Research and Information Needs Assessment to Support Sustainable Watershed Management in Northeast British Columbia

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S. Lapp, T. Redding, K. Ronneseth, and D. Wilford

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Resource development in northeast British Columbia is resulting in increased pressure on water resources. The concurrent development of multiple resources in a remote and diverse landscape has led to many questions about the state of water resources and how to manage them in a sustainable manner. To help identify specific knowledge gaps and develop strategic priorities for research, an information needs assessment was conducted by surveying key people involved in water research and management in northeast British Columbia. In total, 65 respondents completed the survey and identified priority topics for research, monitoring, tools, and policy.

Priority research needs consistently identified by respondents included the following:

- water balance research that quantifies fluxes (e.g., evapotranspiration, recharge) and storage (e.g., groundwater, lakes, wetlands) for the range of landscapes and land cover types (e.g., wetlands, upland forests, ponds) present in northeast British Columbia. Due to differences in physiography and climate between the northeast and other regions of British Columbia, knowledge gained from long-term watershed research in other areas may not be directly transferrable;
- development and testing of methods/models for defining environmental flow needs;
- aquifer identification and characterization to quantify the availability and extent of groundwater resources;
- climate change effects on all aspects of water resources, aquatic ecology, and natural hazards; and
- development of methods for quantifying cumulative effects of resource development and land use change on water quantity and quality.

Most respondents identified the need for baseline monitoring of surface and groundwater quantity and quality along with climate data. Currently, the lack of data is seen as an impediment to sustainable water management in northeast British Columbia. The low spatial density of monitoring sites and short temporal records make the development and testing of predictive models (e.g., stream flow, water quality) difficult. Baseline monitoring is necessary for detecting trends and setting guidelines and thresholds for identifying resource development–related impacts.

Many respondents also identified the need to make monitoring and research data and results easily accessible to water managers and industry. The need for consistent, mandatory data collection, archiving, and dissemination was also strongly recommended.

The results of the survey identified many of the same themes and topics identified in previous assessments (Redding and Nickurak 2007; Johnson 2010; Lapp 2012; Carbon Talks 2013; Fraser Basin Council 2013; PICS 2013; Rivera 2014). Based on the commonalities between these past assessments, it

is apparent that the underlying priorities have not been addressed. In order to bridge the gaps between research and resource development activity in the northeast, these priority topics require action. This report provides details on specific recommendations and additional identified needs. A database of data and information sources and relevant research from British Columbia and adjoining jurisdictions was also compiled (www.bcwatertool.ca/info-sources). It is intended to provide researchers and managers with a first step in locating key water resource information of regional relevance.

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1 INTRODUCTION

1.1 Project Purpose

Watershed management issues are among the many challenges facing natural resource managers in British Columbia. These issues are especially prevalent in northeast British Columbia, where development of multiple natural resources is occurring rapidly. The B.C. Ministry of Forests, Lands and Natural Resource Operations (MFLNR) conducted a research and information needs assessment survey to support sustainable water resource management in northeast British Columbia.

This assessment, combined with a compilation of relevant research and data/information sources for northeast British Columbia, will form the basis for developing an applied research strategy to support sustainable water resource management in this region. Key people involved in water and natural resource management were asked to participate in a survey to help identify these information needs.

The survey was divided into five main topical themes: surface water (quantity and quality), groundwater (quantity and quality), groundwater–surface water interactions, aquatic ecosystems, and resource development hazards. The key respondents were asked to identify:

- priority research questions relevant to northeast British Columbia;
- knowledge gaps and data requirements;
- policy and regulatory needs; and
- historical and current water research, databases, and monitoring activities conducted within northeast British Columbia or regions directly relevant to assist in water resource management in northeast British Columbia (e.g., Alberta).

The identification of these information needs will aid in the development of applied water research, monitoring, and tools to support sustainable water resource management.

1.2 Report Format

This report presents the data collection methods used in the survey, a profile of the respondents, the ranking (High, Moderate, Low) of key research needs by topic area within each theme, and a summary of the written comments for each of the five main topical themes.

Appendices 1 through 8 present the respondent survey comments, Appendix 9 provides the covering letter sent to the respondents, and Appendix 10 presents the survey questions. A separate database of data and information sources and relevant research from British Columbia and adjoining jurisdictions has been compiled (based on Adelaide Consulting 2013) and is available at www.bcwatertool.ca/info-sources. The database spreadsheet contains descriptions of, and links to, data sources and publications related to water resource management in northeast British Columbia. To support applied research and modelling, information sources from other jurisdictions have been included where knowledge gaps exist for northeast British Columbia.

2 METHODS

2.1 Study Design

A list of potential key respondents was compiled and prioritized in conjunction with staff from MFLNR. Selection was based on the respondents' profession and their experience within their organizations. All respondents were familiar with water issues in northeast British Columbia.

2.2 Study Delivery

An introduction to the project and a link to the survey questions were sent by email to each respondent (Appendices 9 and 10). Respondents completed the survey online, by telephone, or during an in-person interview. The survey was carried out from February 3rd to March 1st, 2014.

3 RESULTS

3.1 Profile of Respondents

Identifying a respondent's affiliation or sector helped determine where research is being conducted (or not), what research or monitoring needs exist, and what opportunities for future collaboration are possible. In total, 88 individuals were contacted, of which 65 completed the survey: a response rate of 74%. Table 1 lists the number of individuals contacted at each affiliation and the number of responses.

TABLE 1 *The number of individuals contacted at each affiliation and the number of respondents*

Affiliation	Contacted	Responded
Agriculture and Agri-Foods Canada	2	1
BC Oil and Gas Commission	1	1
B.C. Geological Survey	1	1
B.C. Ministry of Energy and Mines	2	2
B.C. Ministry of Environment	36	27
Conoco Phillips	1	0
Consultant – Environmental	5	3
Consultant – GW/SW Hydrology	6	6
City of Dawson Creek	1	1
Ducks Unlimited	1	0
Encana Corporation	1	1
MFLNR	14	12
Foothills Research Institute	1	1
FP Innovations	1	0
Geoscience BC	1	1
Nexen	1	0
Northern Health	1	1
Pacific Climate Impacts Consortium	2	2
Progress Energy	1	0
Resources North	1	0
Simon Fraser University	3	2
Shell Canada Limited	1	0
University of Northern British Columbia	3	2
University of Victoria	1	1
Total	88	65

Respondents were asked to select the sector or affiliation that best applied to them. Eleven categories were listed in the survey, and the respondents could select more than one (Table 2). The respondents were employed predominately by the provincial government, followed by industry, academia, and other organizations.

TABLE 2 *Respondents' sector/affiliation (more than one sector/affiliation could be selected)*

Sector/affiliation	Number
Provincial government	42
Consultant	10
Academic	7
Community/stewardship/nongovernmental organization	3
Others[a]	3
First Nations	1
Oil and gas industry	1
Forest industry	1
Local or regional government	1
Mining industry	0
Federal government	1

a Others include Northern Health, Provincial Commission, and government–industry interface.

Respondents were asked to select their primary areas of practice from a list of 20 categories (Table 3). Given the targeted nature of the survey and dominance of provincial government employees, most respondents' practices were in the areas of surface water and groundwater hydrology and water management and research.

TABLE 3 *Respondents' field/area of primary practice*

Field/area	Number
Surface water hydrology	28
Water management (monitoring)	20
Groundwater hydrology	20
Groundwater hydrology—science/research	16
Water management (allocation)	14
Fisheries and aquatic ecology	14
Geoscience and engineering	14
Other[a]	11
Oil and gas development	10
Renewable resource management	9
Groundwater management (monitoring)	9
Groundwater hydrology—consulting	6
Mining	5
Groundwater management (regulations)	5
Groundwater hydrology—development	4
Agriculture	3
Water purveyor	3
Groundwater management (allocation)	2
Waste management	1
Industrial waste water disposal (produced, process, backflow)	0

a Other includes: climatology, climate change, source water protection, watershed management, flood response, drought, water stewardship planning, soils, surficial geology and terrestrial ecosystem inventory, and water quality guidelines and standards.

3.2 Survey Response Summaries

Respondents were asked to provide information about the following theme areas:

- surface water quantity and water management;
- surface water quality and water management;
- groundwater quantity (shallow and deep) and groundwater sustainability;
- groundwater quality (shallow and deep) and groundwater sustainability;
- groundwater–surface water interactions;
- aquatic ecosystems; and
- management for natural hazards (e.g., landslides, erosion, drought) and resource development hazards.

Types of information requested for each of these theme areas included:

- key research needs (by topic area within each theme);
- data and information needs;
- system and methodology needs;
- policy and regulatory needs;
- applied research, or monitoring activities that would support applied research, that the respondent's organization was currently conducting;
- applied research, or monitoring activities that would support applied research, that was being conducted by any other organization or people; and
- priority research questions or knowledge gaps related to key water management decisions.

This information was then summarized under the following headings for each theme area:

- priority research questions;
- knowledge gaps;
- priority data needs; and
- system and policy needs.

The information contained within each of these themes was summarized by the authors based on the respondents' comments. Where possible, they are ranked by frequency of response—most common to least.

It is important to differentiate between research needs, knowledge gaps, and data needs. Research needs are driven by specific questions about a process or the functioning of a process in a specific location (e.g., How do evaporation rates differ between a range of land cover types such as bog, fen, pond, and upland forest?) A knowledge gap is the gap between current knowledge and what knowledge is necessary to make a decision. A knowledge gap is typically addressed through a research question and extension of the knowledge or a synthesis of available information. Many knowledge gaps identified by the respondents were addressed through research questions. Data needs are dependent upon the research or management questions. This involves more routine data collection to parameterize models and understanding anthropogenic and natural impacts on the environment (e.g., monitoring daily streamflow and weather).

3.3 Surface Water Quantity and Water Management

Respondents were asked to rank their priority research and information needs as High, Moderate, or Low. If a respondent did not rank a need, it was classified as not answered (NA). The highest-priority topics selected by respondents focussed on low flows (magnitudes and timing) and cumulative hydrologic effects (Table 4).

TABLE 4 *Frequency of respondents' priority ranking of key research and information needs for selected topics related to surface water quantity*

Research and information needs	High	Moderate	Low	NA[a]
Low flow magnitude	30	11	3	21
Low flow timing	28	11	4	22
Cumulative hydrologic effects	28	11	3	23
Peak flow magnitude	24	13	5	23
Current allocation and water availability	23	11	7	24
Oil and gas development effects	23	13	6	23
Climate change effects on water quantity	21	19	3	22
Peak flow timing	20	15	6	24
Annual water yield	16	16	11	22
Forest management effects	14	19	10	22
Mining effects	14	15	10	26

a Not answered.

Priority research questions

1. How do components of the water balance vary spatially and temporally across the range of land cover types in northeast British Columbia? These data are required to support model development and testing.
   - What is the role of wetlands in catchment water balance?
   - How do evapotranspiration rates vary across different land cover types in northeast British Columbia?
   - What is the spatial variation in snow accumulation and melt across different land cover types (e.g., conifer forest, deciduous forest, wetlands, and disturbed areas)?
   - Can we develop comprehensive models that integrate surface water, groundwater, wetlands, cumulative water demands, etc.?
   - How do we ensure surface water availability and sustainable allocation to oil and gas development on smaller watersheds/streams/aquifer systems?
2. What are the effects of resource development, especially oil and gas along with forest management, on surface water quantity?
3. What are the effects of water extraction (both anthropogenic and natural) on the health of wetland communities, post-fire erosion and flooding, landslides, methane release, floods, and sediment supply?
4. How do low flows vary in space and time?
   - How can this inform the development and testing of environmental flow methods and guidelines?
5. What are the likely impacts of climate change on low flows, peak flows, water yield, and hence water availability?

Priority data needs

1. Baseline monitoring data:
   - hydrometric data, particularly for smaller streams and watersheds, and those with high rates of resource development;
   - monitoring of low flows during winter months;
   - spatial and temporal variation in snow accumulation and melt;
   - climate data; and
   - soils data and land use data.
2. Data necessary to parameterize and run a comprehensive water balance model: cumulative water demand, agricultural water demand, water storage, groundwater–surface water interactions, and wetlands.
3. Floodplain and ecosystem mapping.

Priority system and policy needs

1. Consistent data collection and metadata standards, and archiving at a location that is easily accessible to all users. Many data are being collected but not shared.
2. Mechanisms to use research results and data to better inform and develop policy in a timely manner.
3. Financial and personnel support for development of community watershed plans and mapping.
4. Continue to improve, evolve, and validate the Northeast Water Tool (NEWT).

3.4 Surface Water Quality and Water Management

The highest-priority topics selected by respondents focussed on physical water quality (e.g., temperature, suspended sediment) and oil and gas and mining effects on surface water quality (Table 5).

TABLE 5 *Frequency of respondents' priority ranking of key research and information needs for selected topics related to surface water quality*

Research and information needs	High	Moderate	Low	NA[a]
Oil and gas effects	21	9	8	27
Physical water quality (e.g., temperature, sediment/turbidity)	19	12	6	28
Mining effects	18	11	8	28
Forest management effects	14	16	10	25
Chemical contaminants (e.g., industrial effluent, spills)	12	10	11	32
Chemical water quality (e.g., nutrients)	10	12	12	31
Biological water quality (e.g., algae)	8	11	13	33
Algae blooms	3	10	18	34

a Not answered.

Priority research questions

1. What are the individual and cumulative effects of forestry, mining, and oil and gas development, combined with water usage and land alterations, on chemical and physical (e.g., temperature, suspended sediment) properties of water, particularly in high-demand areas?
   - How does this affect drinking water supplies and fisheries?

2. What are the point sources and concentrations of pathogens (anthropogenic) and contaminants (heavy metals, industrial chemicals, etc.), their viability, and travel distance?
3. Are we able to quantify the relationships between water quantity and quality?

Knowledge gaps

1. Tracking of source-water protection plan implementation.

Priority data needs

1. Baseline data, particularly in high water demand areas or watershed systems with limited supply:
   - physical, chemical, and biological water quality data, including source-water sampling (i.e., raw water in both community and non-community watersheds);
   - land use data;
   - spatial data, including environmental permitting (e.g., discharge/effluent permits); and
   - snow quality (e.g., chemistry) sampling to assess air pollution from oil and gas operations.
2. Complete the aquatic biomonitoring network using the reference condition approach and the Canadian Aquatic Biomonitoring Network (CABIN) so that benchmarks in undeveloped areas are available.

Priority system and policy needs

1. Watershed plans:
   - drinking water sources and source-water protection.
2. Archiving of baseline water quality data:
   - develop a database using standard methodology.
3. Development of bilateral agreements (for cross-border water bodies) that include protecting water quality and aquatic ecosystems:
   - a policy for water allocation and mines that provides standard guidelines and objectives for acceptable concentrations of chemicals in the streamflow; and
   - water quality thresholds for chemicals and fine sediments associated with the development and operation of mines and access structures.
4. Provincial protocols/standards when Canadian Council of Ministers of the Environment (CCME 2014) standards are not in place.
5. Mechanism to use research results and data to better inform and develop policy in a timely manner.

3.5 Groundwater Quantity (Shallow and Deep) and Groundwater Sustainability

Key research needs include understanding groundwater in its natural state, aquifer mapping, and the effects of oil and gas development on groundwater and groundwater use (Table 6).

TABLE 6 *Frequency of respondents' priority ranking of key research and information needs for selected topics related to groundwater quantity*

Research and information needs	High	Moderate	Low	NA[a]
Oil and gas development effects (e.g., hydraulic fracturing)	25	13	3	24
Water levels	24	11	4	26
Recharge	24	11	5	25
Aquifer mapping	24	11	5	25
Groundwater use	24	9	6	26
Groundwater vulnerability	23	9	6	27
Surface waters	22	13	5	25
Yield potential	20	13	8	24
Groundwater allocation	20	12	8	25
Permeability and porosity	17	13	9	26
Flow direction	17	13	8	27
Mining and other industry users	17	12	10	26
Saline water	16	14	6	29
Storativity	15	10	11	29
Climate (precipitation, evapotranspiration)	15	15	9	26
Geomorphology and lithology	14	16	9	26
Land use	9	21	8	27

a Not answered.

Priority research questions

1. How well do we understand the distribution and flow of groundwater in its natural state?
   - Which is the more important groundwater flow system, local or regional, to be considered when developing water budgets?
   - How are the concepts of land use activities (i.e., extensive linear developments to support resource extraction) that alter surface water movement affecting recharge?
   - What are the vertical profiles of groundwater temperature, chemistry, and hydraulic head?
2. How much groundwater can be sustainably allocated on a seasonal basis?
   - What are the seasonal differences in recharge fluxes?
   - Is any "aquifer mining" occurring in the region?
   - What are the cumulative effects of groundwater use?
   - How do borrow pits affect groundwater flow systems?
   - What are the thresholds for sustainable groundwater allocation?
3. What are the differences between, and within, both unconsolidated and bedrock aquifers?
   - What are the fracture porosity properties, including yield potential, of shallow bedrock aquifers?
4. Where are the aquifers and how are they connected:
   - shallow and deep aquifers;
   - non-saline and saline aquifers;
   - groundwater and surface water; and
   - groundwater and precipitation?
5. What are the direct and cumulative impacts of climate change on groundwater availability?
6. What are practical indicators for "state of groundwater," "impacts on groundwater," and "responses to impacts on groundwater?"

