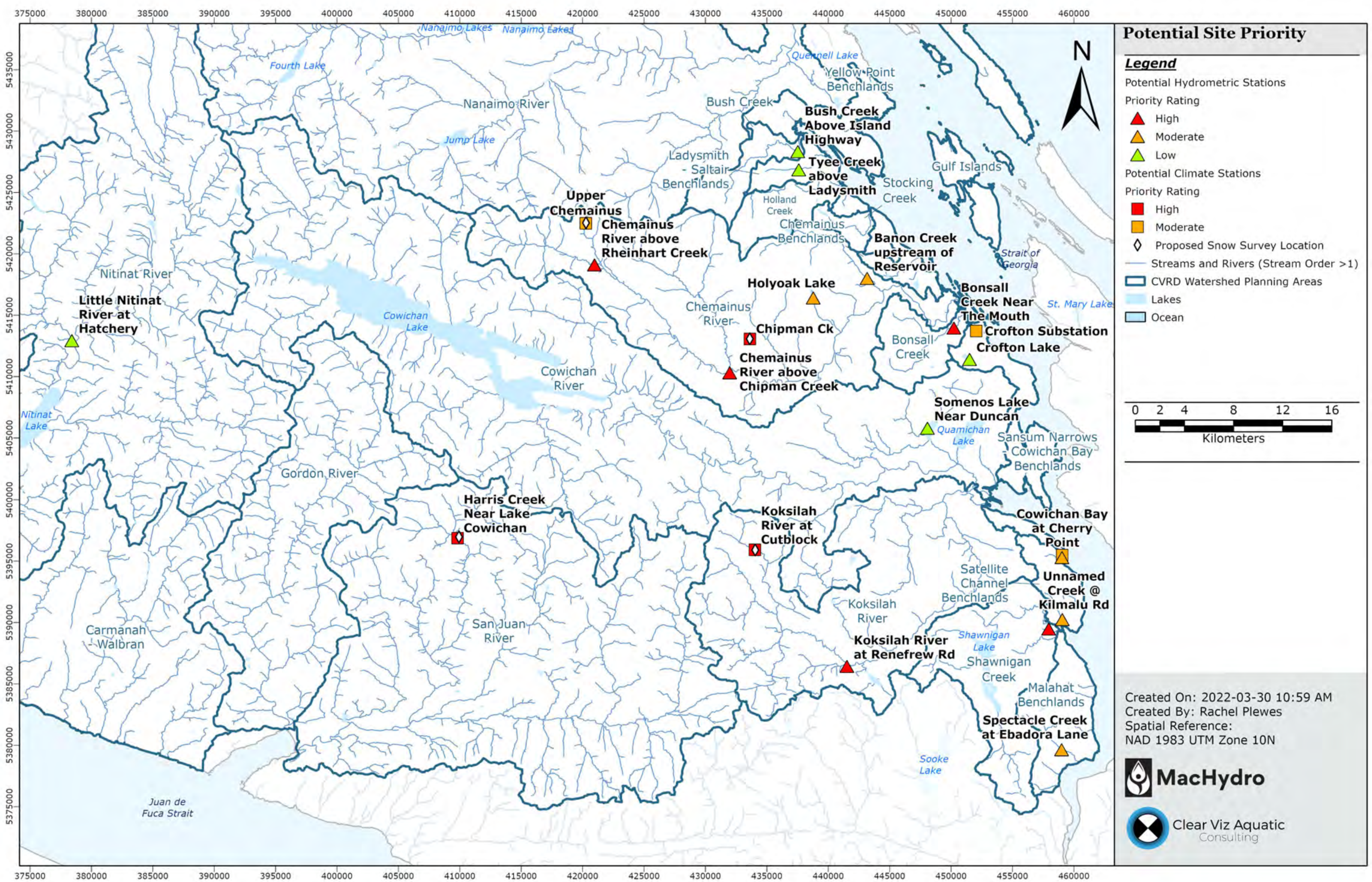

Figure 13: Map of potential hydrometric and climatic stations ranked by priority.

