Draft Report

Development of a Water Monitoring Framework for the Kaslo and District Community Forest Society

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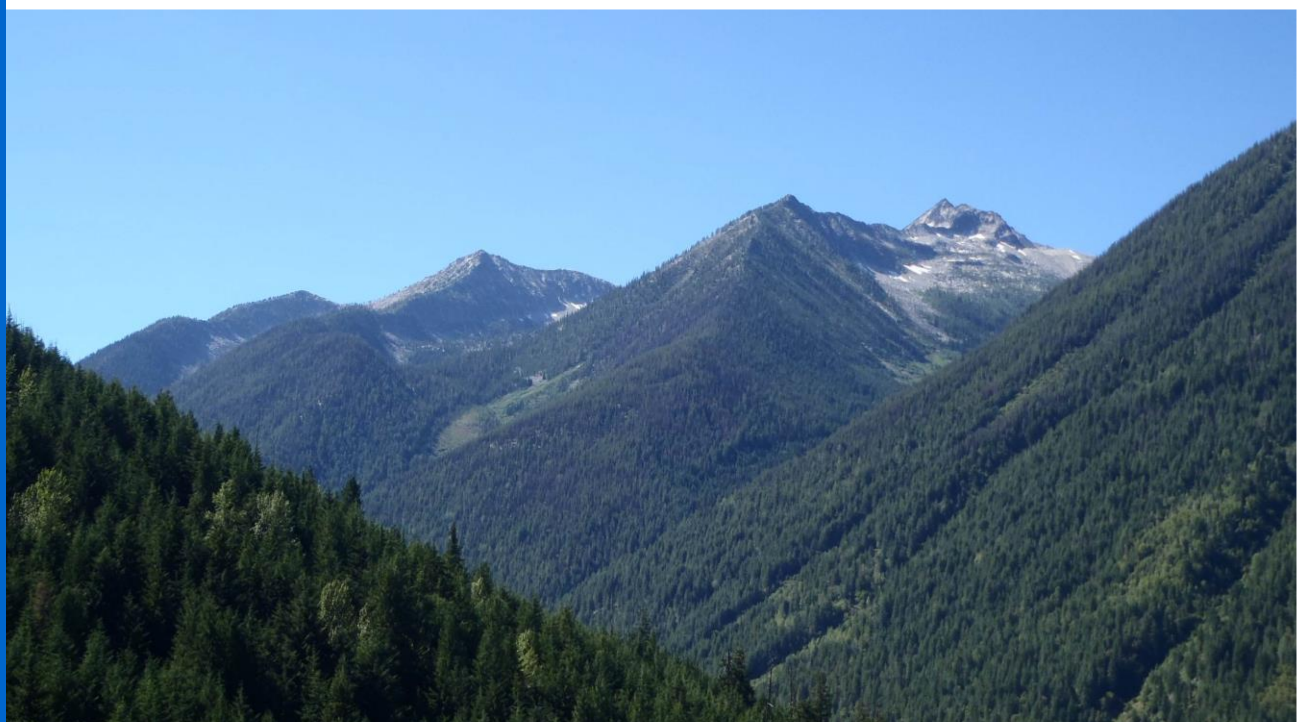

Prepared for

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1 Introduction

The Kaslo and District Community Forest Society (KDCFS) contracted WaterSmith Research Inc. (WSR) to develop a long-term (e.g. 50 year) water monitoring framework to measure the impacts of watershed disturbance (e.g. forest development, wildfire, forest pests) and climate change on water supply within the KDCFS management area. The KDCFS has been monitoring the impacts of watershed disturbance on water quantity on a sporadic basis since the late 1990s. In 2008, the monitoring stations were upgraded and regular annual monitoring was initiated. With increasing demands for water related to ongoing residential and commercial development and with escalating concerns about the potential for climate change impacts on water, KDCFS initiated this project to develop a more comprehensive water monitoring framework.

Wildfire and/or forest development have impacted hydrologic processes throughout most areas of the KDCFS operating area including the Kemp Creek watershed, which is the primary water supply for the Village of Kaslo. Moreover, annual air temperature and precipitation are predicted to increase by approximately 1.9 °C and 5 %, and winter and spring snowfall are predicted to decrease by 9 % and 52 % in the Central Kootenays by the 2050s, respectively [*Pacific Climate Impacts Consortium*, 2012]. Designing a monitoring system to detect watershed disturbance and climate change signals in the water supply requires an extensive knowledge of monitoring designs, infrastructure, and maintenance, and a clear understanding of the potential impacts of watershed disturbance and climate change on upslope and in-stream physical, biological, and chemical processes, as impacts can be highly varied in their nature and severity.