Priority data needs

1. Data needed to map, characterize, and model aquifers include:
    - surficial and bedrock geology information (e.g., type, formation, stratigraphy, lithology, structure);
    - water-well record information (e.g., lithology, reported yield);
    - groundwater hydrology data (e.g., porosity, permeability, recharge, transmissivity, hydraulic gradient, groundwater volumes, flow rate);
    - water-level time series data (seasonal, annual, long term);
    - climate and surface water data (precipitation and snowmelt, evapotranspiration, recharge estimates, water quality);
    - water usage by all users;
    - soils data (e.g., texture and thickness);
    - improved mapping of capture zones for water supply wells; and
    - permafrost data (location, thawing rates, effects of land use changes).
2. Baseline water levels to monitor any impacts of groundwater withdrawals for industrial purposes and from climate change.
3. Soils and surficial geology:
    - a structural analysis (orthophoto and air photo analysis, coupled with on-the-ground mapping) of the location of lineaments and faults in the northeast; and
    - an aeromagnetic (or other geophysical) survey of the northeast to confirm depth to bedrock and locate paleo-channels, especially in the Horn River Basin.
4. Water use trend data (e.g., industry [mines, oil and gas], populations served).
5. Effective water budgets and numerical models for aquifer types found in northeast British Columbia, taking into account unique variables such as permafrost and peatlands.

Priority system and policy needs

1. Ability to capture, archive, and disseminate data and information (e.g., hydrology, climate, geology, geophysical, allocation, groundwater use, abandoned wells) from numerous sources:
    - synchronize different data collection platforms in time and space (groundwater monitoring wells with hydrometeorological stations); and
    - improve government internet mapping sites (e.g., adding elevation of groundwater levels coverage to help establish direction of groundwater flow).
2. Improved monitoring network and monitoring well design, operation, and maintenance.
3. Improved co-operation between government agencies, academia, Oil & Gas Commission, and industry to capture and share groundwater and geology (especially surficial and shallow bedrock) data, and to upload data to government databases.
4. Timely enactment of the *Water Sustainability Act* and associated phases of the groundwater protection regulation.

3.6 Groundwater Quality (Shallow and Deep) and Groundwater Sustainability

The highest-priority topics selected by respondents focussed on the impact of chemical contaminants from agriculture and industrial activities on groundwater quality, and the chemical and physical parameters of groundwater (Table 7).

TABLE 7 *Frequency of respondents' priority ranking of key research and information needs for selected topics related to groundwater quality*

Research and information needs	High	Moderate	Low	NA[a]
Chemical contaminants from agriculture, oil and gas, forest management, mining, other industrial/commercial activities (e.g., volatile organic compound, nitrates)	21	10	7	27
Chemical and physical parameters (e.g., sodium, chloride, nitrate, pH, temperature, turbidity)	17	14	7	27
Radiological parameters (e.g., isotopes)	8	13	14	30
Bacteriological parameters (e.g., coliforms, turbidity)	5	11	15	34
Biological parameters (e.g., algae)	2	8	21	34

a Not answered.

Priority research questions

1. What is the natural groundwater quality in the northeast?
   - What areas require groundwater vulnerability mapping?
   - Where are the potable and non-potable aquifers found?
   - What should be the saturated zone (e.g., aquifers below 1000 metres in depth) or level of water quality (e.g., groundwater with concentrations > 4000 mg/L total dissolved solids) that the environmental standards are set to?
   - What are the natural dynamics between poor water quality (e.g., 4000 – 10 000 mg/L TDS), including saline waters, and adjacent potable aquifers and surface water?
   - Currently, we assume that if coliforms exist, there are viruses, and similarly, if there are no coliforms, then no viruses are present. Is this true?
   - Can the age of groundwater help identify the recharge areas?
2. What are the potential effects of industry, especially oil and gas activities, on groundwater quality?
   - What are the effects of groundwater extractions and hydraulic fracturing on water quality?
   - When you inject or withdraw water into/from high-total dissolved solids/saline aquifers, is there an impact from over- or under-pressuring the system?
   - What are the potential groundwater contamination risks from flowback (hydraulic fracturing fluid) and produced waste water (brackish reservoir water)?
   - Are there environmental consequences of down-hole disposal of used hydraulic fracturing water into underlying aquifers?
3. What are the geochemical processes that alter substances (e.g., methane) as they travel through various geologic materials?

4. What are the natural and anthropogenic (e.g., climate change and land use) impacts on water quality?
5. What is the residence time required to determine how susceptible the resource is to contamination/exploitation issues?
6. What is the long-term integrity of the well casings?

Priority data needs

1. Continuous groundwater quality data and an increased number of monitoring wells are required throughout northeast British Columbia. Data are needed on:
   - total dissolved solids;
   - giardia and cryptosporidium;
   - baseline chemistry; and
   - monitoring well casing integrity.
2. Aquifer characterization for other major, heavily used aquifers in the region outside of the Dawson Creek groundwater research project.

Priority system and policy needs

1. A publically accessible central database to capture and store water quality data from numerous sources, and disseminate the data as both data and information:
   - include isotope data (e.g., the Environmental Monitoring System does not currently support the capture and storage of these data); and
   - link applied water research monitoring to the various provincial databases (e.g., provincial Observation Well Network, Environmental Monitoring System).
2. Policy manuals and guidance documents on monitoring well networks and operations, groundwater sampling, and data consistency and reliability.
3. Improved co-operation between government agencies, academia, and industry to capture all groundwater quality data.
4. More direction and education from government to industry (e.g., groundwater quality sampling for environmental assessments), water purveyors, and the public about water quality issues.
5. Regulations governing:
   a. baseline water quality testing and reporting to government; and
   b. saline water disposal.
6. Capacity to effectively manage current numbers of observation wells in the provincial Observation Well Network, especially in northeast British Columbia.
7. What are the current standards for well casings?

3.7 Groundwater–Surface Water Interactions

The highest-priority topics selected by respondents focussed on the effects of resource development on the interface zones where groundwater is connected to surface water (Table 8).

TABLE 8 *Frequency of respondents' priority ranking of key research and information needs for selected topics related to groundwater–surface water interactions*

Research and information needs	High	Moderate	Low	NA[a]
Development (e.g., roads, agriculture, mining, forest management, oil and gas activities) effects on interface zones where groundwater is hydraulically connected with wetlands, springs, lakes, streams, riparian ecosystems, and aquatic ecosystems	33	9	2	21
Water withdrawal effects on the interface zone	27	12	0	26
Process differences (e.g., location, velocity, residence time)	19	14	7	25
Characteristic differences (physical or chemical differences [e.g., level of solutes, age of water, level of dissolved oxygen, temperature variation])	8	20	7	30

a Not answered.

Priority research questions

1. What are the relationships between surface water bodies, surrounding riparian zones, wetlands, aquatic systems, peatlands, permafrost, borrow pits, and shallow and deep saline aquifers?
    - Which groundwater–surface water interfaces are the most vulnerable to human activity?
    - What is the impact of surface water and groundwater withdrawals?
    - What amount of groundwater can be sustainably allocated without affecting groundwater contributions to environmental flows in streams?
    - How sensitive is an aquifer's connectivity to surface water?
    - How long does it take to recharge groundwater and travel to surface water bodies?
2. How can areas of groundwater–surface water interactions be identified and characterized?
    - What are the geologic/landscape characteristics at the groundwater–surface water interface?
2. What role does permafrost and melting permafrost play in groundwater–surface water interactions?
3. What is the relationship between groundwater and surface water, particularly in wetland/musket/peatland areas of the northeast?
4. Is there a hydraulic connection between the Peace River and the underlying bedrock that could be affecting water quality (i.e., chloride levels)?
5. What are the effects of establishing borrow pits, roads, and pipelines on muskeg?
    - Are there other impacts from oil and gas activities?

Priority data needs

1. Baseline data:
    - hydrometric data, including low-flow data for streams and rivers;
    - hydrogeological data, including data on groundwater levels, and quantity and quality of surface water and adjacent groundwater; and
    - climate data, land use / land cover data, and soils and geological data.

Priority system and policy needs

1. A user-friendly database to capture groundwater–surface water data and information, and disseminate the data as interpreted information to managers (e.g., a map-based tool to display the likely locations of groundwater–surface water interactions).
2. Increase research partnerships to leverage research capacity on groundwater–surface water interactions.
3. *Water Sustainability Act* regulations regarding groundwater allocation and licensing, and surface water environmental flow needs policy for water allocation.

3.8 Aquatic Ecosystems

The highest-priority topics selected by respondents focussed on low flows and environmental flow needs, aquatic ecosystem health, and the effects of resource development (Table 9).

TABLE 9 *Frequency of respondents' priority ranking of key research and information needs for selected topics related to aquatic ecosystems*

Research and information needs	High	Moderate	Low	NA[a]
Low flows and environmental flow needs	26	9	2	28
Aquatic ecosystem health	21	11	4	29
Development (e.g., roads, agriculture, mining, forest management, oil and gas activities) effects on aquatic ecosystems and adjacent riparian ecosystems	20	12	4	29
Fish habitat	18	8	9	30
Riparian management	17	11	7	30
Climate change	16	12	7	30
Stream temperature and temperature-sensitive streams	15	15	6	29
Fish populations (e.g., numbers, geographic extent)	14	8	10	33

a Not answered.

Priority research questions

1. Can we develop, test, and improve predictive tools for designating environmental flow needs for fish and aquatic ecosystems (i.e., water temperature management)?
    - What are the minimum flow thresholds by stream type?
    - What is the response of fish (and stream capacity/production) to changes in stream flow (in particular low flows), peak flows and timing, and winter allocations?

2. What are the potential cumulative effects of climate change, natural disturbance, and human-related activities on boreal and wetland hydrology, permafrost, and seasonal ground frost, on aquatic species and habitat?
3. What is the effect of road and pipeline development on peatlands (e.g., interruption of water flow and subsequent ecological effects)?
4. What is the effect on the hydrology and aquatic ecosystem of peatlands when water is withdrawn from nearby lakes, borrow pits, and aquifers?
5. What are the aquatic species and populations at risk in northeast British Columbia (i.e., high-value or indicator species)?
    - Where are the worst barriers to fish migration so that we can prioritize them for remediation?
6. What are the connections between water quality (e.g., hydrocarbons, pesticides, selenium, and temperature), quantity, and aquatic health (fish populations and habitat)?
    - Is there a connectivity of fish to non–fish-bearing streams and impacts of sedimentation?

Knowledge gaps

1. Users are unable to easily locate what data are available and where to locate them.

Priority data needs

1. Spatial data sets:
    - identification of sensitive streams (e.g., temperature, quality, high demand);
    - streamflow;
    - land use (e.g., roads);
    - long-term climatic and hydrometric data;
    - baseline stream temperature across the region; and
    - fish and fish habitat inventory (e.g., Arctic grayling, bull trout, burbot).
2. Better information on ecological communities, biodiversity, predator–prey interactions, migration corridors, and other biological/physical environment interactions that affect abundance, distribution, survival, and productivity of native fish species.

Priority system and policy needs

1. Develop and validate models:
    - fish habitat;
    - environmental flow needs that account for flow effects on productive capacity (e.g., prey, temperature), not just habitat; and
    - predict flows, particularly low flows, in ungauged basins/streams.
2. Rebuild/update/modernize our data gathering, storage, and management systems so that we can more easily load fish and aquatic data and disseminate them to users to facilitate research and reporting.
    - new mechanisms are needed to integrate species and habitat management objectives into decision-making.
3. Updated environmental flow needs policy to reflect unique geography and water licence reviews.
4. Revive Watershed Assessment Procedures and include riparian areas in a policy framework such as the clean energy guides so that they are used

as a best management plan, particularly in mountain pine beetle– and salvage harvest–affected watersheds.

5. Application of tools to predict and evaluate potential future outcomes for resource values in order to inform the decision process and subsequent assessments related to higher-level strategic plans:
   - Timber Supply Review;
   - permitting processes; and
   - cumulative effects assessments.
6. Ecosystem-based Management:
   - Wildlife Habitat Areas and Government Actions Regulation requirements to meet wildlife (aquatic and terrestrial) and biodiversity objectives that apply across all sectors/industries.
7. Do the Treaty 8 First Nations vary in the management of aquatic ecosystems?

3.9 Management for Natural and Resource Development Hazards

The highest-priority topics selected by respondents were the effects of drought, climate change, and development on hazards (Table 10).

TABLE 10 *Frequency of respondents' priority ranking of key research and information needs for selected topics related to management for natural and resource development hazards*

Research and information needs	High	Moderate	Low	NA[a]
Drought	19	7	5	34
Other impacts from human-related development (roads, agriculture, mining, forest management, oil and gas activities)	17	12	2	34
Climate change	15	11	7	32
Permafrost degradation	12	8	9	36
Surface erosion	11	12	6	36
Surface erosion from roads and development sites	10	13	7	35
Slope mass movements	8	12	10	35
Methane gas release	4	9	14	38

a Not answered.

Priority research questions

1. What are the effects of climate change on:
   - forest resources;
   - natural hazards (e.g., post-fire hazards, landslides, floods, and alluvial fans);
   - drought and flood hazard management: on low and peak flows; impact, value, and implications of water storage; peak flows in developed watersheds; management of developed watersheds (e.g., Dawson Creek); and
   - what role does permafrost (and thermokarst) play in surface water and groundwater hydrologic conditions in the northeast watersheds (e.g., Fort Nelson area)?

2. What are the cumulative effects associated with:
    - oil and gas development;
    - natural hazards;
    - survey cut lines on permafrost; and
    - human-related development in watersheds such as the Kiskatinaw River (in particular) road systems, and the effectiveness of erosion control measures in roadside ditches?
3. Can we develop or use a mapping program to extrapolate the presence, absence, and thickness of permafrost using a few sampling points over the northern region?
4. Where are the drought-sensitive watersheds?

Priority data needs

1. Spatial data sets:
    - road inventory and up-to-date reporting of all new linear developments;
    - floodplain mapping; and
    - Light Detection and Ranging (LiDAR) data to map landslides, creep, and permafrost features.
2. Hydrometric monitoring.
3. Climate data.
4. Ground temperature monitoring for permafrost degradation.

Priority system and policy needs

1. Improve information availability:
    - links to the River Forecast Centre regarding floods related to ice jams; and
    - integrate with sediment management, floodplain delineation and management, water control structures (e.g., dykes), destabilization of alluvial fans, etc.
2. Policy on infrastructure and development that is associated with potential land movements and impacts outside the direct area of influence (e.g., downstream impacts to users not directly affected by landslides caused by road development).
    - revisit and refine predictive tools for post-fire hazards, landslides, and floods, and incorporate cumulative effects.
3. Reporting requirements for geohazard events and centralized corporate data storage and management for geohazards and erosion risk:
    - mandatory reporting of landslide events for any activities on Crown land (no causation, just occurrence), and voluntary reporting on private land.
4. Drought monitoring system tied in with surface water levels, groundwater levels, and river flows.
5. Regulatory tools to respond to water shortages.

3.10 Other Information Needs for Northeast British Columbia

Priority system and policy needs

1. Extension of results from research by government or industry so we have more consistency between companies.
2. How can we better integrate data from various sources so we are confident that we have the best information for modelling and making recommendations?

3. What are the data standards to upload and manage data in a central location?
4. Can planning needs for allocation, flood risk/management, water quality protection, and other interests be included in water sustainability plans?

4 SUMMARY

The intent of this needs assessment survey was to identify specific knowledge gaps and provide guidance in the development of strategic priorities for water research and management in northeast British Columbia. These results are meant to be informative not directive, and guide the process to prioritize research and address knowledge gaps within the MFLNR. In order to further refine the needs and prioritize research questions, a follow up survey could be conducted using these results.

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APPENDIX 1 Surface water quantity and water management survey comments

Comments from different respondents are separated by a line – some respondents provided more than one comment.

Surface Water Quantity and Water Management. Data and Information Needs.

- Baseline information and easy access to it. Continuous monitoring.

- Water balance studies on boreal watersheds (e.g., build credible databases based on snowfall, rainfall, and real-time monitoring of water flow).
- A better understanding of wetland hydrology in boreal ecosystems (as affected by climate change and industrial activities).

- Hydrometric data, including more data on smaller stream systems.
- Increased spatial resolution of weather data.
- High-resolution weather forecasts.

- What are the development effects of wetlands and storage, such as cumulative effects and surface runoff on sedimentation?
- Better gauge information on tributaries; develop rating curves.
- A better characterization of intermittent flow. Fish stream classification information related to pathways to sedimentation.
- There is a lack of definition of fish-bearing stream classification in highly erodible areas. Are they fish-bearing in lower reaches? Connectivity of fish to non-fish-bearing streams and impacts of sedimentation. Increased FREP analysis. Can we measure protection for both fish and water quality?
- Need to know chemical composition of other sub-water storage sites and need to know what's in pipeline chemical constituents, particularly associated with fracking water storage. This is currently treated as proprietary by the OGC.

- More Water Survey Canada stations that provide better resolution of various hydrometric properties at the ecoregion scale.
- Habitat Suitability Index criteria for northern fish species by life stage and season.
- Biological data showing empirical response to flows. Develop a long-term research project to relate fish mortality to density-independent factors such as drought, extreme freezing, etc.
- Information needs to better scope cumulative water allocations in streams with a long history of water licensing, such as the Pouce Coupé River, which is transboundary with Alberta.

- Increased meteorological, streamflow, and hydrometeorological data.
- Information about soils data from a hydrological perspective, such as soil depth, etc., and evaporation data.