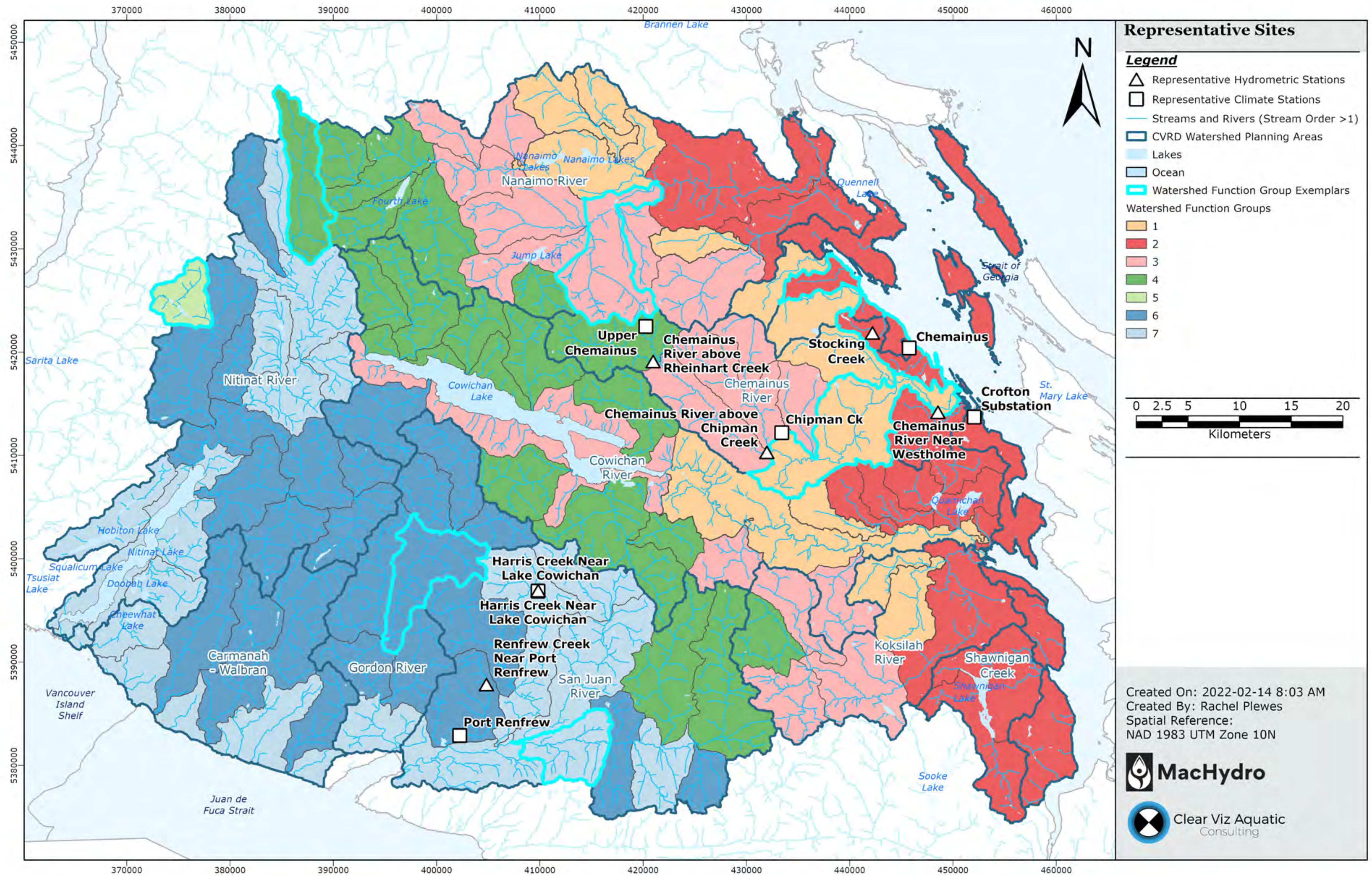

Figure 14: Representative sites for each Watershed Group.

Table 8: Recommended list of new (and reinstatement) hydrometric monitoring stations to measure discharge with rationale for addition of monitoring station into the hydrometric monitoring network. Priority ranking includes: high (within 1 – 2 years); moderate (within 5 years); and, low (after 5 years).

Station Name	Parameter	Watershed Planning Area (Watershed Group)	Station Status	Cellular Coverage[1]	Data Retrieval	Priority Rating	Rationale
Shawnigan Creek Below Shawnigan Lake	Discharge	Shawnigan Creek (2)	Inactive	Likely	Manual	High	Reinstatement to monitor the major stream in the Shawnigan Creek WPA for watershed planning.
Bonsall Creek Near the Mouth	Discharge	Bonsall Creek (2)	Inactive	Likely	Manual	High	Reinstatement to monitor the major stream in the Bonsall Creek WPA for watershed planning.
Koksilah River at Renefrew Rd	Discharge	Koksilah River (3)	Assumed Inactive	No	Real-time – Satellite	High	Reinstatement to monitor the Koksilah River before extensive irrigation and industrial water use. AQUARIS WebPortal indicates station is "Active", but short data record shows summer low flow measurements for two summers ending in 2019. Recommend upgrading to an all-year station.
Chemainus River above Chipman Creek	Discharge	Chemainus River (3)	New	No	Real-time – Satellite	High	To monitor the middle reaches of the Chemainus River to evaluate water balance and streamflow regime at multiple watershed scales.
Chemainus River above Rheinhart Creek	Discharge	Chemainus River (4)	New	No	Manual	High	To monitor the headwaters of the Chemainus River to evaluate water balance and streamflow regime at multiple watershed scales (Group 4 representative watershed). There is an active BC ENV water quality monitoring site at Meade Creek Bridge upstream of Rheinhart Ck tributary. The stream gauging section could be located in the same location or downstream of Rheinhart Ck confluence at the mouth of the assessment watershed.
Garnett Creek at Cherry Point Beach /Unnamed Ck @ Kilmalu Rd	Discharge	Satellite Channel Benchlands (2)	New	Likely	Manual	Moderate	Installation to monitor a stream in the Satellite Channel Benchlands WPA for watershed planning. Another option is Unnamed Ck @ Kilmalu Rd and selection between Garnett and Unnamed Creeks would be based on field reconnaissance.
Spectacle Creek at Ebadora Lane	Discharge	Malahat Benchlands (2)	New	Likely	Manual	Moderate	Installation to monitor the major stream in the Malahat Benchlands WPA for watershed planning.

Station Name	Parameter	Watershed Planning Area (Watershed Group)	Station Status	Cellular Coverage[1]	Data Retrieval	Priority Rating	Rationale
Banon Creek upstream of Reservoir	Discharge	Chemainus River (1)	New	Likely	Real-Time – Cellular	Moderate	Used as a supplemental drinking water source for the Chemainus System.
Little Nitinat River at Hatchery	Discharge	Nitinat River (6)	New	No	Manual	Low	Installation to monitor the Little Nitinat River upstream of confluence with Nitinat River that flows into the Nitinat Lake. The gauge would also monitor flows from the stream that drains the Group 5 representative watershed (receives highest precipitation). Adjacent to an ECCC climate station (cooperative community network) and located approximately 300 m outside of the regional boundary of CVRD. Potential community partner to maintain the station similar to the climate station. There is also a real-time water level gauge monitored by DFO somewhere upstream of the Nitinat Lake that could be a potential partner.
Bush Creek above Island Highway	Discharge	Bush Creek (1)	Inactive	Likely	Manual	Low	Installation to monitor the major stream in the Bush Creek WPA for watershed planning. This site is also an active surface water quality monitoring site.
Tyee Creek above Ladysmith	Discharge	Ladysmith - Saltair Benchlands (2)	New	Likely	Manual	Low	Installation to monitor the major stream in the Ladysmith-Saltair Benchlands WPA for watershed planning.

[1] Cellular coverage was estimated based on Canadian coverage from the largest mobile carriers (http://comparecellular.ca/coverage-maps/).

Table 9: Recommended list of new (and reinstatement) hydrometric monitoring stations to measure lake level with rationale for addition of monitoring station into the hydrometric monitoring network. Priority ranking includes: high (within 1 – 2 years); moderate (within 5 years); and, low (after 5 years). All are classified as manual data retrieval.

Station Name	Parameter	Watershed Planning Area (Watershed Group)	Station Status	Cellular Coverage[1]	Priority Rating	Rationale
Holyoak Lake	Primary Water Level	Chemainus River (2)	New	Likely	Moderate	Used as a supplemental drinking water source for the Chemainus System.
Somenos Lake Near Duncan	Primary Water Level	Cowichan River (1)	Inactive	Likely	Low	Used as a supplemental drinking water source for the Municipality of North Cowichan.
Crofton Lake	Primary Water Level	Sansum Narrows - Cowichan Bay Benchlands (2)	New	Likely	Low	Used as a backup drinking water source for the Town of Crofton.

[1] Cellular coverage was estimated based on Canadian coverage from the largest mobile carriers (http://comparecellular.ca/coverage-maps/).