Higher air temperatures associated with climate change can result in earlier onset of seasonal snowmelt or more transient snowpacks, earlier and/or higher peak flows, lower summer flows, higher summer stream temperatures, and higher stream turbidity, particularly during the early phases of the spring freshet [*Barnett et al.*, 2008; *Maurer et al.*, 2007; *Pike et al.*, 2008a; b; *Vicuna et al.*, 2007]. Forest harvesting can also result in earlier snowmelt, earlier and/or higher peak flows, higher summer stream temperatures, and higher stream turbidity; however, the actual impacts vary substantially depending on the distribution and intensity of forest cover removal, the extent of riparian harvesting, and the influence of roads on natural drainage patterns, among other factors [*Pike et al.*, 2010]. These potential impacts are also highly dependent on the natural physiography of the area. For instance, the climate regime, soil depth and permeability, vegetation characteristics, and topographic variability all strongly influence runoff and aquatic processes [*Pike et al.*, 2010; *Smith*, 2011].

Suitable monitoring sites are those where variation in water quality, quantity, and/or timing are sensitive to the phenomena of interest. A challenge is to find a good balance between monitoring objectives and site desirability. With streamflow monitoring, a desirable site is one with (1) stable geophysical features, (2) inexpensive access in all seasons, and (3) safe monitoring conditions. Site selection affects long-term data persistence, data quality, data representativeness, operational costs, liability risks, selection of data processing/analysis methods, and reliability risks [*Hamilton*, 2012].

This report describes the terms of reference for the project, the regional geography, the proposed monitoring framework, and potential funding opportunities. The project incorporated three phases of work including project scoping, site selection, and sampling protocol development. The scoping phase included a project initiation meeting, identification of the baseline data requirements, and development of criteria for identifying suitable monitoring sites. The project initiation meeting was held via teleconference on June 12, 2012 to clarify the project scope, deliverables, budget, and time constraints. Identification of the baseline data requirements and the criteria for identifying suitable monitoring sites were derived directly from the monitoring program objectives. The site selection phase included a pre-field office review of the spatial analysis results, a field review of potential sites (conducted with Richard Marchand, manager of KDCFS, on August 16, 2012), and a post-field re-evaluation of program objectives, baseline data requirements, and site suitability, including installation, maintenance, and data quality limitations associated with the sites. The sampling protocol development phase involved matching the proposed sites with the baseline data requirements after accounting for site characteristics and program resources.

Russell Smith (WaterSmith Research Inc.) provided project management and hydrologic analysis, Dan Moore (sole proprietor) provided technical advising, and Nick Ochoski (ESSA Technologies Ltd.) and Fergus Stewart (FPS Drafting & Geomatics Ltd.) provided spatial analysis.

2 Terms of reference

The specific objectives of this project were to develop a water monitoring framework (monitoring guidelines and a sampling plan) that can address the following overall goals of an expanded KDCFS water monitoring program:

1. track long-term trends in water quality, quantity, and timing;
2. identify critical water supply periods and trends in the timing, duration, and quantity of streamflow during those periods;
3. determine the amount of human settlement that can be supported by individual watersheds;
4. identify any water conservation measures that should be adopted by the community;
5. identify locations of water availability for fire suppression efforts; and
6. obtain baseline environmental data for addressing any future concerns that might arise.

In response to direction provided by the KDCFS, monitoring of water quantity and timing, and climate change impacts were emphasized over other factors (e.g. monitoring water quality and the impacts of watershed disturbance).

3 Regional geography

The KDCFS management area lies on the east side of the Selkirk Mountains bordering the west side of Kootenay Lake in southeast BC. The management area is comprised of two contiguous pieces of land with a southern piece lying to the west of the Village of Kaslo and a northern piece lying to the west of the Village of Lardeau. Runoff from the watersheds within the management area supplies water to the local villages and rural residents, and at least 30 water licenses are registered. The watersheds are mixed-use areas incorporating forest development on public lands, recreation (e.g. all-terrain vehicle use, off-road motorcycling, mountain biking, snowmobiling, skiing), and rural and agriculture development. An accessible forest road network exists within the eastern portions of the management area, while access to the western portions is restricted by road washouts and inoperable terrain.

Elevations in the operating area range from ~534 m at Kootenay Lake to 2500-2600 m at the highest elevations. Three biogeoclimatic (BEC) zones are represented in the watershed including Interior Cedar Hemlock (ICH), Engelmann Spruce – Subalpine Fir (ESSF), and Interior Mountain-heather Alpine (IMH). Mountain streams are cut into bedrock. Valley bottom streams are cut into till and glaciofluvial deposits with substrates ranging in size from sands to large boulders. Channel morphologies are generally bedrock- and/or boulder-dominated. Measured annual precipitation ranges from ~890 mm in Kaslo (Environment Canada Station # 1143900) to ~1600 mm at nearby Redfish Creek at 2100 m elevation (River Forecast Centre Station # 2D14P) and is more-or-less evenly distributed throughout the year. The percentage of precipitation falling as snow is ~25 % in Kaslo and over 80 % at Redfish Creek. Runoff in the region is snowmelt-dominated. Annual minimum and maximum streamflows in lower Kalso River (Water Survey of Canada Station # 08NH005, Kaslo River Below Kemp Creek) typically occur in February and June, respectively.