- Need streamflow data on smaller systems plus western-flowing sites like the Fontas and Petitot. Most of the systems currently being monitored by the Water Survey of Canada are from mountain runoffs and very large systems. Oil and gas companies want to know what's available in smaller watersheds closer to their operating area. The big systems are far away

and usually located in deeper valleys that are difficult to access for pipelines or water trucks.
• It is important to establish and maintain long-term records of basic hydrometric measurements for major and minor river systems. • An area of interest is in improving understanding of surface water–groundwater interactions, and the role/importance of groundwater discharge to base flows, and environmental flow requirements in ground-dependent ecosystems.
• More Water Survey of Canada gauging stations are required, not only in the northeast but in the north in general.
• Hydrometric data, both empirical and modelled, so that ungauged basins have basic data. • Complete the network of biomonitoring samples using the reference condition approach and CABIN so that benchmarks in undeveloped areas are set.
• Need long-term monitoring to model future impacts due to climate change. • Need more data/information to allocate water. • Forest management—there is good knowledge from other parts of BC that is applicable, but more information is needed to understand the cumulative hydrological effects. • The oil and gas and mining industries require more and better information. • Improve winter measurements and monitoring. • Expand monitoring and data collection to smaller systems. Monitoring is currently limited to big systems only.
• Actual water discharge monitoring, groundwater mapping and quantification, environmental flow needs, cumulative water demand, agricultural water demand, watershed plans and allocations, information requirements document, floodplain mapping, community watershed mapping and planning, water storage implications, winter flows.
• Ability to collate all industries' hydrometric information.
• Northeast Water Tool (NEWT).
• Need a higher density hydrometric data network.
• Time series streamflow data, including peak flow information, climate data, and land use change information.
• The Northeast Water Tool is a fantastic approach to providing information needed for decision-makers. A similar tool in the Omineca is needed. • More real-time hydrometric stations would provide value.
• Ability to maintain and/or increase monitoring. • Need for increased staff/stewardship people.
• Need to transform data into information that is useable to government, industry, and others.
• Identify the areas that may require additional hydrometric monitoring for water management, resource development, etc.

- To better validate and calibrate our hydrologic model, we could really use more information on snow–water equivalent, in regards to both its spatial and temporal evolution over the northeast. We could also apply information on evapotranspiration over the northeast.
- Again, spatial variations and temporal variations would be helpful. More precipitation information would also be useful.

- Improved quality of GIS (input) data.

- A better understanding of forest management effects on water.

- Climate data, forest cover, elevation, hydrometric. Would be useful to have local, actual evapotranspiration estimates from forests in northeast BC. Most of the literature is from carbon-fixing research in boreal Canada. Small, mid-size watersheds at lower elevations in the Peace Region are poorly understood.

- More gauging and hydrometric data would be helpful.
- Lake volume/bathymetry data are quite sparse in the northeast. This makes it tough to calculate water balances and recharge rates.

- Water Survey of Canada hydrometric data.

- Hydrometric network expansion to include:
  - more stations, as coverage is low in the north;
  - create stations in small catchments and at high-elevation types not normally addressed;
  - to help address the development pressure and increase coverage in northeast BC;
  - continue support for prediction in ungauged-basin model development similar to NEWT, as is already underway in Skeena and Omineca; and,
  - validation of NEWT predictions.
  - long-term continuous monitoring of surface water flux and levels.

  - More field data!
  - A source of spatially accurate soils site and soil profile information, including texture thickness and chemistry, that continues to be added to the corporate data set. This is required for soils modelling in support of agricultural water demand modelling, ecosystem mapping, groundwater modelling, etc.
  - Capture of the geologic record and carbon dating, particularly in pre-Fraser glacial deposits.

  - Broader geographic coverage.

  - Hydrometric information for the sustainable management of surface flows and source water protection to address key water allocation, fisheries, and drinking water concerns.
  - Information from BC's long-term research installations and other studies to clarify basic watershed system processes and the effects of natural and anthropogenic factors affecting water.
  - Research to quantify thresholds of instream flow levels to maintain aquatic ecosystem health and fish productivity, especially in consideration of climate change.

  - The use of airborne data to model the hydrologic response on a landscape level. We fly and acquire our own data.

Surface Water Quantity and Water Management. System and Methodology Needs.

- Metadata.
- Testing/validation of the Northeast Water Tool for select watersheds in the northeast.
- Hydrologic modelling.
- Sediment pathway assessments for incremental sediment increases in peak flow periods. Understanding what's beyond the natural component.
- Method needs include fish sampling of sufficient detail to construct Habitat Suitability Index curves, such as for Arctic Grayling, where the criteria account for much of the density variation according to hydraulic profiling at the meso-habitat scale.
- System needs include detailed mapping ability to predict the species distribution by life stage according to stream order, gradient, and mean annual discharge, or unit runoff, plus stream order.
- Systematic data capture in the seasonal low flow and annual low flow (August and February), but we have to make sure there has been no precipitation in that time to compare the systems to each other across the area. Low flows are the hardest to desk design because they are usually associated with incising into the topography, they are soils based (clay-till based soil versus sandstone will yield different base flows based on infiltration), and they are associated with the type of terrain (flat lying, wetland dominated versus rolling, well-drained uplands). Cumulative withdrawal system that is tied to real-time monitoring with quality data, especially data control in winter with under-ice measurements; we need a system that is managing the water and showing what the real impacts are to withdrawing on lakes or rivers.
- Increase the use of NEWT to refine the output.
- Watershed model like NEWT.
- Update BC modified tenant approach to assess instream flow needs.
- Northern issues: permafrost and frozen soils, ice hydrology in channels, cumulative effects.
- Instream flow needs methodology for northeast region, climate change modelling in NEWT, spatial capture for Sec 8/9, electronic database for all Sec 8/9 and water licences (including Oil & Gas Commission information), reporting database (access to data collected by all water users and baseline data collected by industry), water quality database.
- Need for a system that incorporates all government water approvals and can report out on allocations and actual water usage.
- Reliable and accessible database management system for streamflow and climate information.
- Ability to create and modify databases—the electronic capture of data.
- Develop tools to transform and display hydrology information (e.g., NEWT).
- Require additional fields (e.g., seasonal allocation amounts) from BC water licensing data be made accessible for use in water application tools.
- GIS.

- Guidance/coordination of third-party data collection—support sharing and contribution by other organizations.

- GIS, flow works.

- Continued support for prediction in ungauged-basin model development similar to NEWT, as is already underway in Skeena and Omineca.
- Validation of NEWT predictions.

- Updated inventory standards for soils, terrain, and ecosystem data.
- Support for the management of provincial corporate databases that house these data sets.
- Data management and publication is at least 10% of research projects that collect significant data so that the data go somewhere centralized and useful.

- Statistical packages and computing facilities.

- Allocation/withdrawal effects, particularly in low-flow times.

- Continued development and evolution of hydrologic models, including NEWT, Raven and Distributed Hydrological Soils/Vegetation Model (DHSVM).
- Develop, test, and improve predictive tools for instream flow requirements for fish and aquatic ecosystems (i.e., environmental flow needs).
- Water balance model for northeast wetlands, including groundwater–surface water interactions.
- Refine predictive tools relative to post-fire hazards, landslides, floods, and cumulative effects.

Surface Water Quantity and Water Management. Policy and Regulatory Needs.

- Reporting of all water consumption to a central archived data warehouse, accessible to all users.

- Better standards for classifying stream assessments. More harmonization between oil and gas and forest/range development. *Forest and Range Practices Act* should be in the same alignment as oil and gas for sediment control.

- Policy needs include cumulative assessments that are mandatory depending on the threat degree of a class of development.
- The development of an instream flow policy is required that directs where and when certain water allocations can be made.

- A water bailiff to monitor the data capture and complete a quality assurance program on lake levels, river flows to make sure what the company is saying is true. With Ministry of Highways, they went to a system of the contractor monitoring the quality of work, and then the Ministry of Transportation completes a 5 – 10% quality assurance check on the quality control program being run. Consulting companies are working for the oil company, and the consulting company may not have the right experience to gather the data to provincial standards.

- Policy on conjunctively managing surface water/groundwater systems, including the impacts of groundwater allocations on surface water and environmental flow needs are lacking but are urgently needed with passage of the *Water Sustainability Act*.

- We need the new *Water Sustainability Act* to be enacted ASAP.

- Need a *FRPA* regulation regarding watershed-level impacts and % cover removal therein.
- Policy on application of the reference condition approach for use in assessing cumulative impacts on water resources. Need regulatory levers to address significant impact signals, either by the reference condition approach or cumulative effects.

- Dugout policy, instream flow needs policy, higher appeal fees, better definition of a stream, community watershed regulation (for watersheds larger than the Forest Practices Code designation), water quality testing requirements.

- Water storage policy that is consistent across government agencies and across the province.

- *Water Sustainability Act* and associated regulations and policies.

- Proposed provisions in pending *Water Sustainability Act* to help respond to water scarcity.

- All data must be collected using acceptable standards.

- Continued and improved regulatory oversight of the oil and gas sector. This has much improved in the past few years with new initiatives in the Peace Region; a continuation of this work is needed.

- Ability to change policy and regulatory regimes more rapidly as new information becomes available.

- What will/might be the impact of the *Water Sustainability Act* on demands for additional hydrometric monitoring in the future?

- Results from our work provide regional climate stakeholders with the information they need to develop plans for reducing the risks associated with climate variability and change.

- We need applied science research to determine the actual response of fish biomass/production to changes in flow. This is to both establish benchmark flow needs for fish in different regions/stream types, and to validate instream flow models and indices that are applied to infer flow needs for fishes but have extremely limited validation.

- Data to support regulatory review/changes.

- Actual water use reporting, improvements to government database to support better representation of water licence terms and conditions (i.e., seasonal allocations).

- *B.C. Water Act*.

- Policy requirement for all data related to drilling, soils profiles, terrestrial ecosystem, geotechnical field site information, etc., collected on Crown land, to be submitted to a provincial data repository. This should be a requirement of all licensing and permitting processes. Currently, soils and surficial geology data collected for development and resource use on Crown land are treated as proprietary.
- Policy for the protection of rare and unique landforms that contribute to water quality and quantity and that add to the body of knowledge about paleoclimates (cumulic landforms and pre-Fraser).

- A better definition of wetland in the *Water Act*!
- Government water policy:
  - *Water Sustainability Act* (MOE developed, MFLNR delivered);
  - MOE environmental flow needs policy;
  - integrated decision-making;
  - *Oil and Gas Activities Act*; and
  - development and operational effects of mines and access infrastructure on surface flows.

Surface Water Quantity and Water Management. Are you or your organization currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory?

- Snow monitoring in the Kiskatinaw River basin (which I am currently doing), and a water balance study for a small watershed north of Fort Nelson (Coles Lake), which is currently being done by a graduate student at UNBC (Richard Kabzems and John Rex—http://bvcentre.ca/files/Misc/14-03-05-Sina-Abstract.pdf).

- Conduct peak flow and low-flow monitoring and analysis (e.g., low-flow return period analysis, flood frequency analysis).
- Potentially developing new project on rainfall-intensity-duration curve analysis using the provincial climate network.

- Updated water quality risk assessment, which includes a spatial activities update that is tied to improved biophysical, ecological, and hydrological assessment. Fine-tuning water quality risk assessment using soils, etc. Develop that into further field audit. 1st phase is complete for Dawson Creek. Available on Water Page website.

- Publication by Ptolemy (2013) *Predictive models for differentiating habitat use of coastal cutthroat (*Onchorhyncus clarki clarki*) and steelhead trout (*Onchorhyncus mykiss*) at the reach and landscape scale.*

- Developing applied hydrological projections for all of British Columbia, including the northeast.

- We are completing a large project with a First Nations company and a large oil company northwest of Fort Nelson with a training program built in to capture baseline data. We are also working with the City of Dawson Creek on a small headwater lake in the east Kiskatinaw that is a reservoir for the city during droughts, and are looking at recharge from groundwater during droughts to determine what volumes are available to supply the city during extended droughts.

- In the Omineca, we are engaged in stream monitoring on small watersheds to develop longer term water management plans.

- Yes—several areas related to groundwater impacts from oil/gas; forestry impacts on watersheds and small streams as a result of salvage and other mountain pine beetle harvesting.

- Conducting base-level surface water monitoring in Horn River Basin. Knowing what additional research is being done in this area is important and beneficial.

- Groundwater well monitoring.

- Working on cumulative impacts in forested environments, primarily for watershed values related to surface waters.

- Part of the northeast flow policy program and NEWT model. In 2012, released a report concerning flow needs and environmental flow needs during the winter. From this developed a risk framework.

- Cumulative effects study on Murray River in relation to mining sector.
- Objectives development program on Murray River system in relation to mining sector—also applicable to other industry users.
- Benthic biomonitoring to develop model to aid in regulatory activities for all sectors.

- Currently, I am not involved in applied research or monitoring activities; however, the Ministry of Environment is involved in collecting weather data and snow data.

- Data collection/monitoring and management related to surface and groundwater quality in the Omineca and Peace Regions through the MOE.

- FREP water quality monitoring (for forest management and range activities).

- Recently developed the NEWT model to display hydrological information (e.g., monthly and annual flows)—check the OGC website.
- Developing a northeast BC water portal to more easily access and better display water data from a number of sources that produce data (e.g., federal water hydrometric data).

- PCIC carries out applied research on the impacts of climate change on hydrology. Our findings are freely available, and data will be ready for download on our website in the coming months. The Peace River basin above Taylor is the watershed in the northeast we have modelled to this date. Our projections are for 23 scenarios (up to eight Global Climate Models run under the A2, B1, and A1B scenarios). We have a publication in the journal Hydrologic Processes—Impacts of climate change in three hydrologic regimes in British Columbia, Canada—that includes the Peace River. You can also find our reports at www.pacificclimate.org/resources/publications. We have plans to look at more basins in this area in the near future.

- Some modelling work on instream flow methods (Jordan Rosenfeld); ongoing development and regionalization of instream flow standards (Ron Ptolemy).

- BC OGC Water Portal is providing access to existing water quality and quantity data (surface and groundwater) in northeast British Columbia.

- Culvert/fish passage assessments at road crossings in selected watersheds.

- Cumulative effects of soils and surficial geology modelling, nutrient and moisture modelling, and, geology interpretations for soil texture and nutrient class.

- We have 10 meteorological stations in operation to monitor atmospheric and soil surface conditions across the Cariboo Mountains.

- Carnation Creek Experimental Watershed Project (Project lead).
- Cowichan River Project.

- Watershed-based Fish Values Monitoring Protocol (WFVM) for Watersheds with High Fish Values (MFLNR – MOE).
- Morice watershed assessment (water values and watershed processes assessment; salmon habitat and populations assessment and forecasting regarding industrial developments and climate change effects).
- Forest and Range Evaluation Program (FREP): stream-riparian-fish habitat post-harvest monitoring.

- Yes, with BC Geological Survey in Dawson Creek area.

- University of Northern British Columbia (UNBC) Natural Resources and Environmental Studies Institute (NRESi) Biodiversity Monitoring & Assessment Program http://bmap.unbc.ca/

Surface Water Quantity and Water Management. Are you aware of any other organization or persons currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory? If so, please specify and provide links or contact people.

- Pacific Climate Impacts Consortium.

- BC MOE/PCIC Climate Related Monitoring Program (e.g., Ted Weick).
- Oil & Gas Commission—NEWT project (Allan Chapman).
- PCIC/BC Ministry of Transport and Industry—Climate Change Engineering Vulnerability Assessment of Three British Columbia Highway Segments.

- BC Hydro Water Use Planning (Peace) in the northeast as well as Site C ongoing research. Various Independent Power Projects in development in the northeast acquiring specialized inventory data.

- Environment Canada on the Athabasca—oil sands related. They may also be doing the Peace River. Talk with Terry Prowse at UVIC.
- Oil & Gas Commission at the NEWT model.
- Fraser Basin Council—Northeast vulnerability assessment. Conduct a user needs assessment and produce a vulnerability assessment in northeast BC to run workshops. Restricted to PCIC data from the Peace River region.

- Dave Murray—Kerr Wood Leidal is one company that we work under; they have a few projects on the go.
- Steve Dunk is a contact for Progress Energy. We are currently gathering data from this company, and they may have a keen interest in setting aside one or two sites strictly for research. We could complete the field work under the MFLNR direction.
- Agriculture Canada has produced a document called *Annual unit runoff on the Canadian prairies*, which is an excellent analysis of runoff across Canada. They have extended it up into northern BC for the 2013 report.

- John Rex, MFLNR; Ben Kerr—consultant who worked on development of NEWT; could provide background on issues and assumptions built into model and where more information would have been helpful; and Celine Davis—MOE lead on Northeast Water Strategy would be a very good person to contact.

- All of the coal mine companies, City of Dawson Creek, wind tenure applications, oil and gas industry, agriculture sector (grain producers, climate action, Regional District).

- Possibly the OGC.

- Most of the work in the Horn River Basin is being conducted by oil and gas companies—the information does not go back to the public domain. Water Survey of Canada does have one hydrometric station in the region.

- Yes—BC government and partners, GeoScience BC.

- Drinking Water/Source Water Risk Assessment—led by Reg Whiten, Dawson Creek.

- The Mining Association of British Columbia is actively involved with a number of initiatives in the northeast.
- Pierre Beadry and Associates is actively involved with government staff on water research.

- Water Survey of Canada.

- Oil and gas industry is monitoring surface water quantity data to support their water licence application. GeoScience BC has 5–6 hydrometric stations in the Horn River Basin (the second year of a 3-year project).
- Industry is mapping deeper aquifers in the Liard basin.

- Hydrometric stations operated for GeoScience BC in the Horn River Basin (Kerr Wood Leidal Associates Ltd.). NEWT by the OGC (Allan Chapman).

- The Fraser Basin Council (Jim Vanderwal) and Climate Action Secretariat (Jen Pouliotte) are conducting the Northeast Climate Vulnerability Assessment.

- Mike Bradford, DFO/SFU www.rem.sfu.ca/crmi/dfomem.html
- Wendy Palen, SFU https://www.sfu.ca/biology/people/profiles/wpalen.html
- Dan Moore, UBC Geography www.geog.ubc.ca/~rdmoore/

- Multiple—contact Zaid Jumean (250-356-9343) for full list. Suzan Lapp contacted Zaid and confirmed not much going on in the northeast; lots going on throughout the province.

- Yes—Many CAPP members are collecting hydrometric data, but they are inaccessible. CAPP should be pushed to not have their members compete on environmental issues. CAPP is tied in to the Northeast Water Strategy with K. Ciruna. Geoscience BC has been in the press regarding their desire to support new monitoring. Should be pursued as a beneficial source of additional funding.