5.2 Hydrometric (Groundwater Levels)

There were four high priority sites selected for additional groundwater monitoring (Table 10; Figure 15; Figure 16), which would provide data on two groups of aquifer subtypes that are not currently monitored in the CVRD. Additional sites were selected to increase the number of aquifers monitored in a specific aquifer subtype and rating (North Duncan, Shawnigan Lake, Malahat Ridge, and Cobble Hill). These aquifers also have high population and/or development pressure. In addition, Malahat Ridge and North Duncan have a high density of wells per square kilometer of aquifer area compared to others in the subtype. In addition, more groundwater monitoring sites were selected to collect data to improve the understanding of surface water – groundwater interactions or between layered aquifer systems. For example, there is a need for baseline monitoring prior to significant change from the level of anticipated development in new residential subdivisions in the area of Aquifer 178 (actively monitored) and 182, which overly the deeper confined Aquifer 179 (personal communication, Sylvia Barroso, Regional Hydrogeologist – BC Water Protection). Monitoring of this layered aquifer system would also improve understanding of the relationship to Cowichan River baseflow and is an important area of interest to Cowichan Tribes. It may be worthwhile to investigate inactive PGOWN wells located in unmonitored aquifers (Table 11). However, the condition of the wells and potential issues with monitoring or land agreements are largely unknown, and these wells would have been decommissioned for a reason.

Table 10: Recommended list of new groundwater monitoring wells with rationale for addition into the groundwater monitoring network. Priority ranking includes: high (within 1 – 2 years); moderate (within 5 years); and, low (after 5 years). All are classified as manual data retrieval.

Aquifer ID	Location	Aquifer Subtype	Aquifer Rating	Station Status	Priority Rating	Rationale
189	Honeymoon Bay & Mesachie Lake	Unconfined sand and gravel - deltaic	Moderate	New	High	No current monitoring in aquifer type/rating. Hydrologic connection to lake and tributary streams that flow into lake. Gather representative data for upper Cowichan watershed.
190	Youbou	Unconfined sand and gravel - deltaic	High	New	High	Install to monitor aquifer with high rating and no current monitoring in aquifer type/rating. Hydrologic connection to lake and tributary streams that flow into lake. Gather representative data for upper Cowichan watershed.
191	North Lake Cowichan	Unconfined sand and gravel - deltaic	High	New	High	Install to monitor aquifer with high rating and no current monitoring in aquifer type/rating
203	Shawnigan Lake/Cobble Hill	Fractured crystalline bedrock	Moderate	Inactive	High	High population and/or development pressure, high groundwater reliance (well density) and no current monitoring in aquifer type. Monitor to understand hydrologic connection to Shawnigan Creek and Shawnigan Lake flow system. Potential to reinstate inactive PGOWN (Obs256 and Obs380)
175	North Duncan	Fractured sedimentary rock	Moderate	New	Moderate	Increase number of aquifers monitored in aquifer type/rating, high population and/or development pressure, high well density. Likely contributes to Averill Ck baseflow.
205	Shawnigan Lake area	Unconfined sand and gravel – late glacial outwash	Moderate	New	Moderate	Increase number of aquifers monitored in aquifer type/rating, high population and/or development pressure.

Aquifer ID	Location	Aquifer Subtype	Aquifer Rating	Station Status	Priority Rating	Rationale
208	East & South Slope of Malahat Ridge	Fractured crystalline bedrock	Moderate	New	Moderate	Increase number of aquifers monitored in aquifer type/rating, moderate to high population and/or development pressure, high groundwater reliance.
946	North-eastern shore of Cowichan Lake	Fractured crystalline bedrock	Moderate	New	Moderate	High population and/or development pressure. Part of Aquifer 191/946/948 layered aquifer system that borders the Cowichan River.
948	West shore of Marble Bay, Cowichan Lake	Confined Sand and Gravel – Glacial	Moderate	New	Moderate	High population and/or development pressure, high groundwater reliance. Part of Aquifer 191/946/948 layered aquifer system that borders the Cowichan River.
179	Sahtlam	Unconfined Sand and Gravel Aquifer – Medium Stream System	Moderate	New	Moderate	High population and/or development pressure. Part of Aquifer 178/179/182 layered aquifer system. Hydrologic connection with Cowichan River.
182	Paldi - Sahtlam	Fractured sedimentary rock	Moderate	New	Moderate	High population and/or development pressure, high groundwater reliance. Part of Aquifer 178/179/182 layered aquifer system. Hydrologic connection with Cowichan River.
201	West slope Cobble Hill, along east bank Koksilah River	Unconfined sand and gravel – late glacial outwash	Moderate	New	Low	Increase number of aquifers monitored in aquifer type/rating, moderate to high population and/or development pressure.
170	Panorama Ridge, Chemainus	Fractured crystalline bedrock	Moderate	New	Low	High groundwater reliance. Part of Aquifer 170/171/172 layered aquifer system with strong hydrologic connection to Chemainus River.
171	Mount Sicker, Crofton - Chemainus	Fractured sedimentary rock	Low	New	Low	High groundwater reliance. Part of Aquifer 170/171/172 layered aquifer system with strong hydrologic connection to Chemainus River.

Table 11: List of inactive PGOWN wells located in mapped aquifers within the CVRD.

Aquifer ID	Location	Aquifer Subtype	Aquifer Rating	Condition[1]
203	OBS Well 380 – Mill Bay (Kinnoull Cr.)	Fractured crystalline bedrock	Moderate	Potential land agreement issue
203	OBS Well 256 – Mill Bay (Kilmalu Rd.)	Fractured crystalline bedrock	Moderate	Unknown
186	OBS Well 298 – Cowichan Bay (Southeast)	Unconfined sand and gravel – medium stream system	High	Physically buried
188	OBS Well 297 – Cowichan Bay (Southeast)	Confined sand and gravel – glacial	Moderate	Unknown
162	OBS Well 315 – Ladysmith	Fractured sedimentary bedrock	Low	Unknown

[1]Information about the condition of some wells was obtained from Jessica Doyle, Sylvia Barroso and Graeme Henderson, FLNRORD.