4 Proposed monitoring framework

4.1 Baseline data requirements

Objectives 1 through 5 of the monitoring program deal with the quantity and/or timing of water supply, which is typically addressed through streamflow monitoring. Objective 1 also deals with water quality (and associated timing). Water quality includes measurable variables that relate to the biological, chemical, and/or physical characteristics of the water. There is a vast array of water quality variables that can be monitored; however, many require manual sampling and complex laboratory analyses, and, thus, are expensive and/or time consuming to monitor. Water temperature and turbidity (i.e. lack of clarity typically caused by suspended sediments, dissolved organics, bacteria growth, or pollutants) are important water quality parameters for humans and fish, and can be monitored on a continuous basis using relatively simple and inexpensive in-situ automated sensors (e.g. ~$130 for a water temperature logger; ~$6400 for a turbidity sensor, logger, and power supply; ~$1000 for manual turbidity meter to analyze grab samples).

Monitoring water quality and quantity to identify the timing and duration of critical water supply periods requires frequent observations on a year-round basis so that water quality and quantity dynamics can be properly characterized. In particular, daily or sub-daily continuous data recordings are valuable for characterizing important metrics like annual, seasonal, or monthly maximums, minimums, averages, or sums. Since a key emphasis of objective 1 is to monitor conditions over a long time scale (e.g. 50 years), the baseline data should allow the monitoring infrastructure to be highly resistant to failure caused by localized disturbance and/or instrument reliability, and should facilitate cost efficient maintenance of the monitoring network and data processing. Streamflow and water temperature and turbidity monitoring systems can typically be designed to satisfy these requirements.

Objective 6 is non-specific in terms of data needs; however, it requires monitoring a useful cross-section of variables so that a range of potential water related concerns can be investigated. In addition to monitoring streamflow and water temperature and turbidity, it will be valuable to continuously monitor meteorology and periodically monitor snowpack water content and watershed disturbance. Obtaining a record of meteorological data will facilitate analysis of local climate change patterns and will serve as forcing data for water supply modelling. Snowpack observations will permit additional detailed analyses of climate change impacts on hydrology, and will provide additional data for calibrating a runoff model for water supply modelling. Obtaining a long-term record of watershed disturbance along with the snowpack measurements will help with identifying the causes of any potential changes in the water supply, particularly with differentiating the influences of watershed disturbance and climate change. Table 1 provides additional details of the baseline data requirements.

Table 1. Summary of the baseline data requirements.

Variable	Details
Streamflow	Should represent a large range in watershed physiography among both reference and developed sites.
Stream temperature	
Stream turbidity	
Meteorology	Measure at least air temperature and precipitation, but preferably also global radiation, relative humidity, and wind speed. Should represent a large range in elevations. Meteorology stations should be located in open sites that will not be influenced by ongoing vegetation changes to ensure a consistent record for detection of climate change influences.
Snowpack water content	Should represent a large range in elevations and exposures.
Watershed disturbance	Should include the distributions of roads, stream crossings, forest cover, landslides, surface erosion, agricultural activity, and/or community infrastructure. Consider elevation, slope gradient, solar exposure, upslope drainage area, and proximity to streams. Most elements can be addressed by applying the Interior Watershed Assessment Procedure (IWAP).

4.2 Site selection

The proposed network for the expanded KDCFS water monitoring program includes stations for monitoring stream water quantity and quality, snowpack depth and water content, and meteorology at local and regional sites. The monitoring network is founded on the Reference Condition Approach (RCA), which allows the impacts of climate change to be differentiated from the impacts of watershed disturbance by designating reference sites (e.g. sites with minimal local and/or upstream watershed disturbance) and development sites (e.g. sites covering a range of local and/or upstream watershed disturbance levels). The RCA is a useful approach for the objectives of this project due to the potential for the water supply to be impacted by multiple factors, including climate change, development, and natural disturbance, and their interactions. Klein *et al.* [2011]

successfully applied the RCA to monitoring turbidity levels in forested watersheds of various disturbance levels in northern California. Tables 2-5 provide prioritized lists of the proposed sites. For streamflow, water quality, and snowpack monitoring, the second priority sites are intended to increase replication within the range of physiographic conditions captured by the first priority sites. For meteorological monitoring, the second priority variables are intended to support more process-focused analyses. Accordingly, the prioritizations allow for adaptation to future funding resources and changing program objectives.

The monitoring network is designed to span a large physiographic range so the natural variation in processes influencing water quality, quantity, and timing can be represented well, which is essential for addressing the broad program objectives. In particular, the network is designed to capture a large range of snowpack regimes since the effects of climate change and forest cover disturbance on snowpack processes can vary with the characteristics of the snowpack regime, and since runoff dynamics in snowmelt-dominated systems are strongly influenced by snowpack processes. Climate and snowpack regimes are strongly correlated with elevation and biogeoclimatic zone. The network is also designed to incorporate community watersheds that are important now or may be important in the future.