- OGC—Allan Chapman—northeast hydrological modelling.
- MFLNR—Dave Wilford—groundwater isotopes and other studies.
- UNBC—Juey Sui—Kiskatinaw watershed.
- MFLNR/UNBC—Fort Nelson wetlands water balance.

- We have partners in AAFC, SFU, UBCO, UNBC. Contact information can be obtained upon request and with the permission of the individuals.

- My colleagues Phil Owens and Ellen Petticrew conduct sediment studies (sources, apportionment, etc.) mainly with the Quesnel River basin.

- MFLNR Hydrology/Geomorphology Research Discipline Group (I was a former member and leader during my time in that ministry). See David Wilford, Skeena Region for a list of MFLNR researchers.
- MFLNR climate researchers (David Spittlehouse, Caren Dymond).
- FREP: Monitoring of *FRPA* effectiveness for water quality, riparian-stream ecosystem integrity/function, biodiversity, soils, and more. See Pete Bradford, Resource Practices Branch, MFLNR.
- Academia: e.g., Dan Hogan, BCIT; Dan Moore and Marwan Hassan, UBC; others at SFU and UNBC.
- Federal–provincial hydrometric network.

- Yes—BC OGC.

- Many of the oil and gas companies in the Horn River Basin (including Geoscience BC) have done research for water availability.

- Kerr Wood Leidal completed the installation of hydrometric gauges and a weather station for Geoscience BC.

Surface Water Quantity and Water Management. What are your priority research questions or knowledge gaps related to key decisions?

- Climate change impacts on water availability in northeast BC.
- Cumulative effects of natural resource uses of water.

- Water balance for Kiskatinaw watershed, which supplies water for the City of Dawson Creek.
- Testing of NEWT for select watersheds in northeast BC by acquiring data to determine water balance.

- Wetland dynamics, particularly in the Fort Nelson area, where surface water is accessed for industrial purposes, based on limited hydrological information.
- For First Nations, the implications of changes in water levels beyond the range of natural variation affect wildlife habitat, access for exercise of treaty rights, and productivity of the land base.

- Frequency and magnitude of extreme events.
- Potential changes in hydrologic processes (including peak flows and low flows) due to climate change.

- Source water protection plan for the city of Dawson Creek has a Memorandum of Understanding in an appendix, and Oil and Gas is not a signatory. This constraints their decision ability.

- Given that animals, including fish, have adapted to the environmental stressors in the northeast, what are the key mortality pathways that can be made worse with certain types of resource development? We already know that access and roads can lead to increased fish mortality beyond what is sustainable through too much harvest.
- Another question relates to known sediment impacts on the aquatic environment and the fact that streams in the Boreal Plains, Taiga Plains, and Northern Boreal Mountains ecoprovinces may be more prone to fine sediment inputs due to low gradient, soils, and geological character.

- Data to help us do the applied research.

- Comparison of data captured at a site during a time period to a long-term station in that runoff zone; we don't have a lot of stations. Period.

Our unit runoff changes rapidly as we move away from the mountains, but we have only a handful of stations in those zones. What is the normal range of flows for that system and what type of year was it that we captured the data? Water Survey of Canada systems are large and originate in the mountains, which have snowpack runoff versus the plateau.

- Understanding the role of groundwater extraction on surface flows and environmental flow needs.

- Low-flow requirement on smaller systems for allocation of the resource.

- Winter monitoring of low flows.
- Saline groundwater flow back to surface.

- Actual water discharge monitoring (real-time and historical), groundwater mapping and quantification, environmental flow needs, cumulative water demand, agricultural water demand, watershed plans and allocations, information requirements document, floodplain mapping, community watershed mapping and planning, water storage implications, flood and drought predictions and planning.

- Shallow groundwater mapping via airborne geophysics in Montney gas trend.
- Expanding surface water monitoring networks in Liard basin.

- Cumulative impacts on surface water/watershed values and social licence to operate.

- Understanding how to incorporate environmental flows into decision making.
- More hydrometric data, particularly on small streams.
- Understanding the hydrological variability—it's a challenge to make decisions using averages.

- There is just a general lack of detailed and long-term data on all fronts.
- We need to know the long-term effects of industry on water quality and quantity, both in terms of surface water and groundwater.

- With respect to water quantity, there is a need to treat water as a resource. How much water is available (including how does water move through the system—timing and volumes), what are the environmental needs, how much can safely be taken out of the system for human needs? Until we can answer those basic questions, all other questions appear irrelevant.

- What are the locations where future hydrometric monitoring is required to support water management, resource development, and climate change monitoring? What is the priority for monitoring within the existing network of stations? Is there a need for baseline volume runoff data in the northeast?

- Our priority research question is, "What is the impact of climate change on hydrology in watersheds of the northeast out to 2100?" How will this affect average monthly conditions, as well as extremes, such as peak flow and low flows? You can find our research plan at www.pacificclimate.org/sites/default/files/publications/Schnorbus.HI_Plan_April2012.pdf

- Knowing (with some level of confidence) what the responses of fish (and stream capacity/production) are to changes in stream flow (in particular, low flows).

- Establishing minimum flow thresholds by stream type based on credible research relevant to BC streams.
- Research to validate that predictions from widely applied models and minimum flow rules of thumb are accurate.
- Development of new instream flow modelling approaches that account for flow effects on productive capacity (e.g., prey, temperature), not just habitat.

- How can watershed processes be monitored to understand impacts on fish habitat?

- Lake volume/bathymetry data are quite sparse in the northeast. This makes it tough to calculate water balances and recharge rates. I have been involved in the development of a new digital bathymetric standard for BC and have helped regional staff do bathy surveys on lakes of interest in their areas. Presumably, approvals staff in the northeast would need access to lake volume data for their decision-making process for withdrawals. I think that the onus should be put on applicants to perform bathy surveys for water bodies that would be affected by their proposed activities.

- How much water is available for oil and gas use?

- Appropriately scaled water budget information is unavailable for many areas of the province, most notably now in the northeast.
- How will climate change affect water availability scarcity?
- What is the current watershed condition/health in the wake of mountain pine beetle and salvage harvesting?
- Biomass harvesting Best Management Practices—What are the current effects of biomass harvesting on site hydrology and aquatic habitat? Biomass harvesting differs from traditional harvesting processes, but there are no guidelines in place.
- Model development for predicting flow in ungauged basins.

- Surface–groundwater interaction and recharge/discharge are critical to understanding the short- and long-term sustainability of our watersheds. We need to know more about the timing of fluxes, their relation to climate, and the impacts of climate change on how they operate.

- There is a general lack of water-related data for the northeast of BC.

- Where are the fans and the floodplains? Where are the lacustrine deposits? Where are the very thick deposits of unconsolidated materials and what are their properties (e.g., texture, bedding)? Where are the pre-Fraser glacial deposits? What paleoclimate and paleo-ecological records do they hold? What is the distribution of soil thickness and texture across the BC landscape at a variety of scales?
- What are the soils, terrain, and ecosystem attributes that can be reliably predicted?
- Where are the mapping exceptions to what is reliably predicted?

- How is climate change affecting water resources, including the contribution of snow to runoff generation and its timing, in British Columbia?

- The direct and cumulative impacts of resource allocation decisions on species, their populations, and habitats.
- The effects of climate change, new human activities, and invasive species on aquatic and terrestrial species and habitats.

- Develop tools to project the influence of climate change/climate variability on natural hazards.
- Empirical information and model development on the effects of run-of-the river projects on channel morphology and fish habitat to guide decisions.

APPENDIX 2 Surface water quality and water management survey comments

Surface Water Quality and Water Management. Data and Information Needs.

- Baseline studies and ongoing monitoring prior to industrial activity.

- Effects on the thermal regime.
- Water temperature information.

- Snow sampling for water quality analysis. Snow captures air pollution and stores it for months, then releases it in spring. The pollution in the snow is released in the first 20% of the runoff. We should be looking at cumulative water quality and using the snowpack as the sampling medium as it is very hard to capture the water quality in the spring freshet due to timing constraints and variability of start of runoff. Also, the effect of coal mines on water pollution: we have found coal dust up to 22 km away from the coal mine during some sampling and research we have done on the effects of energy production on the quality of snow.
- Transportation of produced water is a big issue. Trucks are hauling this material everywhere. Companies haul fresh water and produced water in the same truck. Truckers have told me they need to prime the pump and they keep on a 1/2 cube of condensate or produced water and let it flow back from the pump to prime the line before they start filling from a water source. Things go down the river that are not supposed to be going down the river.

- What is the impact of shoreline development on lake health? In the Omineca, there is a growing trend of shoreline development.

- What are the cumulative effects from resource development and other pressures?
- What are the impacts from agriculture?

- Baseline water quality levels, spatial capture of environmental permitting of discharge/effluent permits, water quantity–quality relationship quantification, thresholds for water quality, and point source water quality issues.

- Always a need for more and better data.

- What is the impact of forest management, oil and gas development, and mining on community drinking water supplies?

- Develop design flow, and know the concentration of chemicals in the effluent as well as in the streamflow.

- Ability to maintain and/or increase monitoring as needed.
- Need for increased staff/stewardship people.

- Baseline water chemistry as an index of biological (prey) production.
- Need to develop regionally predictive capacity relationships between water chemistry and fish standing crop (Ron is working on this).

- What are the forest management effects on water quality?

- What is the influence of development (forestry and oil and gas) on surface/shallow groundwater regimes and quality? Mining is also particularly relevant in relation to roads/crossings, erosion–sediment control, and turbidity. The latter is more of a data need; however, as opposed to research, considerable work that has documented the effect of roads/crossings on sediment in streams is already available.

- What is the frequency with which surface waters contain viable enteric viruses?

- Monitoring in strategic areas where high use or demand are identified. Physical and chemical data provide the basis of this framework.

- Using turbidity as a metric for erosion.

- Hydrometric data for gauged rivers and streams.

- Sufficient water quality data to characterize water bodies.
- Up-to-date land use information.
- Information on potential future developments.

- Hydrometric information for the sustainable management of surface flows and source water protection to address key water quality issues regarding aquatic ecosystem "health" and drinking water concerns.
- Information from BC's long-term research installations and other studies to clarify basic watershed system processes and the effects of natural and anthropogenic factors affecting water quality.
- Research to quantify thresholds of instream flow levels to maintain water quality parameters, including temperature (especially for temperature-sensitive streams), and the relationship to fish abundance and productivity.
- The effects of climate change on the above.

Surface Water Quality and Water Management. System and Methodology Needs.

- Take Allan Chapman's watershed units and sample snow during the mid-March period across the northeast in the active zones, analyze the results, and compare the water quality parameters to see if anything shows up; then you can look at the activity in the area and see based on wind direction what the source may be.

- Develop better working relations with local government on land use development.

- Water quality database, spatial capture, and availability of discharge/effluent permitting.

- Standard methodology and software for estimating design flow, database for baseline information.

- Ability to create and modify databases—the electronic capture of data.

- Expanded monitoring network may address some of the water quality

challenges driven by development. Recommend that they are maintained by industry as part of the permit process and that government provides quality assurance/quality control or peer review.

- Up-to-date GIS land use layers.

- Continued development and evolution of hydrologic models, particularly in relation to low flows and effects on thermal and chemical water quality parameters.
- Develop, test, and improve predictive tools for instream flow requirements for fish and aquatic ecosystems (i.e., environmental flow needs regarding water temperature management).
- Water balance model for northeast wetlands, including groundwater–surface water interactions.

Surface Water Quality and Water Management. Policy and Regulatory Needs.

- Air pollution is permitted for one site, but it takes a lot of trucks, drilling rigs, pipelines, and camps to support one permitted facility. By sampling snow, we can look at cumulative effects of the whole operation. Maybe this will lead to cumulative effects management.

- Stronger legislation on lakeshore development.

- Develop a better policy for water allocation and mines that reflects the volume of water required for dilution of effluent.
- Need a regulatory requirement for the collection of baseline water quality for all industries.

- Watershed planning for drinking water source protection.

- Standard guidelines and objectives for acceptable concentration of chemicals in the streamflow.

- Ability to change policy and regulatory regimes more rapidly as new information becomes available.

- Need to adhere to provincial standards, and where lacking, CCME.

- Need to deal with wastewater re-use. MOE refuses to treat water treatment plant effluent as wastewater.

- Develop a government water policy:
  - *Water Sustainability Act* (MOE developed, MFLNR delivered);
  - MOE environmental flow needs policy;
  - integrated decision-making;
  - *Oil and Gas Activities Act*; and
  - policy on development and operations for mines and access structures regarding chemical water quality and fine sediments.

- What are acceptable gas emissions from oil and gas wells?

Surface Water Quality and Water Management. Are you or your organization currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory?

- Base level monitoring in the Horn River Basin.

- Water Quality Objectives Attainment Monitoring—related to mining and municipal effluent impacts.
- Volunteer Lake Monitoring Program—general water quality studies.

- During the past 5 years, I initiated and coordinated widespread data collection in the Peace Region related to assessing the effects of mine effluents on selenium and small-bodied fish.

- Providing Land Based Investment Strategy funding to UBCO to investigate biological pathogens (source and concentrations) in community watersheds.

- Although their focus is on water quantity, the Water Survey of Canada does have the ability to collect some water quality parameters, such as temperature and sediment/turbidity. Currently, water temperature data are being collected at 10 stations in the Williston basin. However, this initiative is no longer funded, and the sensors have been left in place as run-to-failure.

- Need to develop regionally predictive capacity relationships between water chemistry and fish standing crop. (Ron is working on this.)
- Need to develop relationships (regional, by stream type) between water chemistry and prey abundance for fish, and relationships between how prey abundance responds to variations in discharge (largely independent of water quality).

- Northern Health collects data monthly on *E. coli* and total coliform in regulated water supply systems. Currently, emphasis is on treated water rather than source water. I'm pushing to include more source sampling.

- Modelling soil nutrient regime.
- Field data collection of soil chemistry.

- Meteorological data collection.

- Carnation Creek Experimental Watershed Project (Project lead).
- Cowichan River Project.
- Watershed-based Fish Values Monitoring Protocol (WFVM) for Watersheds with High Fish Values (MFLNR–MOE).
- Morice watershed assessment (water values and watershed processes assessment; salmon habitat and populations assessment and forecasting regarding industrial developments and climate change effects).
- Forest and Range Evaluation Program (FREP): Stream-riparian-fish habitat post-harvest monitoring.

Surface Water Quality and Water Management. Are you aware of any other organization or persons currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory? If so, please specify and provide links or contact people.

- Kevin Rieberger—MOE Water Quality Scientist—involved in BC/Alberta bilateral agreement committee; good source of information on committee members and issues related to water quality and quantity; lots of work on source areas.
- Environmental Assessment Office—staff should to talk to Alanya?—is helpful contact to point in right direction.

- Mining companies, oil and gas industry, City of Dawson Creek.

- Swan Lake Enhancement Society—doing lots of work on the Swan Lake watershed.

- Lana Miller, Environmental Quality Section Head with MOE has extensive knowledge on this subject.
- Mining Association of British Columbia.

- Water Survey of Canada.

- See David Wilford, Skeena Region, for a list of MFLNR researchers.
- MFLNR climate researchers (David Spittlehouse, Caren Dymond).
- FREP: Monitoring of *FRPA* effectiveness for water quality, riparian–stream ecosystem integrity/function, biodiversity, soils, and more. See Pete Bradford, Resource Practices Branch, MFLNR.
- Academia: e.g., Dan Hogan, BCIT; Dan Moore and Marwan Hassan, UBC; others at SFU and UNBC.

Surface Water Quality and Water Management. What are your priority research questions or knowledge gaps related to key decisions?

- More temperature data on a broad spectrum of different streams where the stakeholders are wanting water data— typically follow the main stem rivers only.

- Timing of water quality in spring freshet runoff, and when that plume of pollution will reach the stream.

- Water quantity and quality.

- Baseline water quality levels, spatial capture of environmental permitting discharge/effluent permits, water quantity–quality relationship quantification, thresholds for water quality, point source water quality issues.

- What are the effects of water usage for various purposes on water quality? Public often mistrusts us.

- Species in northeast BC sensitivity to selenium (e.g., sculpin, bull trout, Arctic grayling).

- Need a better handle on source and concentration of pathogens, including their viability and travel distance.

- Need to develop regionally predictive capacity relationships between water chemistry and fish standing crop.
- Need to develop relationships (regional, by stream type) between water chemistry and prey abundance for fish, and relationships between how

prey abundance responds to variations in discharge (largely independent of water quality).

- Surface–groundwater interaction and recharge/discharge are critical to understanding the short- and long-term sustainability of our watersheds. Water physical and chemical data allow us to evaluate the interactions and link them to fluxes.
- Our role is to support the development of bilateral agreements that include protecting water quality and aquatic ecosystems. In order to properly classify water bodies according to management objectives and activities, we need the information specified above (i.e., water quality data, and current and proposed land use).
- Identifying and mapping the distribution of temperature-sensitive aquatic species and habitats for input into key decisions.
- Direct and cumulative effects of industrial development and land alterations on chemical and thermal water quality.
- Identifying causes of gas emissions from oil and gas wells.

APPENDIX 3 Groundwater quantity (shallow and deep) and groundwater sustainability survey comments

Groundwater Quantity (shallow and deep) and Groundwater Sustainability. Data and Information Needs.