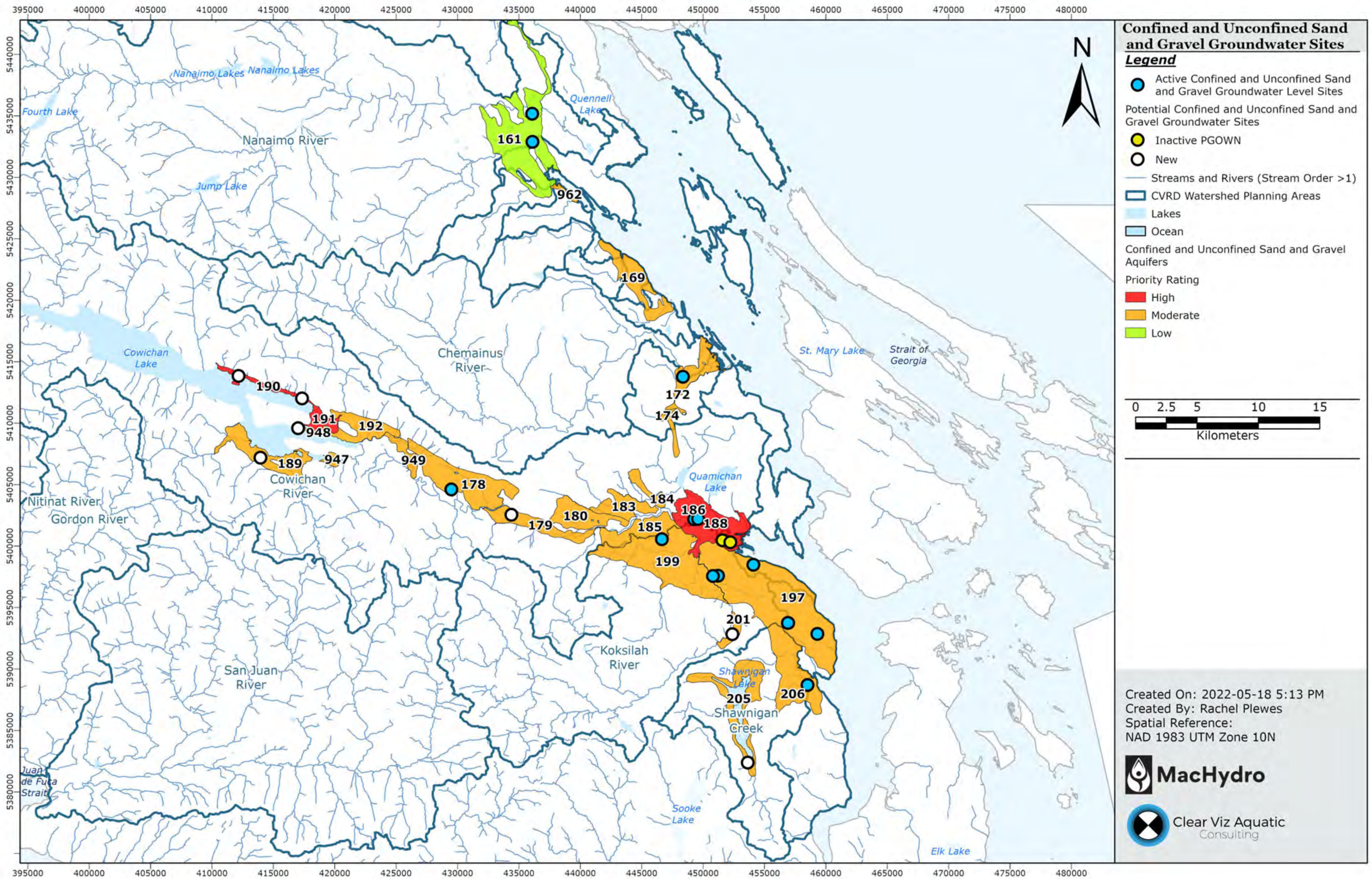

Figure 15: Map of mapped confined and unconfined sand and gravel aquifers ranked by aquifer rating with location of active and inactive groundwater monitoring wells and potential new monitoring sites.

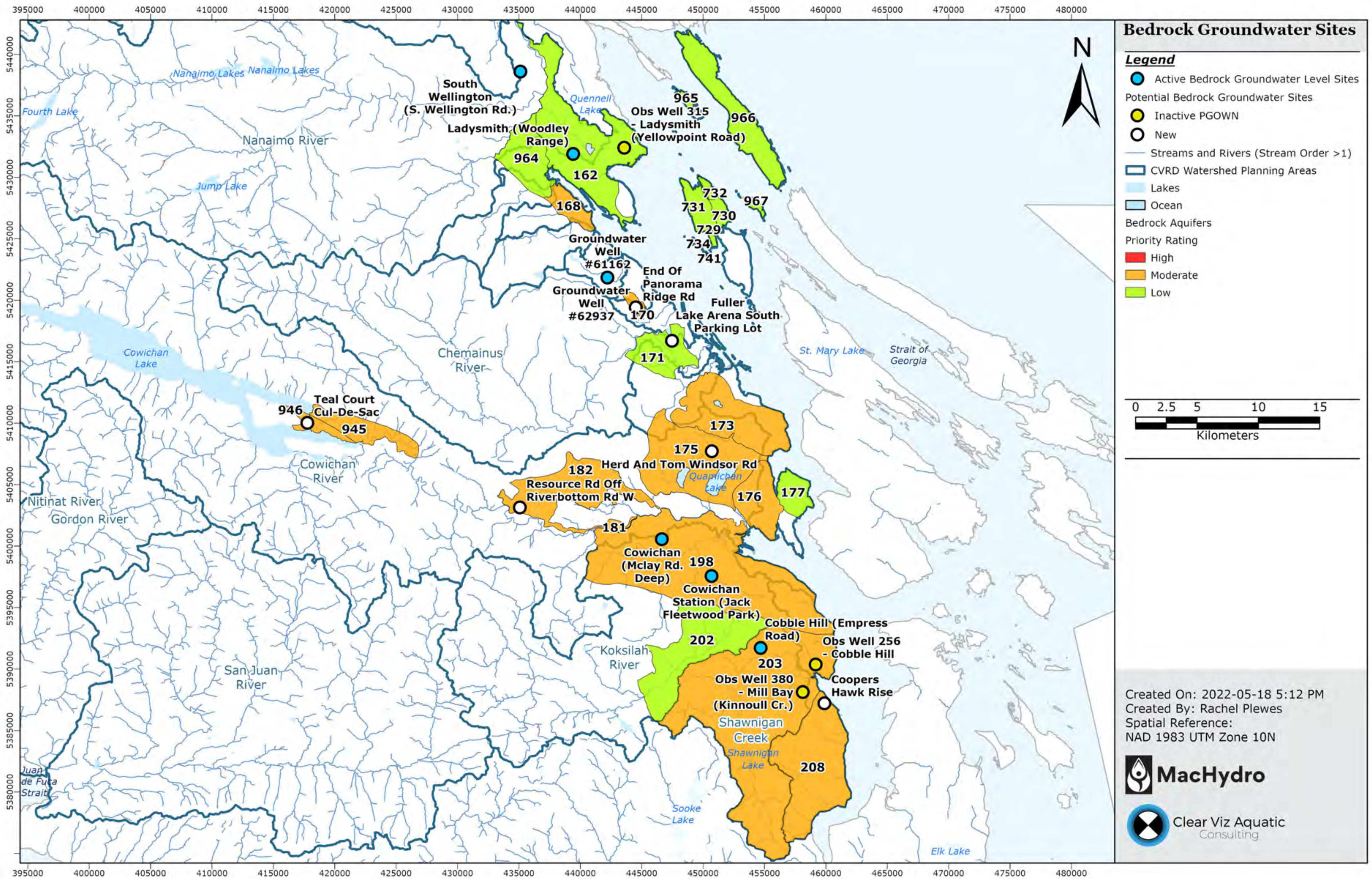

Figure 16: Map of mapped bedrock aquifers ranked by aquifer rating with location of active and inactive groundwater monitoring wells.