Selection and prioritization of the sites was based on a landscape mapping analysis. The analysis helped characterize the distribution of landscape physiography. Variables were also included to address site accessibility, distribution of existing monitoring infrastructure, community development, points of water diversion, and designated community watersheds. The network utilizes existing monitoring stations (KDCFS, provincial, and federal) as much as possible to maximize cost effectiveness and utilization of historical data. Table 6 outlines the features that were considered and the data that were used to identify suitable monitoring sites, along with the corresponding rationale.

Table 2. Reference streamflow sites proposed for the expanded KDCFS water monitoring program (including sites maintained by other organizations). Abbreviations are Q (streamflow), TBa (stream turbidity – automated), TBm (stream turbidity – manual), and Tw (stream temperature). Row shading indicates new sites and existing sites that should be modified, and bold font indicates new variables to be monitored.

Priority level	Site ID	Measurement variables	Elevation (m) / area (ha)	Site description
1	R1	**Q, Tw**	Min: 1500 Max: 2600 Area: 500	Southeast facing watershed (Carlyle Creek) with extensive high elevation area. Low likelihood of development due to OGMA and recreation management designations.
	R2	**Q, Tw**	Min: 1300 Max: 2550 Area: 1300	North facing watershed (Deer Creek) with extensive high elevation area. Low likelihood of development due to OGMA and protected area designations, and inoperable terrain.
	R3	**Q, Tw, TBa**	Min: 717 Max: 1800 Area: 200	Southeast facing community watershed (McDonald Creek) with extensive middle elevation area. Low likelihood of development due to OGMA and community watershed designations.
	R4	**Q, Tw**	Min: 1400 Max: 1750 Area: 250	East facing watershed (upper Milford Creek) with extensive middle elevation area. Low likelihood of development due to OGMA designation and inoperable terrain.
2	R5	**Q, Tw**	Min: 1550 Max: 2650 Area: 1100	Northwest facing watershed (Klawala Creek) with extensive high elevation area. Low likelihood of development due to protected area designation and inoperable terrain.
	R6	**Q, Tw**	Min: 1000 Max: 2350 Area: 1400	Southeast facing watershed (unknown Creek) with extensive high elevation area. Low likelihood of development due to OGMA and recreation management designations.

Table 3. Development streamflow sites proposed for the expanded KDCFS water monitoring program (including sites maintained by other organizations). Abbreviations are Q (streamflow), TBa (stream turbidity – automated), TBm (stream turbidity – manual), and Tw (stream temperature). Row shading indicates new sites and existing sites that should be modified, and bold font indicates new variables to be monitored.

Priority level	Site ID	Measurement variables	Elevation (m) / area (ha)	Site description
1	D1	Q	Min: 800 Max: >2700 Area: 44200	Existing WSC station (Kaslo River Below Kemp Creek, #08NH005) with continuous record since 1964. Large watershed scale integrating a large physiographic range.
	D2	**Q, Tw, TBa**	Min: 1050 Max: 2300 Area: 1400	Existing KDCFS station (Kemp Creek) and main community watershed for Kaslo. Northeast facing watershed with extensive high elevation area.
	D3	**Q, Tw, TBm**	Min: 637 Max: 2550 Area: 2700	Existing KDCFS station (Bjerkness Creek) and main community watershed for Mirrow Lake. East facing watershed with extensive high elevation area.
	D4	**Q, Tw, TBm**	Min: 600 Max: 2200 Area: 500	East facing watershed (lower Milford Creek) with extensive middle elevation area. Can measure runoff from low elevation area after subtracting streamflow at station R4.
	D5	**Q, Tw, TBm**	Min: 579 Max: 2550 Area: 7000	Existing KDCFS station (Davis Creek) and community watershed. Northeast facing watershed with extensive high elevation area.
2	D6	**Q, Tw, TBm**	Min: 651 Max: 2450 Area: 1700	Existing KDCFS station (Fletcher Creek) and east facing community watershed with extensive high elevation area.
	D7	**Q, Tw**	Min: 891 Max: 1850 Area: 200	Existing KDCFS station (Wing Creek) and east facing watershed with extensive middle elevation area.

Table 4. Snow sites proposed for the expanded KDCFS water monitoring program (including sites maintained by other organizations). Abbreviations are Sn (snow water equivalent – snow pillow) and SWE (snow water equivalent – manual survey). Row shading indicates new sites and existing sites that should be modified, and bold font indicates new variables to be monitored.

Priority level	Site ID	Measurement variables	Elevation (m)	Site description
1	S1	Sn	2100	Existing MFLNRO station (Redfish Creek, #2D14P) at high elevation.
	S2	SWE	1072	Existing MFLNRO station (Sandon, #2D03) at low to middle elevation.
	S3	**SWE**	2000	High elevation south facing site within the KDCFS management area.
	S4	**SWE**	1500	Middle elevation south facing site within the KDCFS management area.
	S5	**SWE**	1050	Low to middle elevation valley bottom site within KDCFS management area.
	S6	**SWE**	1300	Middle elevation northwest facing site within the KDCFS management area.
2	S7	**SWE**	1400	Middle elevation east facing site within the KDCFS management area.
	S8	**SWE**	600	Low elevation east facing site within the KDCFS management area.