- Geologic data, both bedrock (type, structural, faults, and lineaments) and surficial geology (type, formation origin, lithology) to establish the framework where groundwater exists and moves.
- Surficial geology mapping to identify alluvial aquifers that might be connected to streams.
- Lithology from well logs.
- More borehole logging when drilling new wells.
- Depth to bedrock, and location of paleoaquifers that may contain potable or non-potable water supplies.
- Data from the Observation Well Network that provide effective coverage.
- Increased number of monitoring wells at industry-maintained wells.
- Seasonal water levels, not just annual.
- Hydrology data, including water levels, hydraulic gradient, flow rate, yield data, especially pump test data, aquifer volumes, sustainable yield potential, stream discharge.
- Recharge values.
- Climate data, including precipitation and snow melt.
- Evapotranspiration data.
- Reasonable evapotranspiration numbers and groundwater use data.
- Water use data (e.g., industry [mines, oil and gas], populations served).
- Land use data.

- Soils data (e.g., texture and thickness).
- Geophysical data to better understand stratigraphy and lithology.
- Soils data (e.g., texture, thickness, permeability) to indicate underlying parent materials, etc.
- Time series (seasonal, annual, long-term) water level data from observation wells.
- Improved capture zones for water supply wells.
- Aquifer mapping as new areas experience groundwater development.
- Characterization of aquifers, including direction of groundwater flow, aquifer volumes, yield potential, etc.
- Pump tests to establish or confirm flow regimes in bedrock aquifers and between bedrock aquifers, especially between deep and shallow aquifers.
- Dump test data from water supply wells.
- Data to establish capture zones. Well capture zones typically only have "arbitrary fixed radius" as there are so little data available—need data to establish better capture zones.
- Data to develop water budgets.
- Data to map, classify, and characterize aquifers (aquifers in the South Peace, shallow aquifers, paleovalley aquifers, etc.) to support the new *Water Sustainability Act*.
- Data to conduct more groundwater "intrinsic" vulnerability mapping to support initiatives, such as the BC/Alberta bilateral agreements.

Groundwater Quantity (shallow and deep) and Groundwater Sustainability. System and Methodology Needs.

- Require means to capture and archive data and disseminate from numerous sources, both as data and as information (e.g., pump tests into aquifer yield potential).
- Synchronize groundwater monitoring wells with hydrometeorological stations to interpret stream flow, precipitation, and snow data with respect to groundwater extraction and climate change aspects.
- Track and assess groundwater allocations in aquifer context, identify aquifers in communication with surface water, and integrate as needed, especially in low-flow years. Establish more observation wells to gauge use.
- Track groundwater allocation and usage.
- Soil texture and thickness field inventory.
- Inventory of decommissioned orphan wells.
- System to capture data from borehole logging, oil and gas seismic data, and other geophysical methods when drilling new wells.
- Improved access to geological data from all sources to improve aquifer mapping.
- Policy manual on use and administration for life of any wells drilled for research projects. Will they be closed at the end of the project, and

are they the responsibility of the agency running the project? If there are other agreements for the lifespan of the well post project, all parties impacted must agree.
• Link new research projects to the provincial groundwater monitoring well system, where applicable.
• A data portal that can access data and information that are often housed in different databases, some of which are not easily accessible.
• Improve access to River Forecast Centre data, including seasonal discharge information.
• System developed to capture groundwater data housed with the OGC in an ongoing process.
• Groundwater flow direction (or at least water table elevations) should be a coverage in iMap (would be extremely useful for water supply studies and spill response).
• Methods to develop reasonable evapotranspiration numbers and groundwater use (e.g., industry [mines, oil and gas], populations served, etc.).
• Water budget methodologies for aquifers found in northeast BC, taking into account permafrost and peatlands.
• Method to synchronize groundwater monitoring wells with hydrometeorological stations to interpret stream flow, precipitation, and snow data with respect to groundwater extraction and climate change aspects.
• Manual with protocols for any wells drilled (including observation wells) for research projects. Will they be closed at the end of the project, and are they the responsibility of the agency running the project? If wells are to be continued as observation wells, the issue of operating and maintaining them must be considered.
• Standard monitoring well design for different aquifer systems (single, multi, bedrock, unconsolidated) for reliable water level and quality data that can be used for dispute resolution and scientific research.
• Standard monitoring well operation and maintenance manual and/or protocol for data consistency and reliability.
• Web application for displaying results of aeromagnetic surveys and other geophysical data.
• NEWT for groundwater.
• Statistical packages and computing infrastructure to assist analysis of groundwater.
• Aquifer models to support groundwater allocation and make better informed management decisions related to groundwater.
• Ability to incorporate geophysical data (e.g., regional airborne electromagnetic and/or magnetic surveys) into aquifer mapping program.
• Application developed to display water level and quality data in iMap.
• Improve guidance documents on sampling for groundwater quality and quantity by industry regarding environmental assessments.
• Improved guidelines on constructing observation and monitoring wells.

- Method to track and assess groundwater allocations at an aquifer scale.
- Application that identifies aquifers in communication with surface water.
- Application that incorporates geological data from all sources to improve aquifer mapping and characterization.

Groundwater Quantity (shallow and deep) and Groundwater Sustainability. Policy and Regulatory Needs.

- Mandatory pump tests and water analysis.
- Mandatory submission of all driller logs.
- Acquire baseline data in areas before, during, and after development takes place.
- Sufficient observation well and monitoring well coverage to meet the required need.
- Develop water budgets for different aquifer types to assess wetland response to water withdrawals by industry, and to allocate groundwater.
- Have dedicated resources to routinely collect and compile key groundwater data (e.g., water levels, reported yields, sustainable withdrawal rates, etc.) on an ongoing basis to license and allocate groundwater under the new *Water Sustainability Act*.
- Link all water research to the provincial Observation Well Network in BC, where applicable.
- Basic geology data as part of resource development permits (e.g., depth to bedrock from regional airborne electromagnetic and/or magnetic surveys) to assist in understanding near-surface geology and potential aquifers.
- Dedicated resources should be committed to enhancing and maintaining a central repository to store the groundwater data in a useful and accessible format so that groundwater practitioners can have improved access to groundwater data.
- Develop a "one-stop" data portal for all groundwater and related data (surface, climate, geology, geophysics, etc.).
- Require better co-operation between government agencies, academia, the OGC, and industry to capture all groundwater data (e.g., WELLS database has only a fraction of wells drilled in area; the OGC has water supply well logs that are not entered into WELLS) and surficial and shallow bedrock data to upload to MOE databases.
- Petroleum industry to log unconsolidated materials over bedrock so their logs are useful in mapping and characterizing potable groundwater supplies.
- Requirement for submitting information related to drilling and excavation.
- *Water Sustainability Act* (MOE developed, MFLNR delivered) regarding groundwater allocation, licensing.
- New *Water Sustainability Act*—Will saline water be licensed and governed, and what will the regulations regarding groundwater withdrawals

look like (e.g., yes to water > 10 000 TDS; maybe to 4000–10 000 TDS if unfit to drink)? What about the situation where 4–10K water is poor quality but found close to surface—what effect is there on adjacent potable aquifers and surface water?

- Covered by new water act? Farm dams/barrow pits providing water to oil and gas industry.
- Thresholds for allocation.
- Regulatory requirement for collection of baseline data prior to allocation.
- Direction on how to determine allocation amount of groundwater.
- Equivalent of Alberta's "depth of groundwater" guidelines for industry.
- MOE environmental flow needs.
- *Oil and Gas Activities Act*—fracking, extraction.
- Policy for run-of-river water allocations, taking into consideration the interconnectedness to groundwater and the accumulative effects on stream flows in flow-sensitive landscapes.
- Increase available planning tools and capacity for watershed/aquifer planning.
- Introduce water use monitoring.
- Improve integrated decision-making.
- Understanding cumulative effects.
- Sustainable management of groundwater resources based on the five elements of groundwater sustainability defined by the Canadian Council of Academies.
- Establish indicators for "state of groundwater," "impacts on groundwater," and "responses to impacts on groundwater."
- Identify adaptive management/blended water use strategies (e.g., surface water during wet season, groundwater during low-flow season[s]).
- Increase capacity at River Forecast Centre to help track and better assist overall data needs.
- Establish additional water survey stations (e.g., in upper Kiskatinaw basin).
- Setting up an inventory of orphan wells, and their decommissioning.
- Administration, use, maintenance, and closure of any wells drilled for research projects. Who is responsible at the different stages of a project?

Groundwater Quantity (shallow and deep) and Groundwater Sustainability. Are you or your organization currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory?

- Bear Hole Lake water balance study. Involves shallow water–lake recharge and outflows to do modelling. Includes a climate station and gauging of tributaries that are feeding the lake, and shallow piezometers or surface gauges.

- Stage discharge curve for intake at Arras (Upper east Kiskatinaw), and will develop for other major sub-basins. Completed peak flow measurements at hydrometric station locations plus a few additional sites, including Arras and other easily accessible sites.

- Japanese-funded study on the water–energy nexus in the northeast:
  - Two SFU undergraduates worked on a part-time basis until late March 2014 to (a) undertake simple recharge modelling in the Montney, and (b) construct hydrogeological cross-sections to aid in groundwater quality interpretation from water wells that were sampled for water quality in the 2011–2013 Montney study. The results will go to Andarge Baye (MOE).
  - Pacific Institute for Climate Solutions (PICS) has four or five projects in BC, with one project proposed for issues related to shale gas development the northeast.
  - A PICS workshop (held in November 2013) focussed on who was conducting research in the northeast, what are the research gaps, and what further research should be done. The scope included physical science, social science, economics, etc. A key outcome was that water sustainability is a critical issue, and coordination among the various organizations (e.g., universities, industry, government, consultants, nongovernmental organizations) is needed. Dave Wilford, Chelton van Geloven, and Andarge Baye attended this workshop. A report will be released from this workshop—it may already be in the hands of PICS but perhaps not distributed.
  - Stephen Dery (Canada Research Chair with UNBC) is working on a water budget for Coal Lake in northeast BC (Fort Nelson area). He is looking at water withdrawals from the lake for fracking purposes.

- Conducting a groundwater characterization project in the Montney Play area south of the Peace River, just north of Dawson Creek. Reviewing groundwater levels and chemistry to understand movement, origins, and the relation between unconsolidated aquifer and underlying bedrock aquifer and quality of groundwater. Klaus Rathfelder (MOE), Chelton van Geloven (MFLNR), Jillian Kelly (MOE), Dirk Kirste (SFU) are involved.

- A MFLNR-led Montney water project, which is aimed at improving understanding of groundwater resources in the south Peace River valley. A groundwater characterization study near Dawson Creek, to understand the existence and movement of groundwater in the bedrock and overlying unconsolidated materials. Contacts: Andarge Baye (MOE) and Dave Wilford (MFLNR).

- Provincial Observation Well Network currently has nine wells in northeast BC.

- Geoscience BC (Carlos Salas) is being asked to partner with the OGC (Alan Chapman) to conduct aeromagnetic surveys to provide understanding of the upper bedrock and define paleochannels in two to three areas in the Horn River Basin, then establish wells to ground-truth the aeromagnetic data, and to see if any aquifers exist. Some of the wells may be employed as long-term observation wells. Finally, develop a web-based tool to effectively display these data and information. Partnerships with people capable of running LiDAR surveys would also be beneficial

(Olaf Nieman [UVIC]), Martin Geertsema [MFLNR]) to better understanding.

- The OGC is marginally involved in the Groundbirch groundwater characterization study with MOE (Andarge) and MFLNR (Chelton), and the paleovalley groundwater study with MOE, MFLNR, and MEM (Adrian Hickin). The MEM paleovalley report is an open file and has been released (A. Hickin).

- Another report (A. Hickin) is due summer 2014, and will be an analysis of the Geological Survey of Canada data from their seismic work conducted in the 2013 summer season in the Groundbirch and Dawson Creek area.
- Compilation of Geological Survey of Canada surficial geology maps for NTS 94A and 93P by A.S. Hickin (MEM) and M.A. Fournier (MAF Geographix).
- Preliminary bedrock topography and drift thickness of the Montney Play area by A.S. Hickin (MEM), cartography by M.A. Fournier (MAF Geographix).
- *Stratigraphy and proposed geophysical survey of the Groundbirch paleovalley: a contribution to the collaborative northeast British Columbia aquifer project* (Hickin and Best 2012).

- Monitoring shallow groundwater levels using nine piezometers at Coles Lake, northeast BC, to infer the lake's water budget. Climate data are also being collected at this site.

- The Oil and Gas geosciences group (MEM), until March 2012, worked on what is known about shallow bedrock units in the northeast and what we might expect them to be like in terms of aquifer potential. Refer to Janet Riddell's (2012) *Potential for freshwater bedrock aquifers in northeast British Columbia: regional distribution and lithology of surface and shallow subsurface bedrock units* for more references, especially pertaining to geology (bedrock and surficial), geochemistry, etc., including some references from Alberta. There is also a draft compilation map of northeast BC bedrock: bright colours show the units with potential for good primary porosity; dark, gloomy colours show the units expected to form regional aquifers. (A page-size version of this map appears in the report above, but with a much simplified legend.)

- The distribution of major geological units in the shallow subsurface can be predicted using bedrock geology maps. Bedrock geology mapping conducted by the Geological Survey of Canada is available for all of northeast British Columbia at 1:250 000 scale (Ridell 2012). This mapping is compiled at the provincial scale and is located on the MEM MapPlace website (MapPlace 2015).

- Stratigraphic studies: Detailed stratigraphic studies on specific formations are abundant (e.g., Fanti and Catuneanu [2010] for the Wapiti Formation, Hay and Plint [2009] for the Dunvegan Formation, and many others). These studies can be valuable exploration tools because they provide descriptions of mappable markers in outcrop and in subsurface gamma-ray logs.

- Upcoming report by E. Johnson on permafrost and thaw changes through time; data from the last 50 – 60 years in northeast BC.

- Report by E. Johnson: Hydraulic Fracture Water Usage in Northeast British Columbia: Locations, Volumes and Trends. www2.gov.bc.ca/gov/DownloadAsset?assetId=44F3DF9C4B99475CB773DF0788817A65

- Waterline Consultants are constantly collecting hydrogeology information in all shale gas development areas in BC. Since this is "frontier type" development where very little data exist, we believe that every piece of groundwater information collected should be classed as "applied research" because it allows us to develop accurate conceptual hydrogeological models of aquifers. Currently, this is being done on a project-by-project basis, and the data reside in energy company files.

- Dick Jackson, Principal Geofirma Engineer and Adjunct Professor at the University of Waterloo is currently working with Maurice Dusseault at the University of Waterloo on wellbore integrity with Alberta Department of Energy.

Groundwater Quantity (shallow and deep) and Groundwater Sustainability. Are you aware of any other organization or persons currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory? If so, please specify and provide links or contact people.

- Shell has a monitoring network in Groundbirch for Shell-specific gas wells.

- A 3-year project with UNBC (Faye Hirschfield, Chelton van Geloven) was completed south of the Peace River in the northeast.
- A project with Stephen Dery and Richard to model climate change effects is in the planning stages. The goal is to get better flow monitoring in Noel and Bear Hole. The information will be integrated with the provincial level.

- An SFU School for Public Policy student, under the supervision of Nancy Olewiler (SFU) and Deborah Harford (Adaptation to Climate Change Team at SFU), is completing a capstone project for her MPP degree on the existing regulatory regime in relation to shale gas development and what policy options are available (component related to water demand).

- The OGC is contemplating a major aquifer mapping project in the North Montney area.

- Shell Canada has been conducting an aquifer study looking at water quality in relation to oil and gas activities.

- Groundwater-level monitoring is being conducted by MOE's Knowledge Management Branch (Tarik Dessouki).

- Stephan Dery's (UNBC) industrial partner in the research at Coles Lake, Quicksilver, also monitors meteorological conditions and collects hydrometric data for the Coles Lake inflows/outflows.

- Hayes (2010) and Hayes et al. (2011) evaluated deep saline aquifers in the Horn River Basin and the Montney Play for their capabilities to produce the volumes of water necessary to support completions and to accept spent hydraulic fracturing (flowback) fluids by deep well injection.

- Brown (2011) reported on the Montney Water Project, a Geoscience BC sponsored collaboration that included projects directed at aquifer mapping and classification (Lowen 2011), surficial mapping compilation (Hickin and Fournie 2011), and delineation of paleovalleys that may host unconsolidated aquifers (Hickin 2011). Wilford (2012) and Hickin and Best (2012) are expanding on this work in the Dawson Creek area.
- Previous aquifer studies: Mathews (1950, 1955) conducted preliminary investigations in the Peace River District for groundwater prospects for domestic and agricultural use. Mathews (1950) identified several surficial and bedrock-hosted aquifers and provided general comments about their yields and water quality. Mathews (1955) defined six physiographic units in the district and assessed their groundwater prospectively.
- Ronneseth (1983) and Cowen (1998) compiled quantitative data on water well yields and water quality from surficial and bedrock-hosted aquifer units in the Peace River valley, and commented on local and regional trends. Both noted that bedrock aquifers generally have lower water yields and quality than surficial aquifers, and that quality tends to be poorer on the plains and better in the Rocky Mountain Foothills.
- Lowen (2004, 2011) identified, delineated, and classified developed aquifers in the Peace River region.
- Jones (1966), Barnes (1977), Hitchon (1990), and Bachu et al. (1993) conducted hydrogeological studies in correlative strata in the Peace River valley in adjacent Alberta.
- Groundwater monitoring and aquifer classification studies are conducted by MOE: www.env.gov.bc.ca/wsd/index.html

- MFLNR Research Community (see David Wilford for list) and MFLNR long-term research installations: Upper Penticton Creek (R. Winkler), Redfish Creek (P. Jordan), others, e.g., Northeast Alberta Wetlands Research Initiative (linked to oil and gas industry initiative).

- Canadian Water Network is looking to fund research into hydraulic fracking and water supplies; it is likely the northeast of BC will figure into this.
- Wilford Laurier University is looking at the hydrology of discontinuous permafrost areas that would be applicable to northeast BC.

- Oil and gas companies typically collect long-term data for operational purposes in order to protect their investment. The data are invaluable to hydrogeologists, but they reside in company files and are not available to manage a public resource.