5.3 Climate

There were three high priority sites selected for climate stations, which includes real-time stations in the Chemainus and Koksilah watersheds. These stations are representative climate stations for the real-time hydrometric stations. There were three moderate priority sites selected to fill in precipitation gaps along the eastern coast and provide another high elevation climate station located in the Chemainus headwaters. Two of the potential climate stations are located in proximity to inactive climate stations (Table 12): Chipman Ck (ARDA) and Harris Creek Near Lake Cowichan (BC Forest Renewal). The Crofton Substation is currently monitoring air temperature as part of the BC ENV-Air Quality Network. We recommend adding a tipping bucket rain gauge with alter shield to the site to fill in a precipitation gap along the eastern coastline. The CVRD should also support the Town of Ladysmith in the installation of the proposed Holland Lake climate station.

Manual snow surveys combined with the snow depth sensor or all-season snow gauge would provide a measure of the quantity of snow in an area (rather than at a point) and provide information for water supply and flood forecasting. Snow survey transects were added to be conducted in proximity to four climate stations: Chipman Ck, Koksilah River at Cutblock, Harris Creek near Lake Cowichan, and in Upper Chemainus (Table 12). However, collection of snowpack data from transects through the winter months will depend on availability of site access via roads. Therefore, the feasibility of a snow survey transect should be assessed to review conditions and suitability of installation and on-going monitoring.

Table 12: Recommended list of new (and reinstatement) climate monitoring stations with rationale for addition of monitoring station into the climate monitoring network. Priority ranking includes: high (within 1 – 2 years); moderate (within 5 years); and, low (after 5 years). Snow surveys provide an estimate of snowpack snow water equivalent in the area near to the climate station.

Station Name	Watershed Planning Area (Watershed Group)	Elevation (m.a.s.l.)	Station Status	Cellular Coverage	Station Type	Snow Survey	Data Retrieval	Priority Rating	Rationale
Chipman Ck	Chemainus River (3)	570	New	No	All-Season	Yes	Real-Time – Satellite	High	Install to provide climate data for the middle reaches of Chemainus River (above Chipman Ck; Group 3 representative watershed) and fill gap in higher elevation precipitation. This site is 890 m NW from the historical FLNRORD – WMB Chipman Ck station.
Koksilah River at Cutblock	Koksilah River (3)	482	New	No	All-Season	Yes	Real-Time – Satellite	High	Install to fill the gap in higher elevation precipitation and provide climate data for the headwaters of Koksilah River for watershed planning.
Harris Creek Near Lake Cowichan	San Juan River (7)	285	Inactive	No	Rain	Yes	Manual	High	Reinstatement to provide climate data for the Harris Creek hydrometric station located in a Group 7 watershed.
Upper Chemainus	Chemainus River (4)	652	New/Inactive	No	All-Season	Yes	Manual	Moderate	Install to provide climate data for the headwaters of Chemainus River (Group 4 representative watershed) and fill gap in higher elevation precipitation. There is an inactive FLNORD-WMB climate station in the area, but road access may be limited as it was decommissioned in 2000.
Crofton Substation	Sansum Narrows - Cowichan Bay Benchlands (2)	40	Air Temperature Only	Likely	*Rain*	No	Manual	Moderate	Install only rain gauge and wind shield to fill in precipitation gap along eastern coast and provide a representative climate station for the Chemainus River near Westholme hydrometric gauge (Group 1 representative watershed).
Cowichan Bay at Cherry Point	Sansum Narrows - Cowichan Bay Benchlands (2)	1	Inactive	Likely	Rain	No	Manual	Moderate	Reinstatement to fill in precipitation gap along eastern coast between Duncan and Shawnigan Lake. Long-term climate history (88 years).

[1] Cellular coverage was estimated based on Canadian coverage from largest mobile carriers (http://comparecellular.ca/coverage-maps/).

6 Hydrometric and Climate Station Descriptions and Costs

The following sections outline the equipment needed for each monitoring station and the typical costs associated with equipment, installation, and on-going maintenance. No additional snow pillows were recommended, but additional snow survey transects were recommended for the network. Stations are either manually operated (delay in data collection because of manual download) or data collected at the monitoring station is transferred in real-time via telemetry to a central database either by satellite (remote) or cellular. Costs would assume installation at site locations that would be provided free of charge. Installation costs assume $175/hr for a hydrologist and $90/hr for a field technician (10-hour day). Routine field visits assume $360/day/person for a field technician (4-hour day). The budgets are based on cost estimates from similar projects and information assembled from the sources below:

- Environmental Sales – Hydrology & Meteorology, Hoskin Scientific
- Environmental Sales – Campbell Scientific Canada
- Drillwell Enterprises Ltd. – Water Well Drilling Specialists, Duncan, BC

6.1 Hydrometric (Discharge and Lake Level)

The components of a hydrometric station include:

1. Water level logger (data logger with pressure transducer)
2. Barometric pressure logger (data logger with pressure transducer)
3. Stilling well
4. Manual water level gauge (staff gauge)
5. Benchmarks (survey level and rod)

The water level logger is used to collect a continuous record of water level. The water level record must be corrected for barometric pressure. Some logger types have a barometric pressure sensor integrated, or are vented to the atmosphere. It is standard practice to survey the benchmarks to the staff gauge to ensure there is no movement of the water level gauge due to discharge or wave action (RISC, 2018). Lake level monitoring only requires the above equipment, but for a hydrometric station water levels are converted to discharge using a water level-discharge relationship (i.e., rating curve). Rating curves can be constructed using known hydraulics from a structure like a weir or culvert or from a series of manual water level and discharge measurements collected in the field. Hydrometric stations usually require at least 10 manual discharge measurements to be collected over a range of flows in the first year to develop the rating curve. Once a rating curve is established for a stream, the stream gauging section needs continued monitoring to confirm the channel conditions (and rating curve) have not changed (at least 5 measurements per year; RISC, 2018).

Manual discharge measurements are most often recorded using the velocity-area method and a flow velocity meter (e.g. Price meter, FlowTracker). However, this method may be difficult to implement in smaller streams, at low flows, or too high flows that are dangerous to wade. Therefore, other methods are often used to measure stream discharge including diverting low flow into a flume (known rating curve), collecting the streamflow in a bucket of known volume/time, Doppler technology to measure the velocity of surface flow, or salt dilution methods. The cost of these methods varies widely and is not included in the cost estimate (Table 13).