Table 5. Meteorology sites proposed for the expanded KDCFS water monitoring program (including sites maintained by other organizations). Abbreviations are Ta (air temperature), BP (atmospheric pressure), RH (humidity), P (precipitation), WSD (wind speed and direction), Rg (global radiation), and S (snow depth). Atmospheric pressure measurements are required for non-vented water level recorders at the streamflow stations. Row shading indicates new sites and existing sites that should be modified, and bold font indicates new variables to be monitored.

Priority level	Site ID	Measurement variables	Elevation (m)	Site description
1	M1	Ta, **BP**, RH, P, S	600	Existing EC station (Kaslo, #1143900) at low elevation within the KDCFS management area.
	M2	Ta, **BP**, RH, WSD, S	1095	Existing MoTI station (Lardeau, #34224) at low to middle elevation within the KDCFS management area.
	M3	Ta, P, S, Sn	2100	Existing MFLNRO station (Redfish Creek, #2D14P) at high elevation.
	M4	Ta, BP, RH, WSD	2215	Existing MFLNRO station (Idaho Peak, #IMA) at high elevation.
	M5	Ta, RH, WSD, S	1070	Existing MoTI station (Fish Lake, #34126) at low to middle elevation.
	M6	Ta, RH, P, S	2070	Existing MoTI station (London Ridge Low, #34128) at high elevation.
	M7	Ta, RH, WSD	2160	Existing MoTI station (London Ridge High, #34129) at high elevation.
	M8	**Ta, BP, RH**	2000	High elevation south facing site within the KDCFS management area.
	M9	**Ta, RH**	1050	Low to middle elevation valley bottom site within KDCFS management area.
	M10	**Ta, RH**	1300	Middle elevation north facing site within the KDCFS management area.
2	M8	**P, WSD, S, Rg**	2000	Add additional measurement variables to site M8 to generate a broader dataset for hydrologic modelling and empirical analyses.

Table 6. Features and data utilized for identifying suitable monitoring sites.

Feature	Data utilized	Rationale
Existing monitoring infrastructure	Monitoring infrastructure maintained by the provincial and federal governments, BC Hydro, and the KDCFS	Should be incorporated in the expanded monitoring network as much as possible to minimize network setup costs and to maximize the utility of historical data.
Accessibility	Road and trail network	Influences the cost efficiency of the monitoring network. Direct road access to a monitoring site can substantially reduce installation and ongoing maintenance costs.
Watershed area	Stream network and elevation contours	Directly influences streamflow quantity and is indirectly associated with factors that influence streamflow timing and water quality (e.g. scale effects).
Watershed elevation	Stream network and elevation contours	Processes such as snow accumulation, melt, and evapotranspiration vary with elevation.
Watershed relief	Stream network and elevation contours	The greater the relief, the greater the diversity of the processes within a watershed that vary with elevation (e.g. snow accumulation, snowmelt, evapotranspiration).
Stream gradient	Stream network and elevation contours	Influences ease of monitoring (i.e. safety and methodology). Influences stream power and, thus, channel morphology and dynamics. Influences stream habitat suitability for different species.
Biogeoclimatic ecosystem classification (BEC)	BEC zones	BEC zones integrate the effects of factors that determine streamflow (climate, soils, topography, vegetation) and provide a useful tool for classifying hydrologic regimes [*Trubilowicz et al.*, 2012].
Solar exposure	Modelled incoming potential solar radiation	Solar radiation is a key driver of snowmelt and evapotranspiration rates.

Table 6. Continued.

Feature	Data utilized	Rationale
Forest cover disturbance	Mature forest cover, cutblocks, and wildfire areas	Forest cover (or lack of) influences precipitation interception, snow accumulation and melt, and evapotranspiration. Riparian forest cover influences stream temperature, bank stability, and a range of ecological processes.
Landscape management regime	Provincial and municipal parks, old growth management areas, and recreation management areas	Determines the extent of forest development and, thus, whether climate change impacts can be isolated from or will interact with forest development.
Community development	Community locations, water licenses, and community watershed boundaries	Influences the distribution of water demand for domestic consumption and fire suppression needs.
Slope stability potential	Slope stability potential	Influences the potential for sediment delivery to streams due to slope failure.
Water works (storage or diversion)	Water licenses, points of diversion	Indicates where streamflow quantity and timing are influenced by flow regulation or diversion and, thus, not suitable for monitoring natural flows.
Fish presence	Not incorporated due to data limitations	Indicates where in-stream flow needs are potentially constrained by fish.
Surface erosion potential	Not incorporated due to data limitations	Influences the potential for sediment delivery to streams due to surface erosion.
Soil type	Not incorporated due to data limitations	Influences the transmission of rainfall and snowmelt down hillslopes to streams, as well as the potential for surface erosion.