Groundwater Quantity (shallow and deep) and Groundwater Sustainability. What are your priority research questions or knowledge gaps related to key decisions?

- How much groundwater, where is it, how much can be allocated, what is the cumulative supply and demand?

- What are the recharge rates and groundwater flow pathways? We require greater knowledge of the subsurface hydrogeologic architecture to answer these questions.

- What are the hydraulic properties of the dominant bedrock aquifer (Dunvegan formation) in the region?

- What are the fracture porosity values for the shallow bedrock units in the northeast?
- What is the relationship between shallow groundwater and surface recharge in East Kiskatinaw? (Facilitate research with Axel Anderson?)
- When you inject water into, or withdraw it from, high-TDS/saline aquifers, is there an impact from over- or under-pressuring the system?
- What are the optimum numbers of observation wells required to understand the effect of shale gas development in the northeast?
- Are there environmental consequences of down-hole disposal of used fracking water into underlying aquifers?
- Is well casing integrity an issue? (This has been a problem elsewhere.) Are there long-term monitoring programs to monitor casing integrity of shale gas wells? And if not, should there be? Is gas moving out into or up the annular space? Will it in the future?
- What are the direct and cumulative impacts of land use and climate change on aquifers?
- Would the airborne work on the Calgary–Edmonton corridor lead to better understanding of the groundwater resource in northeast BC? Given that an aeromagnetic survey is being proposed by the OGC and Geoscience BC.
- Does fracking at depths (around 2000 m) ever affect (QQ plot) groundwater at depths (around 200 m)?
- Using aquifer water budgets, what is the amount of water that can be sustainably allocated without impacting groundwater levels and environmental flows in streams?
- What are the effects of groundwater extractions on aquifers, recharge rates, and relationships to environmental surface flows, and aquatic ecosystems?
- What are the impacts, including wetland response, from oil and gas activities in northeast BC?
- What are the effects of establishing borrow pits?
- What are the effects of water withdrawals and timing of withdrawals from local dugouts, borrow pits, smaller lakes, smaller streams, and aquifers?
- With a comprehensive water budget for Coles Lake, how much fresh water can be extracted safely from the system without damaging the environment?
- What is the effect on the hydrology and aquatic ecosystem of the peatlands when water is withdrawn from nearby lakes, borrow pits, and aquifers?
- Has the NEWT model ever been validated to ensure its robustness?
- With aquifer water budgets, how much groundwater can be sustainably allocated without impacting groundwater levels and environmental flows in streams?

- Are there run-of-river water allocations in the northeast, and if so, if they are coupled with groundwater usage, do they jointly affect flow-sensitive ecosystems?
- Aquifer mapping and more characterization (e.g., recharge, water chemistry) of aquifers in the South Peace.
- Seasonal stream discharge data. Water survey station required in upper Kiskatinaw region.
- Groundwater vulnerability classification and mapping (using Gilles Wendling's work).
- Sufficient data coverage to understand groundwater systems and develop aquifer budgets.
- Water budgets.
- Wetland response to water allocation for oil and gas in northeast BC.
- Effect of borrow pits on the environment.
- Recharge rates and groundwater flow directions.
- Subsurface hydrogeologic architecture.
- Fracture porosity properties of shallow bedrock aquifers.
- Surface and groundwater interconnectivity.
- The location of, and dynamics between, saline and non-saline groundwater zones.
- Yield potential and permeability of bedrock (through pumping tests).
- Wetland response to water allocation for oil and gas industry.
- Aquifer potential of shallow bedrock units.
- Little groundwater data outside of the Fort St. John/Dawson Creek and Peace River areas.
- Understanding of the bedrock porosity at the interface between usable and unusable (saline) water.
- Interaction between surface and groundwater (especially in Horn River Basin).
- Surficial and shallow bedrock mapping to provide a better relationship between geology and groundwater flow.

APPENDIX 4 Groundwater quality (shallow and deep) and groundwater sustainability survey comments

Groundwater Quality (shallow and deep) and Groundwater Sustainability. Data and Information Needs.

- Time series monitoring of groundwater quality to detect change and direction of change.
- More groundwater quality/quantity data in northeast BC. Some data may exist in oil and gas industry files.

- Definition of "shallow and deep" in relation to groundwater depths.
- Reporting and monitoring requirements for groundwater use.
- Research to characterize aquifers, in particular, size and recharge rates, and assessing impacts of current withdrawals, surface development (land use), and climate change.
- Expand the Dawson Creek groundwater research project to provide aquifer characterization for other major, heavily used aquifers.
- Baseline data before oil and gas development activity to detect earliest indication of potential adverse effects (monitoring wells should be on optimal locations from oil and gas activities [well pads]).
- Increased number of monitoring wells at industry-maintained wells.

Groundwater Quality (shallow and deep) and Groundwater Sustainability. System and Methodology Needs.

- Require better co-operation between government agencies, academia, and industry to capture all quantity data.
- A data architecture to capture and store water quality data from numerous sources, and then disseminate the data as both data and information.
- A publically accessible central database that reports groundwater use for industrial purposes and the characteristics of the groundwater being used.
- Standard monitoring well operation, sampling, and maintenance manual and protocols for data consistency and reliability are required.
- Update laboratory methods:
  - Current groundwater chemical analysis methods are based on surface water type sampling and incur a significant expense that is not necessary if sampling methods are appropriate.
- Improve guidance documents on sampling for groundwater quality and quantity by industry regarding environmental assessments.
- Aquifer models to support management decisions related to groundwater.
- Develop models to support groundwater allocation.
- Better use of multi-level monitoring wells.
- Link water research to the groundwater monitoring Observation Well Network in BC.
- Methodology to assess numbers of observation wells that can be managed effectively given the available provincial government resources.

Groundwater Quality (shallow and deep) and Groundwater Sustainability. Policy and Regulatory Needs.

- The capacity of provincial staff to effectively manage current numbers of observation wells in the provincial Observation Well Network is insufficient, especially in northeast BC. Therefore, clear plans for addressing staff capacity are needed when contemplating additional wells for future research projects in this area.

- Develop a publicly accessible central database for housing and disseminating data on drilling activities and groundwater use for industrial purposes, and reporting the characteristics of the groundwater being used.
- Require better co-operation between government agencies, academia, and industry to capture all water quantity and quality data.
- Will the new *Water Sustainability Act* govern saline water? What will the regulations regarding groundwater withdrawals look like (e.g., yes to water >10 000 TDS; maybe to 4000–10 000 TDS if unfit to drink)?
- Link applied water research monitoring to the provincial groundwater Observation Well Network in BC.
- Pass and enforce regulations/management plans that help protect groundwater quality:
  - for example, Phase II of the groundwater protection regulation would strengthen protection of groundwater quality.
- Adopt groundwater management plans, like the Township of Langley did.
- Make it a regulatory requirement to conduct baseline water quality testing and report to government.
- Have required reporting and monitoring requirements for groundwater use.
- Existing regulatory policies in BC focus on assigning liability rather than actually providing guidance to water practitioners, purveyors, and the public. The groundwater resource in BC needs to be managed by the users, and the government needs to take the lead to "protect the public."
- Government needs to commit to policy initiatives on groundwater quality regulations.
- More education on contamination of groundwater.
- Need a clear plan of what will occur with any wells drilled for research projects. Will they be closed at the end of the project, and are they the responsibility of the agency running the project? If there are other agreements for the lifespan of the well post project, all parties impacted must agree.

Groundwater Quality (shallow and deep) and Groundwater Sustainability. Are you or your organization currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory?

- A MFLNR-led Montney water project, which is aimed at improving understanding of groundwater resources in the south Peace River valley. A groundwater characterization study near Dawson Creek to understand the existence and movement of groundwater in the bedrock and overlying unconsolidated materials. Contacts: Andarge Baye (MOE) and Dave Wilford (MFLNR).
- First of a 5-year, $30K/yr Japanese-funded study on the water–energy nexus in the northeast.

- PhD student under the supervision of Dirk Kirste (and Diana Allen) is looking at risks to water (groundwater) from shale gas development (thesis scope yet to be fully defined—likely researching the development of a risk assessment framework for northeast BC impacts of shale gas extraction on the groundwater resource and groundwater quality. Likely will look at water chemistry and water quality risks, using GIS). This is linked to collaboration with the Research Institute of Humanity and Nature (Japan) on risk- and policy-related research that is exploring the energy-food-water nexus.
- Japanese team is leading a broad study on indicators (stressors and resilience) in relation to nexus issues. Northeast BC will be one of the case study areas for this indicator assessment—will tie in to PhD student research.
- Roger Beckie and Uli Meyer (UBC) (funded by the OGC) are conducting research on gas well leakage and monitoring (what chemical parameters should be monitored?).
- Chelton and Dirk are currently discussing methane sampling procedures.

- We (MOE) are currently preparing groundwater quality objectives for the Osoyoos aquifer and the Abbotsford–Sumas aquifer. If required, water quality objectives can be applied to aquifers in the northeast.
- We (MOE) have also prepared a draft guidance document on the design of an underground stormwater infiltration system for the protection of groundwater resources in BC. The document is currently under review.

- Yes, MOE is working with SFU, MFLNR, the OGC, and others.

- Northern Health collects data monthly on *E. coli* and total coliform in regulated water supply systems. Currently, emphasis is on treated water rather than source water. I'm pushing to include more source sampling.

- Janet Riddell (MEM) gave a PowerPoint presentation for the water working group, in, I think 2011, illustrating the problem of the two most important water quality data gaps: (a) the depth gap between the bottom of most water wells (usually 100 m) and the top of most water tests in drill stem tests (almost all below 600 m), and (b) the extremely sparse distribution of surface water wells in most of northeast BC (Ridell 2012).

Groundwater Quality (shallow and deep) and Groundwater Sustainability. Are you aware of any other organization or persons currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory? If so, please specify and provide links or contact people.

- Studies undertaken and data captured (e.g., arsenic study in the northeast, general chemistry parameters inventory and sample sources not tied to a well and in WELLS); Northern Health (Dave Tamblyn).
- Guidance document by Shelly Baines? For proponents getting exemptions from EA reviews.
- Document on how to deal with saline water, by Al Kohut.

- Shell Oil: CABIN gas project in their Montney Play properties—monitoring water quality in local wells.

- The mining industry, oil and gas industry, and the City of Dawson Creek.

- Shell is monitoring groundwater quality in the Groundbirch area with shallow and deep wells (likely using multiport wells?).
- Groundwater monitoring (provincial observation wells) is conducted by MOE Knowledge Management Branch (Tarik Dessouki).
- Shell has a substantial groundwater quality monitoring program in the Dawson Creek area, I believe GW Solutions (Gilles Wendling consultant) has also been active in Dawson Creek and Hudson's Hope.
- Dick Jackson, Principal with Geofirma Engineering, notes the use of identifiers for shallow gas in northeast BC.

Groundwater Quality (shallow and deep) and Groundwater Sustainability. What are your priority research questions or knowledge gaps related to key decisions?

- Where poor quality 4–10K water is found close to the surface, what are the effects on adjacent potable aquifers and surface water?
- What are the geochemical processes that alter substances (e.g., methane) as they travel through various geologic materials?
- What are the direct and cumulative impacts of land uses and climate change on aquifers?
- What effects will climate change have on the availability of clean water?
- What are the recharge rates and flow rates?
- Do cryptosporidium and giardia ever show up in wells, and if so, under what conditions are they excluded?
- Regarding enteric viruses: Currently, we assume if coliforms exist, there are viruses, and similarly, no coliforms, then no viruses. Is this true?
- What are the natural dynamics between saline and non-saline groundwater?
- What areas require groundwater vulnerability classification and mapping (using Gilles Wendling's work)?
- What is happening over time to shale gas well casings, and if compromised, are there potential pathways to aquifers or surface water bodies?
- What are the potential groundwater contamination risks from developing hydrocarbon gases (e.g., methane, BTEX) from the flowback (hydraulic fracturing fluid) and produced waste water (brackish reservoir water)?
- What are the risks from having a lack of appropriate baseline information and a lack of monitoring?
- What are the effects of groundwater extractions, fracking, and rerouting on chemical water quality, including salinity on groundwater?
- To realistically determine how susceptible the resource is to contamination/exploitation issues, what are the residence times of groundwater?
- Is well casing integrity an issue? (This has been a problem elsewhere.) Are there long-term monitoring programs to monitor casing integrity of shale gas wells? And if not, should there be? Is gas moving out into or up the annular space? Will it in the future?

- Knowledge of the overall groundwater resource is needed before it can be responsibly managed or allocated.
- Aquifer mapping in areas not mapped.
- The potential quality and quantity effects of industry, especially oil and gas activities, on groundwater.
- Need to quantify groundwater use.
- Define "shallow and deep" in relation to potable groundwater depths.
- Require a baseline of water quality information.
- Because of the data gap between the base of water wells (generally less than 150 m deep) and top of logged and sampled oil and gas exploration wells (generally greater than 300 m deep), we need to know the depth to the base of fresh groundwater in northeast British Columbia.
- This data gap can be addressed by obtaining new lithological and geochemical data from the upper few hundred metres in a representative number of exploration wells in oil and gas fields. Exploration activity occurring in previously undeveloped areas will provide opportunities to obtain new lithological and aqueous geochemistry data where information has previously been absent or limited.

APPENDIX 5 Groundwater–surface water interactions survey comments

Groundwater–Surface Water Interactions. Data and Information Needs.

- Low-flow data for streams and rivers.
- Groundwater water level and quality data.
- Climate data, hydrometric data, hydrogeological data, land use/land cover data, soils and geological data are all needed to work with coupled surface water–groundwater models.
- Any information about surface water–groundwater interactions would be useful for responsible water allocation and water management decisions.
- Baseline chemistry and continuous tracking. Focus on lower basin (Brassey basin) more than upper.
- Groundwater recharge data on surface water flows: How long does it take to recharge and reach the system? If we have a wet year like this year, are we seeing that recharge now or next summer?
- To develop coupled surface water–groundwater models, information on all aspects of the water cycle is needed (climate data, hydrometric data, hydrogeological data, land use/land cover data, soils and geological data).
- Thermal profiles, chemical profiles, and water levels from piezometers.
- More hydrometric data are needed for the area.
- Water inflow/outflow data along with water extractions and groundwater levels at Coles Lake, northeast BC.

Groundwater–Surface Water Interactions. System and Methodology Needs.

- Groundwater and surface water models and water budgets to help us better understand the groundwater and surface water relationships.
- A methodology to compare thermal profiles, chemical profiles, and water levels from piezometers at the groundwater–surface water interface that is defensible and economical.
- A NEWT for groundwater.
- An infrastructure in place to capture and store data from numerous sources, and then disseminate the data as data and information.
- Need statistical packages and computing infrastructure for working with the groundwater–surface water interface.
- Coupled surface water–groundwater models.
- Development of a water balance model for northeast wetlands, incorporating groundwater–surface water interactions.

Groundwater–Surface Water Interactions. Policy and Regulatory Needs.

- Groundwater regulation with clear thresholds for allocation.
- Policy for allocation of resource.
- *Water Sustainability Act* (MOE developed, MFLNR delivered) regarding groundwater allocation, licensing.
- MOE environmental flow needs policy.
- Integrated decision-making.
- Oil and gas activities legislation, regulations, and policies on water withdrawals and fracking.
- Increase research partnerships to leverage research capacity on groundwater.

Groundwater–Surface Water Interactions. Are you or your organization currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory?

- Vicki Carmichael (MOE): Methodology (analytical model) developed by Klaus and Vicki for future licensing, on which licence gets shut off in times of shortage.
- Diana Allen and Dirk Kirste (SFU) are applying to PICS for a graduate fellowship for potentially two students that can be supported by SFU to do research on this topic: watershed scale model for a region in the northeast—used to obtain a water balance for the watershed, examine interactions between groundwater and surface water in a regional setting, and examine potential impacts of climate change and development on the water balance.
- Klaus Rathfelder (MOE): I am preparing a report entitled An assessment of methods for evaluating the effects of groundwater withdrawal on surface waters in British Columbia.
- MOE is also developing a methodology for evaluating aquifer water budgets from limited data to support allocation of groundwater resources.

Groundwater–Surface Water Interactions. Are you aware of any other organization or persons currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory? If so, please specify and provide links or contact people.

- Klaus Rathfelder (MOE): Currently assisting in policy development for assessing hydraulic connectivity between aquifers and streams, and the administrative procedures for grandfathering and licensing groundwater in connected surface water/groundwater systems.
- Allan Chapman (OGC) noted John Rex (MFLNR) and Stephan Dery (UNBC) are looking at effects (in Horn River Basin) of water withdrawals from shallow lakes and pits on local ecosystems/adjacent vegetation.

Groundwater–Surface Water Interactions. What are your priority research questions or knowledge gaps related to key decisions?

- This topic area is characterized by major and critical data/information gaps. A key gap is to understand what the linkages are among surface waters, groundwater, and aquatic ecosystems.
- What are the effects of deep saline extraction? Does it include subsidence?
- There is a disposal well in Brassey. What's happening there? (Is it related to Tupperwest plant?)
- Where are the more vulnerable groundwater–surface water interaction areas (wetlands, etc.)?
  - What is the surficial geology in these vulnerable areas, and do we need to be concerned during flood events?
- Groundwater recharge on surface water flows: How long does it take to recharge and reach the system?
  - If we have a wet year like this year (2014?), are we seeing that recharge now or next summer?
- What are the impacts from using dugouts for water supplies, and how do these dugouts connect to the groundwater–surface water hydrology?
- What is the interaction of muskeg with river flows?
- What is the effect of road and pipeline development on muskeg?
  - Are we backing the groundwater flow up by placing a road there, creating a dam?
  - Are we draining a muskeg area by intercepting groundwater flows from pipeline trenching?
- What is the groundwater/surface water connectivity?
  - How do we know whether it's connected?
  - How do we assess the stream's potential for depletion (part of the *Water Sustainability Act*)?
  - How sensitive is an aquifer's connectivity to surface water?
- Will require more information on recharge, quantity, etc., to answer the questions above.
- Quantification of the groundwater–surface water relationship to address the impact of water allocation on each resource, including what are the thresholds for allocation?