Table 13: Cost estimates for monitoring discharge at a hydrometric station. The cost estimate for a station depends on manual versus real-time data collection and cellular versus satellite data retrieval. All pressure transducers also collect water temperature. Monitoring station installation, rating curve development and on-going maintenance would be similar for all three data collection methods. Refer to Table 8 for details on phased priority.

Item	Cost Estimate	Comments
Manual Data Retrieval		
Equipment (Data logger, Pressure Transducer, Misc. Installation Supplies)[1]	$1300	Includes the Hobo MX2001 Water level logger with integrated barometric pressure
Cellular Data Retrieval		
Equipment (Data logger with Telemetry, Pressure Transducer, Misc. Installation Supplies)[1]	$5500	Includes Onset RX3000 data logger with vented PS9800 pressure transducer
Annual Subscription Fees	$315	Cloud service (30 min logging rate), 6 hr connection, 5 MB monthly plan
Satellite Data Retrieval		
Equipment (Data logger with Telemetry, Pressure Transducer, Misc. Installation Supplies)[1]	$8000	Includes Sutron XLink 100 data logger with OTT-PLS pressure sensor
Annual Subscription Fees	**$**600	Includes a one-time $700/station charge to set up account. Cloud service $600/year
Installation, Rating Curve Development, On-Going Maintenance		
Monitoring station installation (reconnaissance, site preparation, installation)	$2700	Includes one hydrologist and one field technician for 10 hrs/day. Does not include vehicle costs to travel to and from site.
Rating Curve Development	$10,750 (1st year)	Includes 10 manual measurements in first year and hydrologist data review.
On-going maintenance (visits, QA/QC)	$5500/year	Includes 5 manual measurements/year by two technicians and hydrologist data review.
Typical installation costs (on-going maintenance)/Manual Station	**$14,750 ($5500/year)**	
Typical installation costs (on-going maintenance)/Cellular Station	**$18,950 ($5815/year)**	
Typical installation costs (on-going maintenance)/Satellite Station	**$22,050 ($6100/year)**	

[1] Miscellaneous installation supplies include stilling well materials, staff gauge and benchmarks.
[2]The industry standard for measuring stream discharge in wadable streams is a Sontek Flowtracker ($19,000).

Table 14: Cost estimate for monitoring lake level. The water level logger also collects water temperature data.

Item	Cost Estimate	Comments
Manual Data Retrieval		
Equipment (Data logger, Pressure Transducer, Misc. Installation Supplies)	$1300	Includes the Hobo MX2001 Water level logger with integrated barometric pressure
Cellular Data Retrieval		
Equipment (Data logger, Pressure Transducer, Misc. Installation Supplies)	$1800	Includes the Hobo RX2001 (MicroRX water level station) with upgraded 15W solar panel.
Annual Subscription Fees	$315	Cloud service (30 min logging rate), 6 hr connection, 5 MB monthly plan
Installation, On-Going Maintenance		
Monitoring station installation (reconnaissance, site preparation, installation)	$1400	Includes one hydrologist and one field technician for 5 hrs/day. Does not include vehicle costs to travel to and from site.
On-going maintenance (visits, QA/QC)	$3500/year	Includes 3 site visits/year by two technicians and technician data review
Total Installation Costs (On-going) /Manual	**$2700 ($3500/year)**	
Total Installation Costs (On-going) /Cellular	**$3200 ($3815/year)**	

6.2 Hydrometric (Groundwater Level)

The components of a groundwater observation well include:

- Drilled borehole with casing
- Water level logger (data logger and pressure transducer)
- Barometric pressure logger (data logger and pressure transducer)
- Water level recorder

The water level logger is used to collect a continuous record of the water level. The water level record must be corrected for barometric pressure. Some logger types have this feature installed and an additional barometric pressure logger is not necessary. Similar to a staff gauge, manual water level measurements with the water level recorder (e.g. Heron Dipper Meter) are used to convert pressure readings from the logger into a continuous water level record. Water levels should be measured routinely to check logger collection and ensure no logger drift.

Installing a new groundwater observation well substantially increases the costs (Table 15). The cost of drilling the well would depend on the aquifer material, overburden depth, expected drill depth, type of drill, and size of borehole/casing. Monitoring wells are typically installed as water production wells with a 6” diameter casing to measure water level, water quality and conduct pump tests to estimate aquifer properties.

Table 15: Cost estimate for new groundwater observation well. The water level logger also collects water temperature data.

Item	Cost Estimate	Comments
Manual Data Retrieval		
Equipment (Data logger, Pressure Transducer, Misc. Installation Supplies)[1]	$1450 (unconfined) $1650 (bedrock)	Includes the Hobo MX2001 Water level logger with integrated barometric pressure. Cost of logger will vary dependent on length of cable.
Cellular Data Retrieval		
Equipment (Data logger, Pressure Transducer, Misc. Installation Supplies)	$1950 (unconfined) $2150 (bedrock)	Includes the Hobo RX2001 (MicroRX water level station) with upgraded 15W solar panel. Cost of logger will vary dependent on length of cable.
Annual Subscription Fees	$315	Cloud service (30 min logging rate), 6 hr connection, 5 MB monthly plan
Installation, On-Going Maintenance		
Monitoring station installation	$1400	Includes one hydrologist and one field technician for 5 hrs/day. Does not include vehicle costs to travel to and from site.
Drilling and materials for unconfined sand and gravel – deltaic or late glacial outwash	$8000	Price will vary dependent on depth to water level. Assume 65 ft drill depth with steel casing, steel screen.
Drilling and materials for fractured crystalline or fractured sedimentary bedrock	$7000	Assume 50 ft overburden and 100 ft open borehole bedrock. Price will vary dependent on overburden depth.
On-going maintenance (visits, QA/QC)	$3500/year	Includes 3 site visits/year and technician data review
Total Installation Costs – Unconfined (On-Going)/Manual	**$10,850 ($3500/year)**	
Total Installation Costs – Bedrock (On-Going)/Manual	**$10,050 ($3500/year)**	
Total Installation Costs – Unconfined (On-Going)/Cellular	**$11,350 ($3815/year)**	
Total Installation Costs – Bedrock (On-Going)/Cellular	**$10,550 ($3815/year)**	

[1] A water level recorder is required equipment to measure water level in a groundwater well. Typical meters include a Heron Dipper-T ($900) or a Solinst 101 Water Level Meter ($700).