4.3 Sampling protocol

Table 7 summarizes the proposed sampling timing, frequency, equipment, and methods for individual monitoring variables. The timing and frequency are derived from the baseline data requirements and the program objectives. The proposed equipment and methods are selected to balance cost effectiveness and reliability/accuracy. The equipment brands and models are examples of suitable equipment, but other options are available. The availability of funding will influence trade-offs between the number of installed sites and the types of instrumentation that are used. For instance, since temperature sensors are inexpensive to purchase and maintain compared to streamflow gauging stations and turbidity sensors, it is possible to use different quantities of sites for different monitoring variables. In addition to ongoing monitoring at the proposed sites, watershed disturbance should be assessed at least every 5 years (see section 4.1).

Table 7. Proposed measurement timing, frequency, equipment, and methods for the monitoring variables.

Variable	Timing	Frequency	[1]Equipment/methods
Stage	Continuous	15 minutes	Set up at a naturally constricted cross-section with steel standpipe and water level logger (e.g. HOBO U20, ~$500 per unit).
Streamflow	Manual	6 or more times per year	Involves velocity and depth measurements across the channel width or tracer injection measurements using salt or rhodamine.
Stream turbidity – automated	Continuous	15 minutes	Set up at streamflow stations using in-situ turbidity meter (e.g. package based on YSI 600OMS, ~$6400 per unit).
Stream turbidity – manual	Peak flow & summer low flow	Weekly to bi-weekly	Periodically analyze grab samples at streamflow stations using manual turbidity meter (e.g. package based on Lamotte 2020we, ~$1000 per unit, 1 required).
Stream temperature	Continuous	15 minutes	Water level logger supporting temperature measurements (e.g. as above) or independent temperature logger inserted within standpipe (e.g. TidbiT v2, ~$130 per unit).
Atmospheric pressure	Continuous	15 minutes	Water level logger (e.g. HOBO U20, ~$500 per unit).
Air temperature	Continuous	15 minutes	Air temperature and relative humidity data logger (e.g. HOBO U23 Pro v2, ~$210 per unit) coupled with a solar radiation shield (e.g. RS1, ~$70 per unit).
Humidity	Continuous	15 minutes	
Precipitation	Continuous	15 minutes	All season standpipe precipitation gauge with alter shield (e.g. OTT Pluvio, ~$7600 per unit; or PG-4 High Capacity, ~$5000 per unit).
Wind speed and direction	Continuous	15 minutes	Anemometer (e.g. RM Young wind monitor, ~$1200 per unit). Option of incorporating a wind speed only sensor for cost savings.

Table 7. Continued.

Variable	Timing	Frequency	[1]Equipment/methods
Global radiation	Continuous	15 minutes	Pyranometer (e.g. HOBO Silicon Smart Sensor, ~$300 per unit; this unit is a lower accuracy instruments; thermopile-based pyranometers are more accurate, but are more expensive).
Snow depth	Continuous	15 minutes	Snow depth sensor (e.g. Sommer USH-8 Ultrasonic, ~$3900 per unit).
Snow water equivalent – manual survey	Late winter & spring	3 to 5 measurements per year	10 measurements at each site using a Federal Snow Sampler (~$4000 per unit, 1 required) spaced 10 m apart on contour. Open sites are preferred over forested sites. Forest cover changes should be negligible over the study period.

1. Prices are estimates only at the time of writing and do not include taxes, meteorology station tower, enclosures, power supply, construction supplies, or labour costs.

4.4 Logistical considerations

4.4.1 Streamflow

Generation of continuous streamflow records requires two data inputs: (1) a continuous record of water level (stage) and (2) occasional manual measurements of streamflow to generate a relation between stage and discharge (rating curve), which allows the computation of continuous streamflow from the stage records. General guidelines and standards for streamflow measurement can be found in the provincial RISC documents [*BC Ministry of Environment*, 2009]. The material in this section focuses on specific considerations appropriate to gauging the types of streams found in the KDCFS management area.

Sites for recording stage should ideally have a stable cross-section to avoid shifts in the rating curve. The water level recorder should be housed in a robust standpipe that is installed in a pool to minimize short-term fluctuations in water level. An ideal site would be a bedrock pool upstream of a flow constriction or chute. Installation of a water level recorder and standpipe in boulder/bedrock dominated streams typically requires about 12 hours of field time (including equipment sourcing and site reconnaissance). For safety and logistical reasons, it is often advisable to install in autumn when flows are low and there is no snow.

Manual streamflow measurements for constructing the rating curve can be measured in a different stream section than the location of the water level recorder. In fact, sites that are optimal for recording water level are often not ideal for making manual streamflow measurements. The main considerations in locating water level recorders and suitable manual measurement sites are that (1) there are no major inflows or outflows of water between the manual streamflow measurement site and the location of the water level recorder, and (2) the time required for water to travel between the two sites is, at most, a few minutes. In small streams, substantial changes in discharge can occur on an hourly or even shorter time step.