- What are the natural and anthropogenic impacts on water quality?
- What effects will climate change have on the availability of clean water?
- We do not know recharge rates or flow rates; we need to understand the residence time of the water to realistically determine how susceptible the resource is to contamination/exploitation issues.
- What role does permafrost and disappearing permafrost play regarding groundwater?
- What are the characteristics of the geology at the groundwater–surface water interface in the area?
- The chloride levels from the upper bedrock underlying the Peace River are significantly lower than the chloride levels to the north and south of the river. What is the reason? Is there a hydraulic connection with the Peace River?
- Using aquifer water budgets, what is the amount of water that can be sustainably allocated without impacting groundwater levels and environmental flows in streams?
- What are the effects of groundwater extractions on aquifers, recharge rates, and the relationship to environmental surface flows, and on aquatic ecosystems?
- What are the impacts, including wetland response, from oil and gas activities?
- What are the effects of establishing borrow pits?
- What are the effects of water withdrawals, and timing of withdrawals, from local dugouts, borrow pits, smaller lakes, smaller streams, and aquifers?
- With a comprehensive water budget for Coles Lake, how much fresh water can be extracted safely from the system without damaging the environment?
- What is the effect on the hydrology and aquatic ecosystem of the peatlands when water is withdrawn from nearby lakes, borrow pits, and aquifers?
- Has the NEWT model ever been validated to ensure its robustness?
- With aquifer water budgets, how much groundwater can be sustainably allocated without impacting groundwater levels and environmental flows in streams?
- Are there run-of-river water allocations in the northeast, and if so, if coupled with groundwater usage, do they jointly affect flow-sensitive ecosystems?
- Recharge rates and groundwater flow pathways need to be understood through greater knowledge of the hydrogeologic architecture.
- Supply and demand aspects of groundwater–surface water interaction (through modelling).
- Sustainable groundwater usage for the protection of environmental flow needs.

- Identifying key recharge areas (particularly in rapidly developing landscapes).
- Groundwater-dependent ecosystems in BC Groundwater's contribution to low flows. This could potentially be an issue in the northeast, where many of the most productive aquifers are along major river valleys, and large groundwater extractions may affect winter low flows, particularly if there are areas where groundwater discharges provide temperature refuge for sensitive species.
- Generally poor understanding of groundwater–surface water connectivity, which makes it hard to predict effects at this interface.
- A holistic "health" assessment of aquifers, including quality, quantity, and dependent ecosystems.
- Base flow separation, or the identification of groundwater's contribution to surface water. To help quantify groundwater recharge.
- Water balance inventory for major watersheds and aquifers (easiest if aquifers don't cross watershed boundaries).

APPENDIX 6 Aquatic ecosystems survey comments

Aquatic Ecosystems. Data and Information Needs.

- Boreal wetlands (e.g., fens, bogs) are a critical component of many watersheds in the northeast. Particularly in Fort Nelson, where these wetlands retain water and exchange water with lakes and streams, there are large knowledge gaps regarding the effects of permafrost and seasonal ground frost on hydrology in these systems.
- Low flows and low-flow indicator. The long-term plan is to integrate low-flow indicators based on water quantity.
- Need hydrometric data to consider low-flow effects.
- Water utilization is the primary driver for potential effects.
- Low flows are the strongest driver of ecosystem change.
- Identification of fish species presence/absence, quantification of fish habitat, quantification of environmental needs, identification of drought-sensitive watersheds where allocation should be restricted to protect fish, identification of temperature-sensitive streams.
- Aquatic habitat information.
- Fisheries databases (FISS, EcoCat).
- Flow prediction in ungauged basins.
- Riparian and watershed assessment, particularly in mountain pine beetle and salvage harvesting affected watersheds. These environmental scan data are not currently available and would be helpful not only from a research perspective but also a planning/management perspective.
- Need to know where development (all new roads, for example) is taking place. There is no up-to-date and comprehensive road GIS layer available. We are carrying out assessments of culverts in some watersheds, but it is

not comprehensive at all. We have also been modelling fish habitat, but this is challenging without accurate road and stream layers. There has always been a paucity of data in the northeast for many different GIS layers.

- Long-term climatic and hydrometric data.

- Basic information to support the classification of transboundary water bodies.

- Data and information to support the determination of the direct and cumulative impacts of activities, climate change, and resource decisions on species, their populations, and habitats:
  - improved information on species biology, habitats, and interactions with climate, natural disturbances, and human-related activities;
  - better data on species and populations at risk or of management priority, such as high-value or indicator species;
  - better information on ecological communities, biodiversity, predator-prey interactions, migration corridors, and other biological/physical environment interactions that affect abundance, distribution, survival, and productivity; and
  - better information on species' life history requirements, habitat supply, species' distribution, disease processes, and population genetics.

- More information about peak flows, particularly with respect to cumulative effects of water use across the natural resource sector.
- Ongoing need for more fish and fish habitat inventory at the watershed level and following provincial reconnaissance inventory methodology.
- Need for fish and fish habitat monitoring information to assess population trends and habitat use.
- Need to educate clients about what is already available to them and how to use it.

- We are fish and fish habitat data providers; we do not conduct research. We collect data from a variety of sources, including researchers, regional biologists, and consultants. Most of the data we receive come from scientific fish collection permit holders. As a condition of the permit, the holder is required to submit their fish collection data to our group, in the form of an MS Excel template (we provide) or an MS Access database (again, we provide; i.e., FDISDAT.mdb).
- Most data providers submit only the bare minimum of information. The *Fish and Wildlife Act* legally requires that inventory data collected with a permit data be submitted to us. A person who obtains a scientific fish collection permit is required to submit the following information:
  - who collected it;
  - when the data were collected;
  - type of sampling method used;
  - fish species caught; and
  - count of fish species.
- Our templates/mdbs have fields that would enable someone to submit full sets of inventory data, which in addition to the above information, would also include details of sampling effort, fish details (length, weight, age), and habitat/stream details (e.g., channel width, wetted width, pool depth, instream vegetation, feature type, size, and location). In other

words, we are able to accept a fairly wide variety of data; however, most data submitters do not provide these additional data, even though they may have collected them. Furthermore, regional biologists do not require permits to do sampling, so often we don't receive their data either.
- We have a database that can hold lake survey information (i.e., O_2, pH, temperature profiles, etc.), but we do not have a good mechanism for getting the data into the database. The only system we have for getting these types of data into Oracle is the FDISDAT.mdb. The FDISDAT.mdb is somewhat problematic because the average person has difficulty using it. Needless to say, we don't receive this type of information very often, even though it's often collected.
- Currently, we are not able to accept telemetry and genetic data. We do not have a database set up to hold these types of data.

Aquatic Ecosystems. System and Methodology Needs.

- Aquatic habitat is used primarily as an indicator of watershed health.

- Perhaps we need to revive Watershed Assessment Procedures into a policy framework such as the clean energy guides to be used as Best Management Practices.

- Spatial identification of sensitive streams and more up-to-date entry of information collected by government.

- GIS.

- Prediction in ungauged basins.
- Riparian and watershed assessment—tools and methods (e.g., available funding) need to be in place to provide resources to conduct the assessments.

- Corporate data storage and management systems are in desperate need of updating.

- GIS-based data sets.

- New tools are needed to integrate species and habitat management objectives into decision-making.
- Need tools to predict and evaluate potential future outcomes for resource values to inform the decision process and subsequent assessments related to higher level strategic plans.
- Incorporate projected outcomes into decision-making, such as Timber Supply Review, permitting processes, and cumulative effects assessments.

- Updates to corporate data systems are needed. Plans are underway for this as part of the Natural Resource Sector Transformation Plan.
- Need to modernize and embrace mobile technologies for data collection.
- Ongoing work to customize views and provide access to existing information to facilitate analysis and reporting.

- We need funds to rebuild our data systems so that we can, more easily, load and disseminate fish and aquatic data better to our users.

Aquatic Ecosystems. Policy and Regulatory Needs.

- Understanding and mapping areas of groundwater-dependent ecosystems for sensitive species, and developing policies and tools for conjunctive management of surface and groundwater resources in such areas.
- Make the Watershed Assessment Procedures a requirement of development in watersheds; most specifically, add to the *FRPA* framework for forestry activities.
- Zero withdrawal thresholds policy and methodology, and spatial identification of high-quality fish habitat.
- We have a policy on environmental flow needs, but it keeps coming up in consultation on water licence reviews. Need to ensure it is backed up properly.
- We need applied science research to determine the actual response of fish biomass/production to changes in flow. This is required to both establish benchmark flow needs for fish in different regions/stream types, and to validate instream flow models and indices that are applied to infer flow needs for fishes but have extremely limited validation.
- *Fisheries Act*, *B.C. Water Act*.
- Proponents in all areas of development could be held to higher standards when it comes to submitting inventory and monitoring data to the appropriate provincial data repositories.
- Ecosystem-based management.
- Wildlife Habitat Areas and Government Actions Regulation requirements for meeting wildlife (aquatic and terrestrial) and biodiversity objectives.
- Policy changes required: Reinstate conservation measures that have been repealed with recent federal fisheries legislation.
- Regulatory needs: We need legislation and regulations that apply across all sectors/industries, not just one industry (e.g., Wildlife Habitat Areas under Government Actions Regulation determine only forestry-related impacts on fish and fish habitat but often should also apply to oil and gas developments, agriculture, and mining within watersheds).

Aquatic Ecosystems. Are you or your organization currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory?

- Looking to develop watershed health assessments in key watersheds.
- Environmental flow needs lead is Jen Turner at MOE.
- Aquatic systems: John Rex at MFLNR in Prince George.
- Fisheries program (fisheries-sensitive watersheds), water policy branch (environmental flow needs policy and winter flows).
- FREP water quality monitoring for forest management and range activities.
- Dave Wilford/Scott Jackson, John Rex/Norm Bilodeau, MFLNR: Prediction in ungauged basin Skeena–Omineca.
- Doug Lewis, MFLNR: cumulative effects–watersheds.

- Ian Picketts: Fraser Basin Climate Change Project.
- MFLNR–UNBC: Richard Kabzems/John Rex, Stephen Dery: Wetlands Project.

- The Fish Passage Technical Working Group (funded through the Land Based Investment Strategy) is carrying out assessments of culverts for their ability to allow fish migration in select, high-priority watersheds throughout the province. We have also been developing fish habitat models for the entire province.

- The monitoring of stream condition using benthic macroinvertebrates. This is done in partnership with CABIN.

- Carnation Creek Experimental Watershed Project (Project lead).
- Nechako sturgeon monitoring and habitat/population restoration (Steve McAdam, others).
- Grizzly bear monitoring, research, and recovery (Tony Hamilton).
- Mountain caribou research and monitoring (Dale Seip).
- Westslope cutthroat trout, species at risk (Jordan Rosenfeld, Brett Van Poorten).

- UNBC NRESi Biodiversity Monitoring & Assessment Program: http://bmap.unbc.ca

- Our core work includes the collection, acquisition, storage, organization, management, and distribution of fish and fish habitat information through the use of corporate and provincial systems and tools. So our work directly supports that of researchers, regional staff, and decision-makers. Our work also ensures that the legacy of investment in data and information collection is available to others beyond the scope of the original project.

Aquatic Ecosystems. Are you aware of any other organization or persons currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory? If so, please specify and provide links or contact people.

- Land Based Investment Strategy water funding for fish-sensitive watersheds—inventories and development of evaluation methodology.

- CABIN: Currently building a reference condition approach model for northeast BC. http://ec.gc.ca/rcba-cabin. Main contact: Stephanie Strachan stephanie.strachan@ec.gc.ca

- David Tesch, my manager, also oversees the fish inventory group. David.Tesch@gov.bc.ca
- Susanne is our expert on fish data management. Susanne.Williamson@gov.bc.ca

- Grizzly bear monitoring, research, and management (Bruce McClelland).

- MFLNR, OGC, UNBC.

- MFLNR: Peter Bradford has conducted an inventory of monitoring initiatives across the natural resource sector.
- UNBC: Mark Shrimpton.

Aquatic Ecosystems. What are your priority research questions or knowledge gaps related to key decisions?

- Implications of future climates on boreal wetlands and wetland hydrology.
- Cumulative effects of industrial activities on boreal hydrology as it affects Fort Nelson First Nations treaty rights.

- What are the trends? Hydrocarbons, pesticides?

- Collection of low-flow data, particularly in the winter when affected by ice.
- Ice jam and ice jam flooding.
- Water temperature.

- Identification of fish species presence/absence, quantification of fish habitat, quantification of environmental needs, identification of drought-sensitive watersheds where allocation should be restricted to protect fish, identification of temperature-sensitive streams.

- It would be great to have more data to better validate the NEWT model.

- What are the current conditions?

- We are trying to identify where the worst barriers to fish migration are so that we can prioritize them for remediation.

- How is climate change affecting water resources in north–central BC?

- What is the effect on the hydrology and aquatic ecosystem of the peatlands when water is withdrawn from nearby lakes, borrow pits, and aquifers?

- Our current approach to assessing fisheries impacts as a result of development is site specific and fails to address the larger and more important questions. For example, we don't have answers to basic life history information and habitat use (because we haven't been funded to conduct the necessary research) for those species and aquatic ecosystems that are native to the northeast, such as Arctic grayling, bull trout, and burbot. Without an understanding of these species-specific life histories, we cannot begin to understand the potential impacts of changes to peak flows, timing, and water allocation decisions.

APPENDIX 7 Management for natural and resource development hazards survey comments

Management for Natural and Resource Development Hazards. Data and Information Needs.

- Baseline information, continuous monitoring.

- Permafrost extent and dynamics in the Fort Nelson area, particularly the implication of climate change.
- We lack effective monitoring of the impacts of human-related development in watersheds like the Kiskatinaw River, in particular, road systems and the effectiveness of erosion control measures in roadside ditches.

- Methane gas around intake areas (wells)—low priority, but an interest.

- All data required for an environmental assessment review.

- Concerned primarily with climate change.

- Permafrost is discontinuous in the north, and we do not have a mapping program. We believe we can map by the quality of forest cover; stunted black spruce are easy to pick out. Mapping programs should be able to map similar features, then confirm the presence/absence and thickness of permafrost on a few sampling points and extrapolate over the larger area.
- Drought and dry spells occur, people panic, then it rains. We need to have a better drought monitoring system and a plan for what will happen when the drought comes.

- LiDAR should be applied as broadly as possible.

- Permafrost is a big unknown—extent, properties, and potential response; it drives a lot of the effects on erosion, mass movement, methane release.

- Floodplain mapping; drought prediction and planning; low and peak flow predictions; climate change impacts on low and peak flows; impact, value, and implications of water storage; peak flows in developed watersheds; management of developed watersheds (i.e., Dawson Creek).

- Drought is an important factor in the Peace Region. Need resources at specific times to manage this correctly.

- Monitoring and analyzing climate change impacts on drought and flood hazard management.

- As per water quality/quantity—need basic inventory data—what is happening where and to what degree?

- Effects of climate change on forest resources.

- Permafrost degradation studies and flow augmentation is important to understand from the view of current and future hydrologic condition in northeast watersheds with permafrost.

- Road inventory and up-to-date reporting of all new linear developments.

- Historic photos!! Not readily available through the photo library any more.

- Long-term hydrometric and climatic data.

- Information is needed on the effects of climate change on natural and human-related disturbances. Need to focus research to develop tools to assess the impacts of wildfires (post-fire erosion and flooding), landslides, floods, and sediment supply.

- Link to River Forecast Centre monitoring and forecasting.
- Need to expand capacity to address climate change; e.g., MFLNR research and wildfire management climate stations to fill gaps in area- and elevation-specific coverage.

- Subsurface aquifers have only minimal effect—can affect interaction between surface and groundwater, though.

Management for Natural and Resource Development Hazards. System and Methodology Needs.

- Companies need to supply this information in their general development plan of the area and have a plan for permafrost management.
- Drought monitoring system tied in with surface wetlands, muskeg levels, groundwater levels, and river flows.

- Floodplain mapping, low and peak flow predictions, better mapping within regions from River Forecast Centre (lumped into one Peace area—makes it difficult to use operationally).

- GIS, air photos (UBC library).

- Need a centralized corporate data storage and management for geohazards and erosion risk. More resources to manage this. I am doing it off the side of my desk in an already overloaded portfolio.

- Need to improve information availability. Links to the River Forecast Centre regarding floods related to ice jams. Integrate with sediment management, floodplain delineation and management, water control structures (e.g., dykes), destabilization of alluvial fans, etc.
- Revisit and refine predictive tools relative to post-fire hazards, landslides, and floods, and incorporate cumulative effects.
- Need guidance tools for rehabilitation prescriptions and procedures.
- Develop tools to project the influence of climate change/climate variability on natural hazards
- Need guidance on natural processes and development risks on alluvial fans.

Management for Natural and Resource Development Hazards. Policy and Regulatory Needs.

- Policy on infrastructure associations with possible land movements. Currently, proponents investigate how their "project" activity might increase the risk of landslides, etc.; however, they do not assess the natural hazards upslope outside their footprint. As we continue developing corridors across the region, natural hazards far upslope (high-elevation permafrost areas, for example) may create significant hazards that are not considered a requirement for assessment in our usual Environmental Assessment Office process.

- Easier system for suspending water licence users during drought.

- Proposed regulatory tools to respond to water shortages.

- Reporting requirements for geohazard events. Mandatory reporting of landslide events for any activities on Crown land (no causation, just occurrence). Voluntary reporting on private land.