6.3 Climate

The components of a climate station include:

- Air temperature/relative humidity sensor
- Wind speed/wind direction sensor
- Precipitation gauge
- Snow Depth Sensor (optional)
- Solar radiation (optional)
- Barometric pressure (optional)
- Data logger and enclosure
- Logger enclosure and structure
- Power source (12V battery/solar panel)

Air temperature and wind speed sensors are relatively simple to setup and maintain. However, precipitation gauges can be challenging. The type of precipitation gauge depends on the elevation of the climate station and the predominate phase of precipitation (rainfall versus snowfall) and air temperature. For lower elevation stations, rainfall is the predominate precipitation phase with minimal snowfall, and air temperatures do not regularly fall below zero. Therefore, a tipping bucket rain gauge could reliably be used to monitor rainfall. Adding an ultrasonic snow depth sensor to measure snowpack would help in determining the amount of precipitation that falls as snow.

For higher elevation stations, a higher proportion of annual precipitation is snowfall and air temperatures more often fall below zero. In these locations, it is recommended that a rainfall gauge be used in combination with an all-season snow gauge, which is currently used by the BC Ministry of Environment. These gauges are more resistant to capping of snow over the collection orifice of the gauge. The gauge is filled with an antifreeze mixture that melts the snow and the head of the liquid is measured with a pressure transducer. All-season snow gauges ($6,000) are less costly than a weighing bucket precipitation gauge like a Geonor or OTT Pluvio ($11,000); however, there is less data accuracy. The all-season snow gauge is not available to purchase commercially, but would need to be sourced from a known contractor (personal communications, Frank van der Have, Hoskins Scientific).

Wind shields are helpful to accurately collect precipitation by reducing wind catch and allowing the snowflakes or raindrops to fall in the bucket. Wind shields (i.e., Alter shields) are most important in accurately collecting snowfall to reduce measurement error. Therefore, it is recommended that gauges measuring precipitation be fitted with a wind shield, especially in areas prone to high winds. For tipping bucket rain gauges, the decision to install a wind shield could depend on budget. Rainfall data can be corrected for wind catch using empirical equations.

6.3.1 Snow Survey Transects

Manual snow survey transects near climate stations would provide a manual measurement of snow depth and the volume of water in the snowpack. Snow water equivalent (SWE) is measured with a snow sampler, such as a Standard Federal Snow Sampler ($3000). Several measurements of SWE and snow depth are taken along the same transect often once or twice a month. Ideal transects are in a relatively sheltered area with little overhead tree canopy. For example, an ideal transect would be where the area is a least as wide as the height of trees. Manual snow surveys combined with the snow depth sensor or all-season snow gauge would provide a measure of the quantity of snow in an area and provide information for water supply and flood forecasting. Collection of snow data from snow survey transects would depend on site access (via road) during the winter months; therefore, sites should be assessed to review conditions and suitability of installation/monitoring.

Table 16: Cost estimates for a climate station. Refer to Table 12 for details on phased priority.

Item	Cost Estimate	Comments
Station Type Rain - Manual Data Retrieval		
Equipment (Enclosure, Data logger, Instruments, Power Supply, Mast, Misc. Installation Supplies)	$11,200	Includes the Onset H22 Data Logger, 15 W solar panel, air temperature, relative humidity, wind speed/direction, barometric pressure and silicon pyranometer (estimate evapotranspiration), tipping bucket rain gauge, Sommer ultrasonic snow depth sensor, wind shield ($2000)
Station Type All-Season – Cellular (or Manual) Data Retrieval		
Equipment (Data logger with Telemetry, Instruments, Misc. Installation Supplies)	$27,000	Includes Sutron XLink 500 with industry standard climate sensors (e.g. RM Young wind sensors) for 10 – 20 year investment. Tipping bucket rain gauge with additional all-season snow gauge
Annual Subscription Fees	$315	Cloud service (30 min logging rate), 6 hr connection, 5 MB monthly plan
Station Type All-Season Satellite Data Retrieval		
Equipment (Data logger with Telemetry, Instruments, Misc. Installation Supplies)	$27,000	Includes Sutron XLink 500 with industry standard climate sensors (e.g. RM Young wind sensors) for 10 – 20 year investment. Tipping bucket rain gauge with additional all-season snow gauge
Annual Subscription Fees	$600	Includes a one-time $700/station charge to set up account. Cloud service $600/year
Installation, On-Going Maintenance		
Monitoring station installation (reconnaissance, site preparation, installation)	$2700	Includes one hydrologist and one field technician for 10 hrs/day. Does not include vehicle costs to travel to and from site or time to configure climate station.
On-going maintenance (antifreeze solution (if needed), visits, QA/QC)	$4500/year	Includes 4 site visits/year by two technicians and technician data review
Typical installation costs (on-going maintenance)/Rain Manual Station	**$13,900 ($4500/year)**	
Typical installation costs (on-going maintenance)/All-Season Cellular (or Manual) Station	**$29,700 ($4815/year)**	
Typical installation costs (on-going maintenance)/All-Season Satellite Station	**$29,700 ($5100/year)**	

Table 17: Cost estimates for a snow survey transect. The equipment costs include one-time purchase of a Standard Federal Snow Sampler and avalanche probe for depth measurements ($3,100). Refer to Table 12 for details on snow survey locations.

Item	Cost Estimate	Comments
Monitoring station installation (reconnaissance, site preparation, installation, benchmarks to locate transect over time)	$1600	Includes one hydrologist and one field technician for 5 hrs/day and cost of benchmarks. Does not include vehicle costs to travel to and from site.
Total Installation Costs	**$1600**	
On-going monitoring (visits, QA/QC)	$4500/year	Includes 4 snow surveys/year by two technicians and technician data review

7 Proxy Data Collection

Other proxy data collection could be used to complement the monitoring strategy or be used in the interim while the monitoring system is being effectively built out such as water isotope analyses or local community well monitoring.

7.1 Stable Isotope Tracers

Isotope studies conducted over large spatial and/or temporal scales can provide insights in natural ecosystem functions and the effects of land use change (Kendal et al. 2010). There are a variety of stable isotopic tools that are useful to evaluate issues related to nutrient and organic matter sources (e.g. investigation of land use change) or ecosystem function or health such as Nitrate $\delta_{18}O$, $\delta_{15}N$, and $\delta_{17}O$. More specifically, water isotopes ($\delta_{18}O$ and $\delta_{2}H$) are an ideal conservative tracer of water sources and mixing, and are useful to quantify flow contributions from different tributaries and groundwater. Water isotope tracers are also a sensitive indicator of evaporation. For example, water isotope tracers were used as a monitoring tool over a large spatial scale to track hydrological conditions in northern Canadian lakes over time to generate key process-based insight into lake water balances and isotopic-based hydrologic regimes that included: the dominant source water type (snowmelt versus rainfall) and the evaporation-to-inflow (E/I) ratio to indicate lake sensitivity to evaporation (Tondu et al., 2013). Water isotopes could be used in a similar way for lakes within the CVRD to evaluate the importance of evaporation on their water balance and track changes in lake evaporation in response to changes in climate.