As a practical guideline, at least six streamflow measurements representing the full range of observed flows should be made in the first year to generate a reliable rating curve. The frequency can be reduced to two measurements per year (at high and low flows) in the second year for bedrock channels and in the third or fourth years for other channels, as long as the channel cross-sections remain stable (e.g. have not experienced scour and/or deposition in the channel by sediment transport processes). After each measurement, the new flow value should be plotted on the existing rating curve to check that the curve remains valid (i.e. has not shifted). If the rating curve has shifted or if channel changes are observed, it is necessary to develop a new rating curve. In a snowmelt-dominated hydrologic regime, measurements should be made prior to the onset of spring freshet, during the main snowmelt period, through the summer-autumn recession period, and during any major rain events.

The presence of snow and ice in the channel affects the validity of the rating curve. Therefore, time should be allotted during the first site visit each spring to clear snow and ice from the channel immediately downstream from the water level recorder, if necessary. During each site visit, it is useful to take photographs looking upstream and downstream from the water level recorder to be used as references if shifts in the rating curve become apparent during data processing.

The creeks in the KDCFS management area generally have high roughness (e.g. boulders, cascades, water falls) and high stream power. As a result, tracer methods are generally recommended over velocity methods for manual streamflow measurements, which is necessary for constructing the stage-discharge rating curves (i.e. calibrating the streamflow stations). High stream roughness generates stream turbulence that negatively impacts the accuracy of depth and velocity measurements, but promotes rapid mixing of tracer and, thus, increases the accuracy of tracer-based approaches. Slug injection using table salt or rhodamine WT are two of the most common tracer methods of streamflow gauging. Both tracers are utilized by Environment Canada hydrologists for streamflow gauging.

Rhodamine WT is a synthetic red to pink coloured water soluble dye having brilliant fluorescent qualities that can be measured easily with instruments called fluorometers. It is an ideal tracer for conducting flow studies in natural water courses, as it (1) is non-carcinogenic, (2) is safe when handled with care, (3) has low potential for toxicity and adverse effects in the aquatic environment, (4) can be released at a rate proportional to the discharge rate, and (5) is readily measured in the field at concentrations of 0.013 µg/L or higher, among other factors [*Environment Canada*, 2003; *Martin and McCutcheon*, 1999; *Parker*, 1973; *Wilson et al.*, 1986]. In comparison, material safety data sheets (MSDS) state that lethal concentration limits (50 % mortality of the sample organisms) are greater than 320 mg/L and 170 mg/L for rainbow trout and Daphnia magna, respectively [*Keystone Aniline Corporation*, 1999].

4.4.2 Stream temperature

While modern temperature loggers are highly reliable, a major cause of data loss is the de-watering of loggers during dry weather when the water level drops below the level of the logger. Therefore, frequent site visits are recommended to ensure that loggers remain submerged, especially during the hot, dry weather that can produce elevated stream temperature. During each site visit, it is useful to make a manual measurement of stream temperature that can be used as a check on the recorded temperature. See Quilty and Moore [2007] for more detailed guidelines for installing and maintaining stream temperature loggers.

4.4.3 Suspended sediment and turbidity

Determination of suspended sediment concentration (SSC) requires collection of water samples manually, or by using an automated pump sampler or gravity-fed sampler. Water samples must be analyzed in a laboratory where they are filtered to capture the sediment, followed by drying and weighing of the filters to determine the mass of sediment.

SSC can be highly variable and is typically greatest when streamflow begins rising after a long period of low flow (e.g. at the start of spring freshet or summer rains following dry weather). Short-term spikes in SSC can also occur as a result of unpredictable events such as failure of a stream bank or a landslide.

Turbidity is often used as a proxy for SSC, and water quality standards for domestic use include limits on turbidity. Turbidity can be measured manually in the field using an optical turbidity probe such as the Lamotte 2020we or Hach 2100Q. In addition, turbidity can be continuously recorded on-site with an optical sensor connected to a data logger. However, these instruments require relatively frequent visits to ensure that the sensor is not fouled (e.g. by growth of algae). In addition, air bubbles that are typically common in steep, bouldery mountain streams, especially at high flows, can cause probes to overestimate turbidity [*Jordan*, 1996]. Jordan [1996] provided a thorough discussion of the use of turbidity probes for monitoring streams in the West Arm Demonstration Forest.

4.4.4 Meteorology

For long-term monitoring, meteorological stations should be located in open sites that will not experience changes that could affect the measurements made by the sensors, such as regeneration of nearby trees. Sensors should be mounted on a tower at a height that is at least two meters greater than the expected maximum snow accumulation at the site. A number of agencies, such as the World Meteorological Organization and the US National Weather Service, have published guidelines for site selection for weather stations.