- *Water Sustainability Act* (MOE developed, MFLNR delivered).
- MOE environmental flow needs policy.
- Integrated decision-making policy.
- *Oil and Gas Activities Act*.
- Development and operational effects of mines and access infrastructure on surface flows.
- *Forest Planning and Practices Regulation* of FRPA.

- Methane gas release monitoring is an interesting area of research that we are now starting to think about, especially as it relates to infrastructure (i.e., pipelines). We are interested in addressing airborne monitoring of methane and effects on vegetation. For this, we will need both ground monitoring and airborne data acquisition (e.g., hyperspectral, LiDAR).

Management for Natural and Resource Development Hazards. Are you or your organization currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory?

- Canadian Water Network has issued a call for proposals in five theme areas related to "Hydraulic Fracturing and Water" (governance, land use disturbance, groundwater fracking, waste water, and water demand). There are Letters of Interest from various groups/individuals in BC and across Canada.
- Groundwater and fracking proposal (led by Rene Lefebvre, with Christine Rivard, Tom Gleeson, Diana Allen, Dirk Kirste, etc.). Diana to co-lead a theme on site characterization.
- Wastewater handling, disposal (and water demand) (led by Greg Goss at University of Alberta, with Diana Allen, etc.). An SFU policy student has offered to look at regulations related to wastewater practices.
- Water governance (led by Michelle-Lee [UVIC], etc., with Diana Allen as an advisor): compilation of water governance knowledge in North America, some of which will apply to the northeast.
- FREP water quality monitoring.
- Some modelling work on instream flow methods (Jordan Rosenfeld); ongoing development and regionalization of instream flow standards (Ron Ptolemy).
- Geohazard mapping.
- Soil temperature and moisture monitoring at various sites in the Cariboo Mountains.
- Carnation Creek Experimental Watershed Project (Project lead).

Management for Natural and Resource Development Hazards. Are you aware of any other organization or persons currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory? If so, please specify and provide links or contact people.

- Council of Canadian Academies soon-to-be-released report, chaired by John Cherry, called *Harnessing science and technology to understand the environmental impacts of shale gas extraction*—an evidence-based and authoritative assessment of the state of knowledge about potential environmental impacts of the exploration, extraction, and development of Canada's shale gas resources, and the current state of knowledge regarding associated mitigation options.
- Agriculture and Agri-food Canada drought watch system.
- Marten Geertsema, MFLNR in Prince George, is working on permafrost.
- Climate action group.

- Mike Bradford, DFO/SFU: www.rem.sfu.ca/crmi/dfomem.html
- Wendy Palen, SFU: https://www.sfu.ca/biology/people/profiles/wpalen.html
- Dan Moore, UBC Geography: www.geog.ubc.ca/~rdmoore

- Martin Geertsema/Vanessa Foord, MFLNR: permafrost monitoring project.

- Nexan (and others?) does 3D mapping of micro-seismic activity while fracking.
- Elizabeth Johnson (MEM hydrogeologist) is involved in permafrost studies in the northeast.

- Dr. Antoni Lewkowicz (University of Ottawa) is monitoring permafrost degradation at multiple sites in northern BC.

- MFLNR hydrology/geomorphology research discipline group (I was a former member and leader during my time in that ministry). See David Wilford, Skeena Region for a list of MFLNR researchers.
- MFLNR climate researchers (David Spittlehouse, Caren Dymond).
- FREP: Monitoring of *FRPA* effectiveness for water quality, riparian–stream ecosystem integrity/function, biodiversity, soils, and more. See Pete Bradford, Resource Practices Branch, MFLNR.
- Academia: e.g., Dan Hogan, BCIT; Dan Moore and Marwan Hassan, UBC; others at SFU and UNBC.

Management for Natural and Resource Development Hazards. What are your priority research questions or knowledge gaps related to key decisions?

- What are the implications of climate change on permafrost and seasonal ground frost in Fort Nelson watersheds?

- What are the standards of well casings that are currently there?
- Understand groundwater flow and surface/groundwater relationship (e.g., groundwater recharge).

- Are there any shale gas migratory issues associated with fracking near faults that intersect shallow aquifers, surface water bodies?
- What work has been done (if any) or needs to be done regarding the cumulative effects of all these oil and gas activities?

- What is the effect of withdrawing water from, or injecting it into, the DeBolt formation where it is only 600 m from the overlying potable aquifers?

- Floodplain mapping; drought prediction and planning; low and peak flow predictions; climate change impacts on low and peak flows; impact, value, and implications of water storage; peak flows in developed watersheds, management of developed watersheds (i.e., Dawson Creek).

- Likelihood (quantity and rate) of surface erosion from disturbed ground surfaces, including resource roads.

- Knowing (with some level of confidence) what the responses of fish (and stream capacity/production) are to changes in stream flow (in particular, low flows).
- Establishing minimum flow thresholds by stream type based on credible research relevant to BC streams.

- Research to validate that predictions from widely applied models and minimum-flow rules of thumb are accurate.
- Development of new instream flow modelling approaches that account for flow effects on productive capacity (e.g., prey, temperature), not just habitat.

- What role does permafrost and disappearing permafrost play regarding groundwater?
- What are the effects of survey cut lines on permafrost?
- What are the effects of thermokarst activity on groundwater?

- Where are all the landslides?

- We are interested in addressing the effects of water removal (both anthropogenic and natural) on the health of wetland communities.

APPENDIX 8 Other information needs survey comments

Other Information Needs. Do you have any other information needs related to water resources in northeast British Columbia?

- Improved access to available information.

- Industry planning for water resource protection—planning regime for tracking implementation of existing plans for source water protection.
- Can we roll up planning needs for allocation, flood risk/management, water quality protection, and other interests for water sustainability plans? How do we achieve harmonization in protection in the new water act?
- Need people to work with agriculture communities to support plans. Promote Best Management Practices.
- Extension of results from research conducted by government or industry so we have more consistency between companies.
- Data management standards—there are none. How can we better integrate data from various sources to have confidence that we have the best information to update and model?

- Undertake a review of how studies in other jurisdictions are being carried out. A lot of work is going on in Quebec. Some of this knowledge will stem from the Council of Canadian Academies report, and some will stem from the Canadian Water Network reports in each of the theme areas (however, the latter will not be available until mid-2015).
- Would be beneficial to conduct a structural analysis (orthophoto and air photo analysis, coupled with on-the-ground mapping) of the location of lineaments and faults in the northeast.
- Conduct an aeromagnetic (or other geophysical) survey of the northeast to confirm depth to bedrock to locate paleo-channels, especially in the Horn River Basin.

- One of the challenges is trying to make climate change projections at very small scales.
- Data: streamflow, hydrometeorological, precipitation, and soils.
- Anything that helps run a hydrological model better. Obtaining data to describe the soil is the most important need. (How deep is the soil, and how does water run through it?)

- Try reorganizing identified research needs into short-, medium-, and long-term needs to address policy and decision-making.
- Identify monitoring vs research.
- Quantification/testing/validation of tools—provide case studies to examine where/when the tools work and under what conditions they don't work.
- Does the survey need more questions about agriculture, range, hydropower, and domestic use?
- Transboundary quality/quantity issues between BC and Alberta or BC–Montana in southeast BC.

- We need either more data sharing or more people to get this developing area properly covered!! Proactive is generally better than reactive when the damage is already done!

- Water disposal is going to be a limiting factor for oil and gas development—saline water sources are also potential disposal zones. The OGC is doing some work regarding this issue in the petroleum geology group—Jeff Johnson.

- Need soils and surficial geology inventory in the area.

- An expansion of the meteorological and hydrometric network of stations in northeast BC would provide crucial data in an otherwise data-sparse region.

Hello Participant,

As you know, watershed management issues are among the many challenges facing natural resource managers in northeastern British Columbia. The BC Ministry of Forests, Lands and Natural Resource Operations is currently conducting a needs assessment to identify specific watershed management information needs in northeastern British Columbia. This assessment will form the basis for developing an applied research strategy for FLNRO to support sustainable water resource management in this region. We are requesting your help in this process.

You are among the key respondents we are asking to participate in this survey. Your input will help guide the development of applied research strategies for water resources in northeastern British Columbia.

We would be very grateful if you would help us by completing an interview or online survey. The interview can be completed in about 20 minutes in person or online.

For more information about the development of the research strategy, please contact Dave Wilford (dave.wilford@gov.bc.ca) at the BC Ministry of Forests, Lands and Natural Resource Operations.

If you have any questions about the survey please contact [fill in name and email address]. We would appreciate your participation in either the telephone interview or the online survey by February 28, 2014. I will follow shortly to confirm your interest and set up an interview time.

Thank you for your participation. A more detailed description of the survey and the online link is provided below.

Suzan Lapp and Kevin Ronneseth and Todd Redding

To support sustainable water resource management in NE BC, an applied research strategy needs to identify the key research questions. To do this, we need to:

- Identify **what research** has, is, or is likely to be undertaken in the near future?
- Find out **who** has been, or is, engaged in water research in the NE?
- Identify what data, information, system, methodologies, policy, and regulatory needs are required to answer their, or other, research questions?

The answers to these questions will promote water research that is resource efficient, strategic in its focus and provide opportunities for collaboration.

Your participation is greatly appreciated. Please fill in the on-line questionnaire, which takes about 20 minutes, and is located at this Survey link.

The survey is divided into 5 main themes (surface water (quantity and quality), groundwater (quantity and quality), Gw–Sw interactions, aquatic ecosystems, and resource development hazards).

Please fill out the theme areas you are primarily involved with; and if you are aware of any other research in any of the other theme areas, we would appreciate it if you could forward this information also. If you can provide a contact person, that would help a lot.

Most of the questionnaire involves quickly 'ticking boxes' and choosing if your research needs, in a given area, are high, moderate or low. If the survey choices do not sufficiently cover your area of research, there are text boxes below where you can provide additional comments on:

- Data sets and information required to conduct your research (either currently exists or needed),
- Data systems, GIS platforms or other system requirements (currently used, need to improve, or need to develop),
- Methodologies required to conduct your research (currently used, need to improve, or need to develop), and
- Policy or regulations (research will support policy or regs; or policy and regs required to support the research).

Please note any specific research studies or persons involved (and who they are affiliated with) in the text boxes in each section.

If you know of any "Research Questions" yet to be answered for any of the 5 themes, please note them down in the "Other Thoughts" text box at the end of each Theme section.

Our time frame is short and if you can fill out the survey by Feb 28th we would appreciate it. We will follow up shortly to see if you have any questions.

APPENDIX 10 Key informant survey

Northeast BC Water Needs Survey

Name and Title

Affiliation

1. Which sector best applies to you. Select all that apply.

☐ First Nations
☐ Oil and gas industry
☐ Forest industry
☐ Mining industry
☐ Provincial government
☐ Federal government
☐ Local or regional government
☐ Consultant
☐ Community/stewardship/NGO
☐ Academic
☐ Other: _____

2. In which field/area do you primarily practice? Select all that apply.

☐ Water management (allocation)
☐ Water management (monitoring)
☐ Surface water hydrology
☐ Ground water hydrology
☐ Oil and gas development
☐ Renewable resource management
☐ Fisheries and aquatic ecology
☐ Geoscience and engineering
☐ Agriculture
☐ Water purveyor
☐ Mining
☐ Industrial waste water disposal (produced, process, backflow. . .)
☐ Waste management
☐ Ground water management (allocation)
☐ Ground water management (monitoring)
☐ Ground water management (regulations)
☐ Ground water hydrology–science/research
☐ Ground water hydrology–consulting
☐ Ground water hydrology–development
☐ Other:

3. Please provide your key research needs relating to surface water quantity and water management

	1 - High	2 - Mod	3 - Low
Peak flow timing	☐	☐	☐
Peak flow magnitude	☐	☐	☐
Low flow timing	☐	☐	☐
Low flow magnitude	☐	☐	☐
Annual water yield	☐	☐	☐
Current allocation and water availability	☐	☐	☐
Climate change effects on water quantity	☐	☐	☐
Forest management effects	☐	☐	☐
Oil & gas development effects	☐	☐	☐
Mining effects	☐	☐	☐
Cumulative hydrologic effects	☐	☐	☐

3. Data and Information Needs
3. System and Methodology Needs
3. Policy and Regulatory Needs
3. Are you or your organization currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory?
3. Are you aware of any other organization or persons currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory? If so, please specify and provide links or contact people.
3. What are your priority research questions or knowledge gaps related to key decisions?

4. Please provide your key research needs relating to surface water quality and water management

	1 - High	2 - Mod	3 - Low
Chemical water quality (e.g., nutrients)	☐	☐	☐
Biological water quality (e.g., algae)	☐	☐	☐
Physical water quality (e.g., temperature, sediment/turbidity)	☐	☐	☐
Chemical contaminants (e.g., industrial effluent, spills)	☐	☐	☐
Algae blooms	☐	☐	☐
Forest management effects	☐	☐	☐
Oil & gas effects	☐	☐	☐
Mining effects	☐	☐	☐

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4. What are your priority research questions or knowledge gaps related to key decisions?

5. Please provide your key research needs relating to groundwater quantity (shallow and deep) and groundwater sustainability

	1 - High	2 - Mod	3 - Low
Water levels	☐	☐	☐
Yield potential	☐	☐	☐
Recharge	☐	☐	☐
Permeability and porosity	☐	☐	☐
Storativity	☐	☐	☐
Flow direction	☐	☐	☐
Aquifer mapping	☐	☐	☐
Ground water allocation	☐	☐	☐
Groundwater vulnerability	☐	☐	☐
Geomorphology and lithology	☐	☐	☐
Land use	☐	☐	☐
Climate (precipitation, evapotranspiration)	☐	☐	☐
Surface waters	☐	☐	☐
Groundwater use	☐	☐	☐
Oil & gas development effects (e.g., fracking)	☐	☐	☐
Mining and other industry users	☐	☐	☐
Saline Water	☐	☐	☐

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5. What are your priority research questions or knowledge gaps related to key decisions?

6. Please provide your key research needs relating to groundwater quality (shallow and deep) and groundwater sustainability

	1 - High	2 - Mod	3 - Low
Bacteriological parameters (e.g., coliforms, turbidity)	☐	☐	☐
Biological parameters (e.g., algae)	☐	☐	☐
Chemical and physical parameters (e.g., sodium, chloride, nitrate, pH, temperature, turbidity)	☐	☐	☐
Radiological parameters (e.g., isotopes)	☐	☐	☐
Chemical contaminants from agriculture, oil & gas, forest management, mining, other industrial/commercial activities (e.g., VOCs, nitrates, ??)	☐	☐	☐

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6. What are your priority research questions or knowledge gaps related to key decisions?

7. Please provide your key research needs relating to groundwater-surface water interactions

	1 - High	2 - Mod	3 - Low
Process differences (location, velocity, residence time, etc.)	☐	☐	☐
Characteristic differences (physical or chemical differences e.g., level of solutes, age of water, level of dissolved oxygen, temperature variation, etc.)	☐	☐	☐
Development (roads, agriculture, mining, forest management, oil and gas activities) effects on interface zones where groundwater is hydraulically connected with (wetlands, springs, lakes, streams; riparian ecosystems and aquatic ecosystems)	☐	☐	☐
Water withdrawal effects on the interface zone	☐	☐	☐

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7. What are your priority research questions or knowledge gaps related to key decisions?

8. Please provide your key research needs relating to aquatic ecosystems

	1 - High	2 - Mod	3 - Low
Fish habitat	☐	☐	☐
Fish populations (e.g., numbers, geographic extent)	☐	☐	☐
Low flows and environmental flow needs (EFN)	☐	☐	☐
Riparian management	☐	☐	☐
Stream temperature and temperature sensitive streams	☐	☐	☐
Climate change	☐	☐	☐
Aquatic ecosystem health	☐	☐	☐
Development (roads, agriculture, mining, forest management, oil and gas activities) effects on aquatic ecosystems and adjacent riparian ecosystems	☐	☐	☐

8. Data and Information Needs
8. System and Methodology Needs

8. Policy and Regulatory Needs
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8. Are you aware of any other organization or persons currently engaged in any applied research, or monitoring activities that would support applied research, that would be relevant to the development of a research inventory? If so, please specify and provide links or contact people.
8. What are your priority research questions or knowledge gaps related to key decisions?

9. Please provide your key information and research needs relating to management for natural (e.g., landslides, erosion, and drought) and resource development hazards

	1 - High	2 - Mod	3 - Low
Slope mass movements	☐	☐	☐
Surface erosion	☐	☐	☐
Permafrost degradation	☐	☐	☐
Climate change	☐	☐	☐
Drought	☐	☐	☐
Other impacts from human development (roads, agriculture, mining, forest management, oil and gas activities)	☐	☐	☐
Surface erosion from roads and development sites	☐	☐	☐
Methane gas release	☐	☐	☐

9. Data and Information Needs
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9. What are your priority research questions or knowledge gaps related to key decisions?

10. Do you have any other information needs related to water resources in northeastern British Columbia?

AAFC	Agriculture and Agri-Foods Canada
BCIT	British Columbia Institute of Technology
BC OGC	British Columbia Oil & Gas Commission
CABIN	Canadian Aquatic Biomonitoring Network
CAPP	Canadian Association of Petroleum Producers
CCME	Canadian Council of Ministers of the Environment
FREP	Forest and Range Evaluation Program
FRPA	*Forest and Range Practices Act*
MEM	Ministry of Energy and Mines
MFLNR	Ministry of Forests, Lands and Natural Resource Operations
MOE	Ministry of Environment
NEWT	Northeast Water Tool
PCIC	Pacific Climate Impacts Consortium
PCIS	Pacific Institute for Climate Solutions
SFU	Simon Fraser University
TDS	Total Dissolved Solids
UBC	University of British Columbia
UBCO	University of British Columbia–Okanagan
UNBC	University of Northern British Columbia
UVIC	University of Victoria