Water isotopes could also be used to understand hydrological conditions of surface water and their degree of connectivity with groundwater sources to evaluate their vulnerability to land development or climate change. The assessment of the vulnerability of groundwater dependent streams (Miller and Allen, 2016) could be supplemented with water isotope analyses to understand the proportion of stream water sourced from groundwater over time to understand the potential effect of groundwater pumping rates on surface water.

Collection of water isotope samples can be easily obtained during fieldwork; however, analysis of water isotope tracers requires expert knowledge. It would be advantageous to combine isotope collection with existing monitoring programs (e.g., water quality) to leverage existing field sampling resources. Costs to analyze a water sample (10-25 mL) for $\delta_{18}O$ and $\delta_{2}H$ range from $25 - $80 per sample by laboratories in Calgary and Saskatoon.

7.2 Volunteer Observation Well Network (VOWN)

The other proxy data collection that could be used to complement the monitoring strategy is to build out the local VOWN to supplement the provincial observation well network monitored by the BC government. A more comprehensive VOWN network could (1) build an awareness of groundwater issues in communities located in the CVRD; (2) create a continuous water level dataset for more communities; (3) increase understanding of CVRD groundwater aquifers; (4) increase the number of wells in the CVRD using an affordable monitoring framework; and (5) these data could fill in groundwater monitoring gaps to help advise land use decisions, planning, and development.

There is currently a VOWN being monitored in the Regional District of Nanaimo (Waterline, 2020; RDN, 2022). Beginning in spring 2013, there are at least 31 wells monitored as part of the VOWN (Waterline, 2020). As the CVRD implements the phased strategy, we recommend to put out a request to communities in the CVRD for volunteers that may have unused, relatively newly drilled wells on their properties and are interested in hosting water level loggers to monitor the aquifer's water level. Potential VOWN sites could then be prioritized and selected based on aquifer demand, aquifer vulnerability, and current number of monitoring wells in the aquifer. Costs would be similar to re-activating a provincial GOWN well; however, there would be additional costs associated with technician time needed to train the volunteers.

8 Summary

The CVRD has a reasonably good baseline network of existing climate and hydrometric monitoring stations that provide data to assess regional water vulnerability. However, review of the active hydrometric and climate monitoring stations has identified key gaps in the network to evaluate short-term watershed management and drinking water supply forecasting, and future water strategy development and planning at smaller scales. The most notable gaps include:

- a lack of climate stations above 300 m.a.s.l. that measure precipitation at elevation bands that receive a higher proportion of snowfall;
- a lack of groundwater monitoring in unconfined sand and gravel (deltaic) aquifers (also high-risk rating) and fractured crystalline bedrock as well as limited monitoring in fractured sedimentary bedrock aquifers and unconfined sand and gravel – late glacial outwash aquifers;
- a lack of groundwater monitoring in areas of high population and/or development pressure or high groundwater reliance (i.e., well density);
- a lack of groundwater monitoring to understand surface water – groundwater interactions in aquifers or layered aquifer systems that are hydrologically connected to Cowichan and Chemainus River systems;
- a lack of monitoring of surface waters that are supplemental or backup municipal drinking water sources;
- a lack of monitoring for Holland Lake (proposed station by Town of Ladysmith), which is part of their designated Community Watershed that supplies drinking water to residents of Diamond/Ladysmith Waters Systems;
- a lack of hydrometric stations in the smaller WPAs including the six Benchland WPAs, most of which have potential for future land use development; and,
- a lack of hydrometric stations in the middle and upper reaches of the Chemainus and Koksilah rivers (Group 3 and 4 watersheds).

The gap analysis and site selection identified monitoring stations to add to the existing monitoring network in a phased implementation:

- High Priority (1 – 2 years) - 5 stream discharge, 4 groundwater wells, 3 climate stations and 3 snow surveys;
- Moderate Priority (within 5 years) - 3 stream discharge, 1 lake level, 7 groundwater wells, 2 climate stations (1 station install with rainfall gauge only), and 1 snow survey; and,
- Low Priority (after 5 years) - 3 stream discharge, 2 lake levels, and 3 groundwater wells.

The costs for installation of monitoring stations will range based on specific site selection (access, site preparation, location, power, manual versus telemetry data retrieval, etc.). Typical installation costs (on-going maintenance) per station would be:

- Hydrometric (Stream Discharge) – Manual $14,750 ($5,500/year), Cellular $18,950 ($5,815/year), Satellite $22,050 ($6,100/year);
- Hydrometric (Lake Level) – Manual $2,700 ($3,500/year), Cellular $3,200 ($3,815/year);
- Hydrometric (Groundwater Level) – Unconfined Aquifer: Manual $10,850 ($3,500/year), Cellular $11,350 ($3,815/year); Bedrock Aquifer: Manual $10,050 ($4,000/year), Cellular $10,550 ($3,815/year)
- Climate – Rain Station (Manual) $13,900 ($4,500/year), All-Season Station: Cellular (or Manual) $29,700 ($4,815/year), Satellite $29,700 ($5,100/year)
    - Snow Survey Transect - $1,600 ($4,500/year)

Based on the Phase 3 gap analysis and site selection, we recommend:

1. Sites selected have field reconnaissance to review conditions and suitability for installation;
2. Connect with the provincial government to ensure there are no overlaps with identified potential station locations for the PGOWN;
3. Initiate discussion with land owners at sites to obtain access permission and land tenure for the selected sites;
4. Review cost estimates for installation of monitoring stations on a location-by-location basis after site reconnaissance due to differences in access, travel time, site conditions and preparation, cellular coverage, etc; and,
5. Continually track the operation of the climate stations operated by the cooperative community network to ensure that operation continues into the future as these stations may need to be replaced by CVRD operators.

10 Closing

MacHydro in collaboration with Foundry Spatial (hereafter Project Team) prepared this document for the account of the CVRD. The material in it reflects the judgment of the Project Team considering the information available to the Project Team at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. The Project Team accepts no responsibility for damages, if any, suffered by any third party because of decisions made or actions based on this document.

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We trust the above satisfies your requirements. Please contact us should you have any questions or comments.

Sincerely,

Amy Goodbrand, Ph.D., P.Geo.
Senior Hydrologist

Rachel Plewes, M.Sc.
Data Analyst/GIS Specialist

Reviewed By:

Ryan MacDonald, Ph.D., P.Ag.
Senior Hydrologist

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