Most modern meteorological sensors and data loggers are reliable and do not require frequent maintenance. However, it is useful to conduct site visits to check that equipment is functioning properly. A common cause of equipment failure is interference by wildlife (e.g. chewing on cables connecting sensors to data loggers) or humans (e.g. theft or vandalism). A common problem is "capping" of precipitation gauges by accumulated snow. At least one visit per season should be scheduled, although more frequent visits should be scheduled if possible. If an instrument fails or begins to malfunction, the period of data loss will be related to the frequency of site visits (i.e. more frequent visits will limit the amount of data loss).

4.4.5 Snowpack

The timing of peak snow accumulation and the onset of snowmelt vary with elevation, aspect, and forest cover, and also vary annually as a result of climatic variability. The most common date for snowpack measurements at snow courses operated by the BC government is April 1, and measurements on April 1 have often been used as an index of peak snow accumulation. However, especially at higher elevations, substantial snow accumulation can continue through April (and sometimes May), while at lower elevations, melt often begins earlier than April 1. In addition, one of the key consequences of climatic warming is an earlier onset of spring snowmelt. Based on these considerations, it is recommended that snow surveys be conducted at each site on March 1, April 1, and May 1 (as a minimum), or within $\pm$ 5 days of those dates (to be consistent with the provincial snow survey schedule). Standard snow survey protocols should be followed. The BC River Forecast Centre provides a brief summary of snow survey methods (bcrfc.env.gov.bc.ca/about/snow-survey.htm), while the US Department of Agriculture has produced a more complete manual of procedures (www.wcc.nrcs.usda.gov/factpub/ah169/SnowSurveySamplingGuideHandout.pdf).

4.4.6 Data processing

Monitoring programs generate large amounts of data. Processing of the data is complicated by the use of different data loggers for different variables, each of which will have an idiosyncratic file structure. Therefore, it is imperative that an overall strategy be developed for handling, processing, storing, and maintaining data prior to collecting the data. The strategy should involve protocols for Quality Assurance/Quality Control (QA/QC) and for flagging unreliable data points. While spreadsheet programs are readily available and many people are familiar with their use, they are not suitable for large data sets comprising a range of variables collected at a range of sites. Ideally, the data should be stored in a database system designed specifically to accommodate the future needs and objectives of the monitoring program.

5 Funding opportunities

Several potential funding sources and website links are provided in Table 8 as a resource for KDCFS to utilize in seeking future funding for the monitoring program. It is recommended that KDCFS consider hiring a consultant with expertise in fund raising to identify additional sources.

Table 8. Programs that are potential sources of funding for supporting the monitoring program.

Organization	Website link	Details
Columbia Basin Trust	www.cbt.org/Funding	Funds programs focused on water and environmental stewardship, and climate change adaptation
BC Community Gaming Grants	www.pssg.gov.bc.ca/gaming/grants/community-gaming.htm#one	Supports non-profit organizations providing programs or services that enhance BC's environment or protect the welfare of animals and wildlife
RBC Blue Water Project	www.rbc.com/community-sustainability/environment/rbc-blue-water/index.html	Is a wide-ranging, multi-year program to help foster a culture of water stewardship
NSERC Industrial Postgraduate Scholarships and Industrial R&D Fellowships	www.nserc-crsng.gc.ca/Students-Etudiants/index_eng.asp	Provides financial support for highly qualified science and engineering researchers to gain research experience in industry while undertaking advanced studies in Canada
Mitacs	www.mitacs.ca	An internship program that connects companies with research-based universities through graduate students and postdoctoral fellows who apply their specialized expertise to research challenges
TD Friends of the Environment Foundation	www.fef.td.com/index.jsp	Funds local projects dedicated to preserving the environment
Walter & Duncan Gordon Foundation	gordonfoundation.ca/programs/fresh-water-program	Supports the development of a comprehensive legal, regulatory, and citizen action framework for the purpose of protecting the quality and quantity of fresh water resources
Mountain Equipment Co-op Community Contributions grant program	www.mec.ca/AST/ContentPrimary/Sustainability/CommunityContributions/GrantRecipients.jsp	Funds environmental and outdoor communities in support of conservation, education, and access projects

6 Summary and conclusions

A long-term (e.g. 50 year) water monitoring framework has been developed to expand the existing KDCFS monitoring program to measure the impacts of watershed disturbance and climate change on water supply within the KDCFS management area. The proposed monitoring network includes stations for monitoring stream water quantity and quality, snowpack depth and water content, and meteorology at local and regional sites, and is founded on the Reference Condition Approach (RCA), which allows the impacts of climate change to be differentiated from the impacts of watershed disturbance by designating reference sites and development sites. It is designed to span a large physiographic range so the natural variation in processes influencing water quality, quantity, and timing can be represented well, which is essential for addressing the broad program objectives. The network also incorporates community watersheds that are important now or may be important in the future and utilizes existing monitoring stations as much as possible to maximize cost effectiveness and utilization of historical data. A sampling protocol is also proposed based on the identified baseline data requirements and program objectives. Potential funding sources for future monitoring are identified.

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Appendix

KDCFS Water Monitoring Framework - Map 1

KDCFS Water Monitoring Framework - Map 2